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Effect of seasonal variations of aquifer Characterisation and resistivity values

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ABSTRACT

A geoelectric investigation involving sixteen vertical electric soundings with maximum current electrode spacing of 650m was carried out at Obiaruku, Delta State, Nigeria and environs. This was aimed at determining the effect of seasonal variations of aquifer characterization and resistivity data. The resistivity data got from the survey is interpreted by curve matching and computer iteration techniques where the geological model parameters and curves were obtained. Three to six geological layers were observed within the whole locations. The results show that there was a slight difference in the apparent resistivity values between wet and dry seasons which could be attributed to the degree of wetness (especially the topsoil) experienced during the rainy season. The aquifers, number of layers, curve type and shape, layer thicknesses are approximately the same values for both rainy and dry seasons.

Introduction

Geophysical resistivity methods are based on the response of the earth to the flow of electrical current. In this method, an electrical current is passed through the ground and two potential electrodes record the resultant potential difference between them, giving way to measure the electrical impedance of the subsurface material. The apparent resistivity is a function of the measured impedance and the geometry of the electrode array. The thickness and resistivity of the subsurface were determined from vertical electrical sounding (VES) data. Due to wide variation in resistivity and the absence of good resistivity contrast, the resolution has been less precise and thus the layer parameters interpreted could be ambiguous.

For resistivity measurement, various electrode arrays can be utilized. However, if the earth is assumed to be horizontally stratified, isotropic and homogeneous media such that the change of resistivity is a function of depth, the Schlumberger configuration is the most widely used arrays. As a result of this, the Schlumberger array has been chosen for the purpose of this research (Egbai and Asokhai, 1998).

Resistivity measurements are associated with varying depth depending on the separation of the current and potential electrodes in the survey, and can be interpreted in terms of a lithologic and or geohydrologic model of the subsurface. Data are term apparent resistivity because the resistivity values measured are actually averages over the total current path length but are plotted at one depth point for each potential electrode pair.

Some successful applications of the Vertical Electrical Sounding (VES) were reported on accessing quality of forest soils (McBride et al, 1990), mapping water flow paths (Freeland et al, 1997a), finding perched water locations (Freeland et al., 1997b), and outlining permafrost layers (Arcone et al, 1998).

The method was applied to estimate hydraulic conductivity (Mazac et al, 1990) and texture (Banton et al, 1997) of the stratified soils and sediments. Other applications of the method could be seen from the work of Dafny et al, 2006, Garey, 2004, Ali et al, 1999, and Egwebe et al, 2006.

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Location

Obiaruku is the headquarter of Ukwuani local government area of Delta State, Nigeria. It lies within latitudes $5^0 51^1$ and $5^0 52^1$ N and longitudes $6^0 12^1$ and $6^0 18^1$E. On the north, it is bounded by Obi-Obeti, south by Abraka, east by Utagba-Uno and Amai communities while in the west by River Ethiope.

The community obtains water from River Ethiope about 200m to 2km from the town depending on the location. The soil is very fine and whitish brown in nature. They practice subsistence farming.

The area is of equatorial climate made of two main seasons, the wet and dry season. The wet season begins from April and ends in September while dry season begins from October and ends in March. The area under study has a direct recharge from rainfall, the rate of infiltration and percolation is very high.

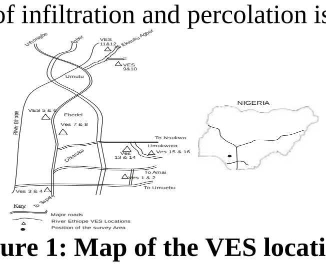

Figure 1: Map of the VES locations

Theory

The electrode configuration for the Schlumberger resistivity survey is as shown in Fig. 2. The recordings necessary in resistivity methods are surface measurements of the potential field distribution due to the current passing through the ground. This potential is a solution to Poisson's equation,

$$\nabla^2 V = 0 \qquad (1)$$

where ∇^2 is a second derivative operator and V is the potential.

The potential, V at a distance r due to current source I on surface of the earth, the solution is given by

$$V = I\rho/2\pi r \qquad (2)$$

where ρ is the resistivity of the subsurface, the solution to Piosson's equation for each pair of current and pair of potential electrodes would give a general form for the measured potential difference.

The resulting potential difference is given as

$$\Delta V = \frac{I\rho}{2\pi}\left\{\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right\} \ldots\ldots\ldots\ldots\ldots (3)$$

Solving equation 3 above, the resistivity ρ of the subsurface region could be determined. The above equation is possible if we assume a homogeneous and isotropic half-space. Since the earth is neither homogeneous and isotropic, a measured voltage difference yields a resistivity value that is an average over the path the current follows. Thus apparent resistivity is given by

$$\rho_a = \frac{2\pi\Delta V}{I}\left[\frac{1}{\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$= \frac{\Delta V}{I} K$$

K is the geometric factor. It is dependent upon the spatial arrangement of electrodes for specific arrays.

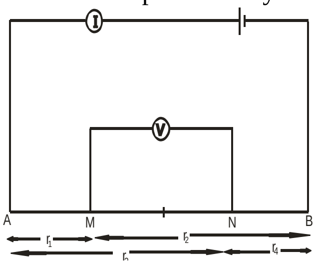

Fig. 2 Schlumberger Electrode Configuration

Data Acquisition and Analysis

The survey covers an area network shown in figure 1. The Schlumberger electrode configuration was used for data collection. The method involves depth control in which electrode spacing is increased to obtain information from greater depths at a given surface location (Egbai, 2011). The method is based on the fact that the wider the current electrode separation, the deeper the current penetration in the subsurface. The instrument used was the Abem SAS (Signal Averaging System) 1000B Terrameter with an inbuilt booster for grater injection of current in the ground.

A total of sixteen VES were carried out close to the various boreholes located in the VES stations. Four electrical resistivity soundings were conducted each in four different locations at **Obairuku and environs. The locations are:**

Location A: Obiaruku

(i) Opposite the secretarial: VES 1 and 2

(ii) Ghana quarters: VES 3 and 4

Location B: Ebedei

(i) Market square: VES 5 and 6

(ii) Ebedei primary school: VES 7 and 8

Location C: Umutu

(i) Michelin Road: VES 9 and 10

(ii) Umutu Mixed secondary school: VES 11 and 12

Location D: Umukwata

(i) Market square: VES 13 and 14

(ii) Umukwata primary school: VES 15 and 16

A maximum current electrode spacing of 650.0m was used for the sounding and this provided enough sub-surface information considering the depth of penetration in the Schlumberger array, which is 0.125 AB (Roy and Apparoa, 1971).

The result of the survey for the various locations are as shown in Tables 2 – 5 below. The curves for some locations are equally shown in figures 3 – 6 with one from each community.

The field data were first curved matched. The results of curved fitting show a rough estimate of layer resistivities, thickness and aquifer depths. The results of the curved matched data were used to obtain quantitative computer iteration. This computer assisted interpretation is based on the algorithm which employs digital linear filters, for the fast computation of the resistivity function for a given set of layer parameters. The data collected in the field were very consistent and of very good quality. The result of the iteration pave way for the model parameters where the resistivities, thickness and depths of the layers are shown. The curves for some locations are shown in figures 3-6

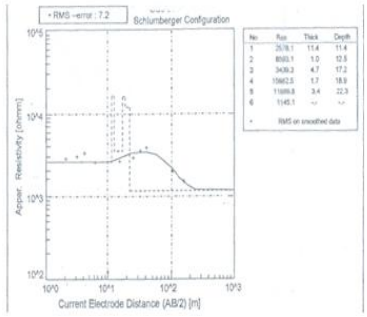

Figure 3: VES for locations 1&2

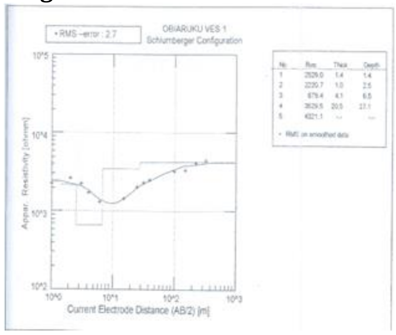

Figure 4: VES for locations 5&6 Obiaruku

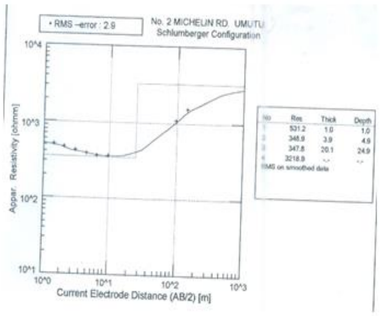

Figure 5: VES for locations 9&10Umutu

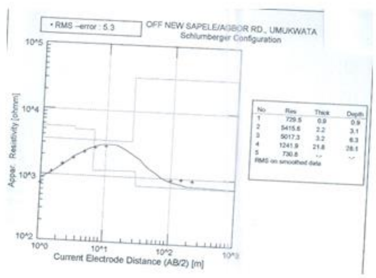

Figure 6: VES for locations 13&14 Umukwata

Results and Discussion

The results showed that apparent resistivities vary slightly for the various VES tables shown in (Table 2- 5). The slight variation in resistivities is due to the degree of wetness during the rainy season especially for the top soil.

Low resistivity indicates the presence of water (or clay) in the formation. Resistivity depends on salinity of water saturation and occurrence of interaction among formations (Egbai and Asokhai, 1998).

For VES 1 and 2 at Obairuku, the aquifers are located in the third layers having resistivity of 679.00Ωm with thickness of 4.1m at a depth of 6.5m. There exist no variation in aquifer for both wet and dry season of April and October respectively. At Obiaruku in location 2 (Ghana Quarters), the aquifer is embedded in the fourth layer for both May and November, 2007 location 1 and 2 at Obiaruku is of QA type curve with percentage error of 4.2.

At Ebedei, VES 5 and 6 for the third layer has resistivity of 3439.9Ωm, thickness 47m at a depth of 17.1m. The curve for these two locations is KKH type curve for both seasons. For Ebedei, location 7 and 8 have their aquifers located in the fourth layer having resistivity 333.9Ωm located at infinity with static water level at a depth of 41.7m. This location is of AK type curve.

Umutu, VES 9 and 10 have the third layer aquifer with resistivity 347.8Ωm, thickness 20.1m at a depth of 25.0m. The curves are of QH type for both locations. There exist very slight difference in resistivity between August, 2009 for rainy season and February, 2009 for dry season but the curve type and aquifer are the same. Location 11 and 12 have very little difference in resistivity but aquifer remain the same for September and March, 2009.

Umukwata, VES 13 and 14 have their aquifer in the fourth layer with resistivity 1241.9Ωm, thickness 21.8m and depth 28.1m. The two locations have K type curve with percentage error of 8.5. VES 15 and 16 have their aquifer in the third layer with resistivity 831.76Ωm and thickness at infinity. It is K type curve with percentage error of 8.5. The parameters are the same for both wet (May, 2010) and dry (December, 2010) for the same locations.

The curves obtained from the two VES from the same location for rainy and dry seasons have the same shape and aquifer in all locations. The results obtained show that VES interpreted geoelectric sections and modern parameters do not change with season. The results of electrical resistivity method is not endangered by seasonal variations.

Conclusion

This research work was extensively carried out at Obiaruku and its environs with the sole aim of finding out if seasonal variations can have effect on aquifer characterization and resistivity values. It is very clear from the research that seasonal variations do not endanger the results of the electrical resistivity method in terms of aquifer characterization and resistivity data. There was high correlation among results obtained from the model parameters and VES interpreted geoelectric sections between rainy and dry seasons.

Acknowledgement

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Table 1.The table of VES survey locations for both rainy and dry season are as shown in

	LOCATION	VES	RAINY SEASON	VES	DRY SEASON
A	Obiaruku	1 3	April 2007 May 2007	2 4	October 2007 November 2007
B	Ebedei	5 7	June 2008 July 2008	6 8	December 2008 January 2008
C	Umutu	9 11	August 2009 September 2009	10 12	February 2009 March 2009
D	Umukwata	13 15	April 2010 May 2010	14 16	November 2010 December 2010

Table 2: VES for Obiaruku for two locations in 2007

Current Electrode spacing AB/2 (m)	Potential Electrode spacing MN/2 (m)	Geometric Factor K	April 2007 Apparent Resistivity	Oct. 2007 Apparent Resistivity	May 2007 Apparent Resistivity	Nov. 2007 Apparent Resistivity
1	0.5	6.28	2273.00	2273.00	313.00	313.00
2	0.5	25.13	2650.00	2650.00	327.00	230.00
3	0.5	56.55	1742.00	2242.00	263.00	263.00
4	0.5	100.53	1760.00	1760.00	277.00	277.00
6	0.5	226.19	1335.00	1308.00	274.00	280.00
6	1.0	113.10	1308.00	1308.00	225.00	280.00
8	1.0	201.06	1259.00	1300.00	260.00	300.00
12	1.0	452.39	1360.00	1360.00	340.00	341.00
15	1.0	706.86	2081.00	1467.00	390.00	390.00
15	2.0	353.43	1467.00	1467.00	360.00	390.00
25	2.0	981.75	2056.00	2036.00	500.00	560.00
32	2.0	1608.50	2335.00	2335.00	740.00	740.00
40	2.0	2513.31	2558.00	2558.00	1092.00	900.00
40	5.0	1005.31	2644.00	2558.00	995.00	900.00
65	5.0	2654.65	2687.00	3000.00	669.00	1600.00
100	5.0	6283.19	3746.00	3289.00	2637.00	2600.00
100	10.0	3141.59	3289.00	3289.00	3145.00	2600.00
150	10.0	7068.58	3403.00	3403.00	4903.00	4903.00
225	10.0	15904.31	4208.00	4208.00		
225	20.0	7952.16	3084.00	4208.00		
325	20.0	33183.07	4416.00	4416.00		

Table 3 VES FOR EBEDEI (VES for tow location

Current Potential Electrode AB/2 (m)	Potential Electrode Spacing MN/2 (m)	Geometric Factor (K)	June 2008 Apparent Resistivity ρa (Ωm) VES 5	Dec. 2008 Apparent Resistivity ρa (Ωm) VES 6	July 2008 Apparent Resistivity ρa (Ωm) VES 7	Jan. 2008 Apparent Resistivity ρa (Ωm) VES 8
1	0.5	6.28	1631.00	1630.00	1000.04	1000.00
2	0.5	25.13	2963.00	2960.00	889.28	869.00
3	0.5	56.55	2639.00	3150.00	686.71	667.00
4	0.5	100.53	3368.00	3365.00	532.34	532.00
6	0.5	226.19	5634.00	2650.00	423.58	424.00
6	1.0	113.10	2164.00	2650.00	382.37	392.00
8	1.0	201.06	2483.00	2480.00	418.95	419.00
12	1.0	452.39	3224.00	2600.00	430.08	430.00
15	1.0	706.86	4669.00	2700.00	497.32	497.00
15	2.0	353.43	5102.00	2750.00	650.57	651.00
25	2.0	981.75	2997.00	2990.00	749.41	749.00
32	2.0	1608.50	4030.00	3600.00	831.40	831.00
40	2.0	2513.31	3974.00	3970.00	815.28	816.00
40	5.0	1005.31	3145.00	3140.00	754.12	740.00
65	5.0	2654.65	3907.00	2900.00	739.86	742.00
100	5.0	6283.19	2648.00	2000.00	596.95	597.00
100	10.0	3141.59	2693.00	2603.00	435.60	436.00
150	10.0	7068.58	1571.00	1570.00		

Table 4 Ves For Umutu for two locations

			August 2009	Feb. 2009	Sept. 2009	March 2009
Current Electrode Spacing AB/2 (m)	Potential Electrode Spacing MN/2 (m)	Geometric Factor (K)	Apparent Resistivity ρa (Ωm) VES 9	Apparent Resistivity ρa (Ωm) VES 10	Apparent Resistivity ρa (Ωm) VES 11	Apparent Resistivity ρa (Ωm) VES 12
1.00	0.15	10.24	510.00	510.00	130.05	130.00
1.47	0.15	22.40	499.99	500.00	180.01	180.00
2.15	0.15	48.19	458.29	458.00	222.16	222.00
3.16	0.15	104.38	420.03	420.00	282.87	283.00
4.64	0.15	225.31	379.87	380.00	340.22	340.00
6.81	0.15	485.61	359.84	360.00	374.41	274.00
10.00	0.15	1047.38	359.25	359.00	432.57	414.00
10.00	0.15	102.40	354.92	355.00	413.70	408.00
14.70	0.15	224.02	349.92	350.00	450.06	450.00
21.50	0.15	481.90	359.98	360.00	530.09	530.00
31.60	0.15	1043.75	440.46	440.00	567.08	568.00
46.40	0.15	2253.12	599.33	599.00	648.90	549.00
68.10	0.15	4856.09	819.82	850.00	738.13	738.00
100.00	0.15	10473.38	1141.65	1100.00	785.54	786.00
100.00	5.00	3135.00	1100.39	1200.00	749.27	760.00
147.00	5.00	6783.54	1499.16	1499.00	80.46	800.00
215.00	5.00	14520.00	2003.76	2004.00	856.68	840.00

Table 5: VES for Umukwata for two locations

			April 2010	Nov. 2010	May 2010	Dec. 2010
Current Electrode Spacing AB/2 (m)	Potential Electrode Spacing MN/2 (m)	Geometric Factor (K)	Apparent Resistivity ρa (Ωm) VES 13	Apparent Resistivity ρa (Ωm) VES 14	Apparent Resistivity ρa (Ωm) VES 15	Apparent Resistivity ρa (Ωm) VES 16
1.00	0.15	10.24	729.59	700.00	251.19	359.63
1.47	0.15	22.40	1079.68	1080.00	398.11	435.04
2.15	0.15	48.19	1400.02	1500.00	575.44	571.48
3.16	0.15	104.38	1800.06	1820.00	700.00	781.85
4.64	0.15	225.31	2199.93	2200.00	900.00	1061.26
6.81	0.15	485.61	2599.96	2620.00	1200.00	1396.25
10.00	0.15	1047.38	2700.15	2800.00	1400.00	1759.39
10.00	1.50	102.40	2830.00	2880.00	2790.00	1860.00
14.70	1.50	224.02	2500.03	2500.00	1800.00	2089.31
21.50	1.50	481.90	2200.12	2100.00	2000.00	2263.75
31.60	1.50	1043.75	1449.77	1450.00	2600.00	2156.10
46.40	1.50	2253.12	1149.09	1149.00	2000.00	1772.87
68.10	1.50	4856.09	951.79	962.00	1800.00	1324.26
100.00	1.50	10473.83	953.12	922.00	1500.00	1021.28
100.00	5.00	3135.00	921.69	920.00	1300.00	900.50
147.00	5.00	6783.54	949.70	950.00	1200.00	894.28
215.00	5.00	14520.00	100.06	916.00	980.00	857.17

Table: Summary of computer iteration and model parameters

VES	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Curve Type	RMS % Error
Obiaruku VES 1 & 2	1	2529.0	1.4	1.4	$\rho_1>\rho_2>\rho_3<\rho_4<\rho_5$ QA	2.7
	2	2220.7	1.0	2.5		
	3	679.4	4.1	6.5		
	4	3529.5	20.5	27.1		
	5	4321.1	–	–		
Obiaruku VES 3 & 4	1	339.8	1.5	1.5	$\rho_1>\rho_2<\rho_3>\rho_4<\rho_5<\rho_6$ HHA	4.2
	2	13.8	11.6	13.1		
	3	192.6	154.6	167.7		
	4	0.9	20.6	188.3		
	5	1.1	68.8	257.1		
	6	11.2	–	–		
Ebedei VES 5 & 6	1	11.4	11.4		$\rho_1<\rho_2>\rho_3<\rho_4>\rho_5<\rho_6$ KKH	7.2
	2	1.0	12.4			
	3	4.7	17.1			
	4	1.7	18.8			
	5	3.4	22.2			
	6					
Ebedei VES 7 & 8	1	346.2	1.0	1.0	$\rho_1<\rho_2<\rho_3>\rho_4$ AK	18.7
	2	478.1	10.2	11.2		
	3	1363.8	30.5	41.7		
	4	333.9	–	–		
Umutu VES 9 & 10	1	531.2	1.0	1.0	$\rho_1>\rho_2>\rho_3<\rho_4$ QH	2.9
	2	348.9	3.9	4.9		
	3	347.8	20.1	25.0		
	4	3218.9	–	–		
Umutu VES 11&12	1	131.0	1.0	1.0	$\rho_1<\rho_2<\rho_3<\rho_4$ AA	5.9
	2	598.5	4.0	5.0		
	3	655.1	34.7	39.7		
	4	978.8	–	–		
13&14	1	729.5	0.9	0.9	$\rho_1<\rho_2>\rho_3>\rho_4>\rho_5$ KQ	5.3
	2	5415.6	2.2	3.1		
	3	5017.3	3.2	6.3		
	4	1241.9	21.8	28.1		
	5	730.8				
15&16	1	300.0	1.0	1.0	$\rho_1<\rho_2>\rho_3$ K	8.5
	2	4000.0	11.8	12.8		
	3	831.76				