academicJournals

Vol. 5(5), pp. 280-288, May, 2013
DOI: 10.5897/IJWREE12.098
ISSN 2141-6613 © 2013 Academic Journals
http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Stratigraphic mapping of subsurface structures and groundwater potentials from electrical resistivity soundings in Onicha Olona, Atuma Iga and Akwukwu-Igbo, Delta State Nigeria

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Accepted 12 April, 2013

Onicha Olona, Atuma Iga and Akwukwu-Igbo have experienced severe hardship in getting reliable boreholes over many years due to their high topography. They are transition towns as it is from here that marked variations in subsurface structures and topography commence. Although the entry point at onicha Olona which is tied to Issele Uku is a flat land by contouring, the western end of the town has evidence of intermittently occurring deep valleys. It is important to study and ascertain the formation strata and groundwater occurrence in these towns. Hence, this study was made in Onicha Olona, Atuma Iga and Akwukwu-Igbo Delta State Nigeria. Seven vertical electrical sounding (VES) stations were sounded using Schlumberger configuration. The apparent resistivity values obtained in the field were plotted against half current electrode spacings. Interpretations of data were done qualitatively and quantitatively from which seven to eight layers with complex curve types of HAK, HAH, HK, QHK, QKHK, HKHKQ and QHKHA were mapped. Parches of springs from faults in the weathered rocks within the valleys at depths of about 30 m and low yield aquifers at depths of 125 m and beyond are delineated in Onicha Olona. Akwukwu-Igbo and Atuma Iga have sustainable aquifers at depths of 85 to 105 m due to topographic variation.

Key words: Formation strata, Schlumberger, apparent resistivity, aquifer, topographic variation.

INTRODUCTION

Subsurface structures in Delta State vary remarkably as the state stretches from near the ocean at Forcados and Warri to the hinterland at Agbor and Issele Uku from where it again slopes into River Niger. Many towns in the high altitude zone of Delta State have inadequate water resources whereas availability of groundwater/portable water is a major determinant of settlement and population growth in rural and urban areas (Okolie, 2010). Onicha Olona, Akwukwu-Igbo and Atuma Iga are towns worst hit in this zone where availability of portable water is obviously a serious problem. Onicha Olona seems to be the transition zone by contouring as the topography gradually drops from here with respect to Issele Uku (Figure 1). Many attempts of citing viable boreholes and deep water wells have woefully failed. These difficulties may be attributed to the structural distributions of the subsurface and neglect of elaborate geophysical investigations capable of delineating the subsurface lithology, prolific aquifers and static water levels (Kogbe, 1976) and (Olorunfemi et al., 1999). The increasing population and aspiration for rapid technological advancement here call for urgent empirical study aimed at providing lasting solutions to this problem. Hence, this empirical investigation was made to stratify the subsurface,

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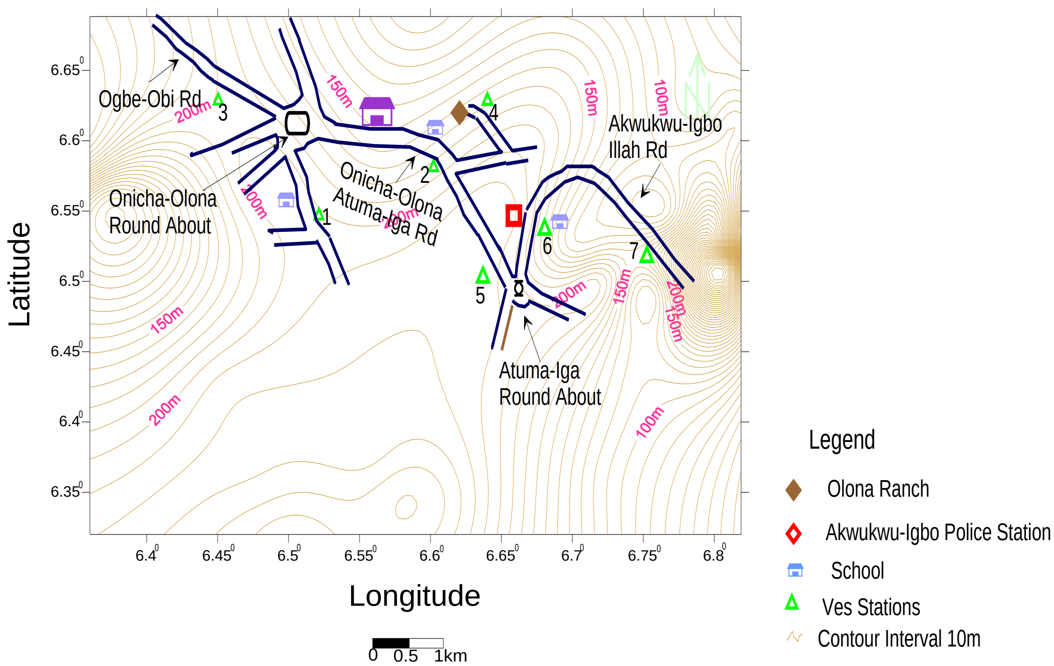

Figure 1. Base Map of Study Area – Onicha Olona, Atuma Iga and Akwukwu-Igbo.

provide geologic and geophysical features and determine the aquifer distributions in this area in order to eliminate unsuccessful well drills. The electrical resistivity method was applied using Schlumberger configuration. The obtained field data was interpreted qualitatively by curve matching to obtain the trend of the strata and quantitatively from Vander resist version (1988 and 2004) iteration technique to deduce the structural lithology.

Location of study area

Onicha-Olona is located in Aniocha North LGA while Atuma Iga and Akwukwu-Igbo towns are located in Oshimili North L.G.A of Delta State. Although the study area is in two different LGAs, the road stretch is only about four kilometres. It is within E006°.34′ and Latitude N06° 22′ in Onicha Olona and E006° 35′ and Latitude N06° 21′ in Akwukwu Igbo on the Western bank of River Niger (Figure 1). It has heavy rainfall for a period of about seven months (April-October) in the year. It has generally flat topography while with patches of undulating terrain and is accessible by network of roads and footpaths.

MATERIALS AND METHODS

Seven vertical electrical sounding (VES) stations were sounded in the area and the topography of each station was recorded with a sensitive GPS and plotted (Figure 1). Electrical resistivity technique is used in delineating subsurface structures. It is based on the fact that the sub-surface structures possess varying resistivities. These differences in electrical properties are probed or investigated and properly analyzed to delineate underground structures and groundwater occurrence. The vertical electrical sounding method measures ground potential differences between suitable implanted electrodes resulting from variations in some important physical properties of the underlain rock formations such as porosity, permittivity and resistivity with respect to a fixed array center, the station. The current and potential electrodes are pegged collinearly with the inter-electrode spacing expanding progressively about the station with increasing sounding number (Okolie, 2011). The VES sounding measures internal variations in *apparent* resistivity since it is an indirect approach. The apparent resistivity is dependent on pressure and porosity which is a function of the pore space resulting from aqueous electrolytes, the fluid viscosity which decreases as the mobility of the ions increases and water saturation in accordance to ARCHIE'S LAW for rock resistivity. Archie's law states that the resistivity of a rock is directly proportional to resistivity of groundwater present in a formation but inversely proportional to the formation porosity and water saturation. Archies law for formation resistivity is therefore given by

$$\varrho_r = a\phi^{-m} \; S_w^{\;-n} \varrho_w \tag{1}$$

Where ϱ_r = resistivity of rock also, ϱ_w = resistivity of groundwater S_w = water saturation, $0 \le S \le 1$ and $\varnothing$ = porosity, $0 \le \phi \le 1$ a, m, and n are predetermined empirical constants given by $0.5 \le a \ge 25$, $1.3 \le m \ge 2.5$ and n = 2.

In Schlumberger arrays, four electrodes are collinearly arranged with the current electrode spacing which is much greater than the potential electrode $^{AB}/_2 \ge 5^{MN}/_2$ where AB is current electrodes spacing and MN is potential electrodes spacing as in Figure 2. The dimensional implication of the array is given by Equations (2 to 6).

$$r_1 = r_4 = \frac{1}{2}[L-b]$$

$$r_2 - r_3 = \frac{1}{2}[L+b] \tag{2}$$

Hence, from theory (Okolie, 2010) and (Lowrie, 1997)

$$\ell = 2\pi\left[\frac{1}{\left(\frac{1}{r_1}-\frac{1}{r_3}\right)-\left(\frac{1}{r_2}-\frac{1}{r_4}\right)}\right]\frac{V}{I} \quad (3)$$

So that

$$\ell_a = 2\pi\left[\frac{1}{\left(\frac{2}{L-b}-\frac{2}{L+b}\right)-\left(\frac{2}{L+b}-\frac{2}{l-b}\right)}\right]\frac{V}{I} \quad (4)$$

$$\ell_a = \frac{\pi\left(\frac{L}{2}\right)^2-\left(\frac{b}{2}\right)^2 R}{b} \quad (5)$$

In which case, the instrument operational Geometric factor "G" is given by

$$G = \frac{\pi\left(\frac{L}{2}\right)^2-\left(\frac{b}{2}\right)^2}{b} \quad (6)$$

The Schlumberger configuration of VES is a choice because of ease of laying field equipment and minimal field logistic of less manpower need since potential electrodes are not frequently moved (Okolie, 2011). Moreover, it has greater probing depths and resolving power than other arrays because of its large current electrodes spacing. Also, Schlumberger curves are generally smoother and step free (Reinhard, 1974). Schlumberger array uses exert logarithmic spacing of the current electrodes from six readings per decade in sequence of 1.00, 1.47, 2.15, 3.14, 4.64, 6.81, 10, 14.7, etc. (Milson, 1992; Reynolds, 1997; Ako and Olorunfemi, 1989).

A total of seven VES stations were sounded. While four stations were sounded in Onicha Olona three stations were sounded at Atuma Iga and Akwukwu-Igbo. In each station, the four electrodes were hammered down collinearly to make good contact with the earth for effective current to flow in the subsurface. Thereafter, the two current electrodes were tightly connected to the current terminals of the terrameter while the other two potential electrodes were similarly connected to the corresponding potential terminals of the equipment. The Signal Averaging System (SAS) 1000 terrameter was powered by a 12 Volts accumulator (Ayolabi, 2005). With this set up the subsurface under investigation was sounded, measured and the mean apparent resistivity value computed by the terrameter was digitally displayed on the instrument screen (Okolie, 2011) and recorded for use on application of relevant theories (Table 1). The terrameter was switched off after each reading to avoid shock on handling the electrodes.

DATA ANALYSIS

The data obtain from the electrical resistivity survey in Table 1 above was plotted on a log-log graph paper with the electrode separation ($^{AB}/_2$) on the abscissa and apparent resistivity (ρ_a) value on the ordinate. The qualitative analysis was made to determine the curve types exhibited by each site. The quantitative analysis was made by employing partial curve matching technique using the relevant Schlumberger standard curves A, Q, K, or H and their corresponding auxiliary curves (Zohdy, 1974). The field curves on the log-log graph were matched segment by segment with the two layer master curves and corresponding auxiliary curves to obtain the actual resistivity and thickness of the first subsurface layer in each station as well as the resistivity replacements (ρ_r), reflection factors and Depth Indices (DI) of the other subsurface layers.

With the above parameter obtained from curve matching, the apparent resistivity (ρ_a) and the corresponding thickness of each of the other layers were calculated for from

$$\rho_{a=k_{(n+1)}} \times \rho_{(n-1)r} \quad (7)$$

where n is an integer greater than one (n >1), and the real layer depth is obtained from

$$h_n = h_{(n-1)} \times DI \quad (8)$$

and used as starting models for the computer iteration technique in which the Win Resist Software was applied based on the work of Vander Velper (1988, 2004) to delineate the actual apparent resistivities and thicknesses of the other layers. This computer iteration involved entering the field spread type (Schlumberger array), plotting half electrode separation 'AB/2' against computed apparent resistivity in the columns provided by the software. Thereafter the total number of layers, the resistivity and corresponding thickness of each layer modeled from the qualitative interpretation in each station were fed into the computer and automatically iterated to its lowest Root-Mean Square (RMS) percentage error. In this application, the thickness and apparent resistivity of the first medium are real. Moreover, although the resistivity of the last layer can be computed for, it has seemly undefined thickness/depth as h_n cannot be evaluated. The results of the computer iterated curves for the seven sites are explicitly shown in the Figures 3 to 7 and Table 2.

DISCUSSION

The qualitative analysis shows that the area consists of heterogeneous lithology with seven to eight layers made of HAK, HAH, HK, QHK, QKHK, HKHKQ, QHKHA curve types (Figure 3 to 7).

The quantitative analysis and computer iteration reveals that the top soil has resistivity of 160 to 1970 Ωm and thickness of 0.5 to 1.0 m and consisting of loose sand except at the ranch area where the top soil consists of weathered rock of anomalous resistivity values with the same thickness range. The anomalous nature (Very high resistivity) around the ranch at Onicha Olona is as a result of the hugh presence of near surface weathered

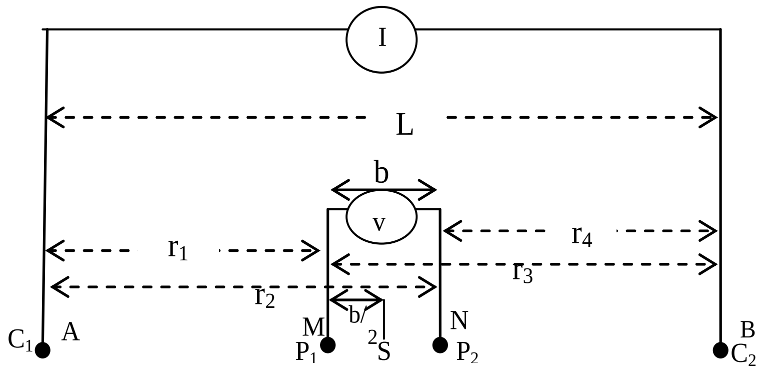

Figure 2. Schlumberger field electrodes configuration. Where “L” is the distance between the current electrodes and “b” is the distance between potential electrodes in station S.

Table 1. Apparent Resistivity field Data as recorded from ABEM SAS 1000 Terrameter.

Current electrode separation AB/2 (m)	Potential electrode separation MN/2 (m)	VES 1 ρ (Ωm) Onicha Olona	VES 2 ρ (Ωm) Onicha Olona	VES 3 ρ (Ωm) Onicha Olona	VES 4 ρ (Ωm) Onicha Olona (Ranch)	VES 5 ρ (Ωm) Atuma Iga (Palace)	VES 6 ρ (Ωm) Akwukwu/Atuma Iga market	VES 7 ρ (Ωm) Akwukwu-Igbo
1.0	0.2	135.20	140.0	1794.8	85760.0	250.90	1500.2	3500.61
1.47	0.2	92.017	116.85	828.80	72110.0	330.29	1121.6	2623.90
2.15	0.2	69.046	130.87	477.94	50033.0	443.20	956.83	1789.22
3.16	0.2	55.24	165.05	340.23	21700.0	469.83	1080.2	1096.38
4.64	0.2	65.272	225.14	344.85	10900.0	462.30	1250.67	875.00
4.64	1.0	66.35	240.14	287.86	11000.0	483.08	1260.64	830.57
6.81	1.0	106.88	290.76	317.16	11500.0	499.90	1406.57	911.28
10.0	1.0	140.88	351.25	420.4	13050.0	623.16	1430.55	700.09
10.0	3.0	150.27	380.6	469.62	13100.0	650.78	1450.17	750.88
14.70	3.0	185.56	560.6	628.06	17500.0	840.74	1062.9	685.17
21.50	3.0	241.37	575.0	1250.4	18279.0	1330.5	907.02	635.9
31.6	3.0	350.72	700.7	1087.5	18900.0	1500.16	950.70	434.6
31.6	8.0	400.12	768.71	1273.49	19049.0	1600.60	974.86	439.8
46.40	8.0	402.49	970.0	1314.2	17240.0	1305.70	1201.7	404.313
68.10	16.0	454.19	1045.5	1783.6	15070.0	950.80	1414.31	424.765
100.00	16.0	435.44	900.7	1968.1	8570.0	1206.10	1289.3	743.14
100.00	30.0	440.36	950.0	1907.6	8600.0	1300.4	1334.6	755.40
147.00	30.0	320.797	802.9	1660.9	4290.0	2000.5	1007.51	1060.13
147.00	50.0	333.92	850.2	1855.7	4306.0	2010.6	1050.76	1065.2
215.00	50.0	320.95	1000.4	1196.98	2174.47	1905.20	830.49	1537.9
316.00	50.0	435.2	1351.6	750.30	1577.7	1445.33	684.39	2057.5

rock and stones as well as human activities on the top soil within and around Olona ranch. This is followed by generally low resistive formation ranging from 30.3 to 50 Ωm at Onicha Olona suggestive of clay stratum with thickness of 1.7 m. The second layer in Atuma Iga and Akwukwu-Igbo has resistivity of 630 to 820 Ωm and consists of clayey sand of thickness of about 1 m but at VES 7 it has a thickness of about 10 m (Figure 3 to 7). The third layer consists of sandy clay of resistivity values ranging from 200 to 480 Ωm. Thus, only VES 5 has sandy clay formation before clay formation. The fourth layer in all sites have moderately high resistivity of 1,300 to 2588 Ωm suggestive of compact weathered rock and granulated sand grain formation with thickness of 8 to 13 m to a depth of about 31 m. At the ranch this layer is to a depth of 65 m. The fifth layer follows with low resistive layer with resistivity range of 390 to 700 Ωm except at VES 7 in Akwukwu-Igbo which has resistivity of 2700 Ωm

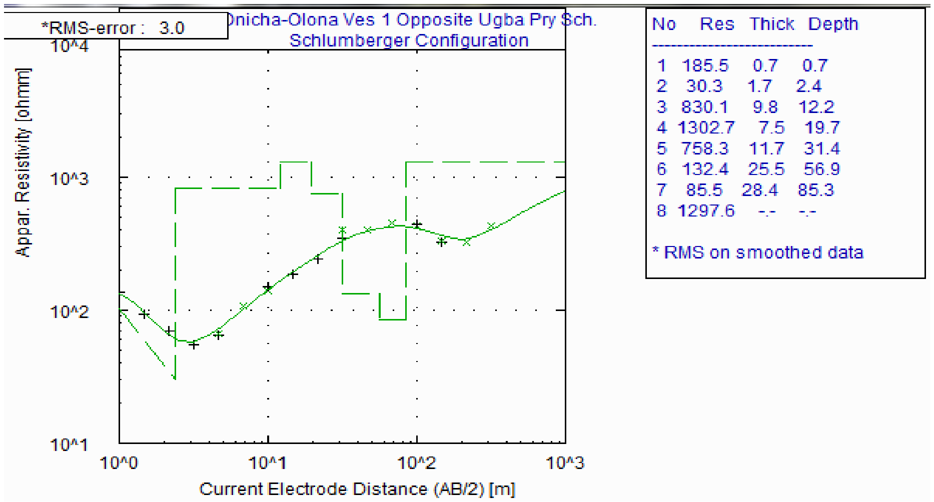

Figure 3. Typical Sounding Curve for Onicha Olona (VES 1) HAK - curve type.

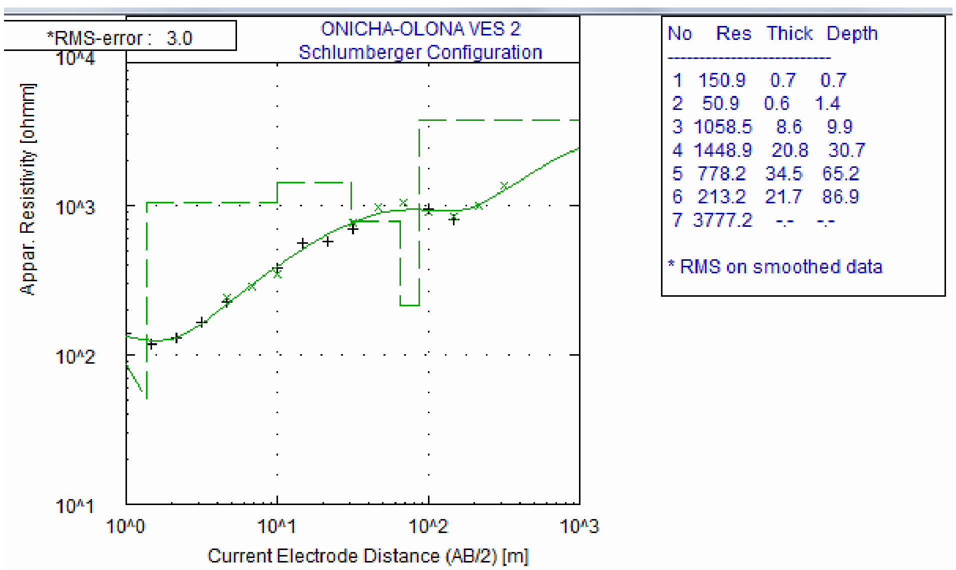

Figure 4. Typical Sounding Curve for Onicha Olona (VES 2) HAH - curve type.

due to drastic topographic change. The sixth layers at Atuma Iga and Akwukwu-Igbo have remarkable high resistivity range of 2244 to 7955 m evident of weathered and granulated rock formations. The seventh and eight layers have low resistivity values which suggest the occurrence of medium to coarse grain sand and gravelly stones respectively indicative of near water bearing medium. Thus, by this study, appreciable groundwater yield at Atuma Iga and Akwukwu-Igbo is at depths of 85 to 100 m with static water level within and about 75 m. Also, the water bearing medium (aquifer) is found to be shielded by the weathered rock formation at Akwukwu-Igbo so it is advisable that wells are drilled to about 95 to 100 m and even deeper around the Ministry of works to obtain appreciable aquifer yield and avoid contamination. The subsurface strata at Atuma Iga consist generally of low resistive formations suggestive of sandy clay, clay and clayey sand formations to far depths. This is indicative of confined aquifer.

At the ranch, the upper layer consists of high resistive weathered rocks. However, at depths below, the resistivities drop drastically suggestive of rock faults and some groundwater. Thus, there is evidence of perched aquifer or near surface groundwater accumulation beneath resulting from continuous flow from rock faults at about 50 m. Here also, there are springs emanating from the faults which eventually form the slow running streams like the 'Iyi Ishiekpe' stream within the valleys. These

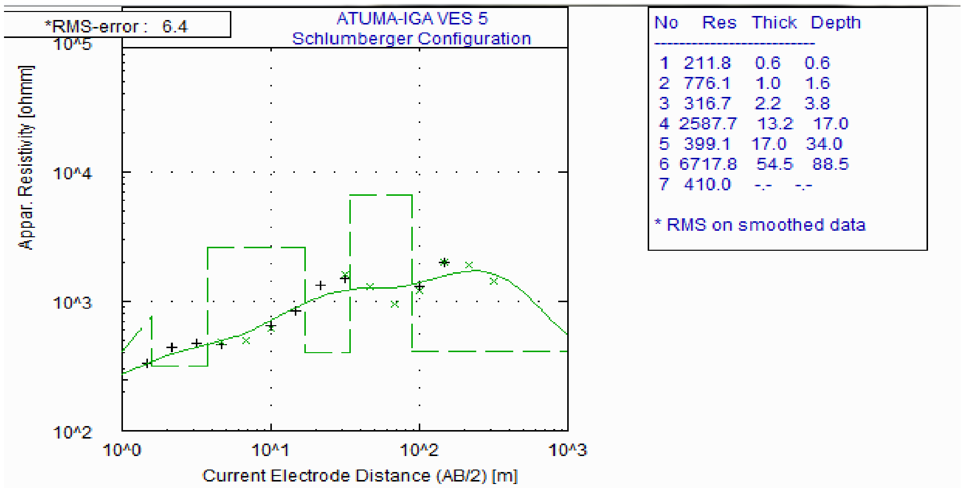

Figure 5. Typical Sounding Curve for Atuma Iga (VES 5) QKHK - curve type.

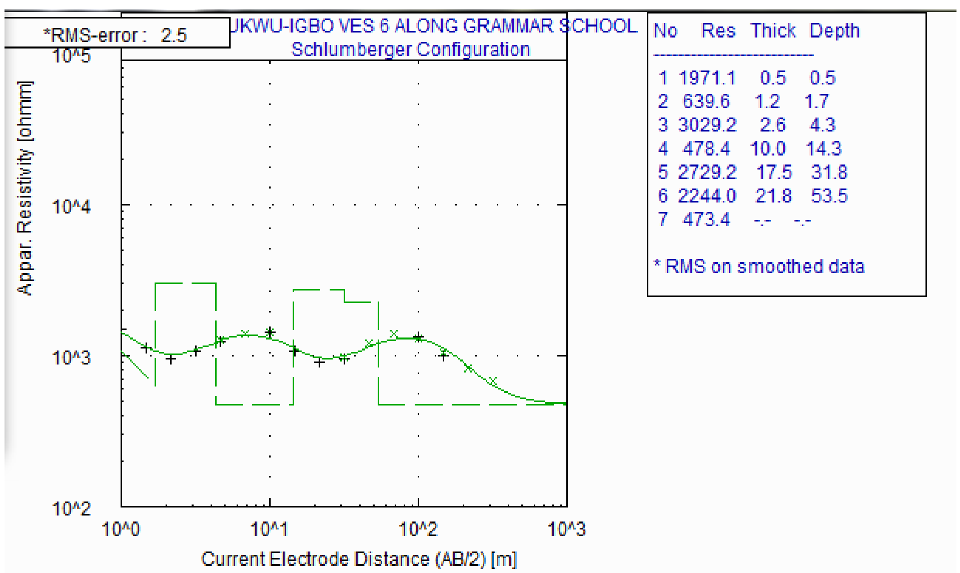

Figure 6. Typical Sounding Curve for Akwukwu-Igbo (VES 6) HKHKQ - curve type.

valley streams stand out as the major sources of the domestic water for the residence of Onicha Olona, Atuma Iga and Akwukwu-Igbo for many years.

The geoelectric parameters and delineated lithology are presented in Table 2.

Conclusion

Onicha Olona, Atuma Iga and Akwukwu-Igbo are true Niger Delta towns with a typical feature of massive subsurface structural deposits. The study shows that the area contains sediments of varying lithology with complex curve types of HAK, HAH, HK, QHK, QKHK, HKHKQ and QHKHA. It consists of a mix of clayey sand with springs from faults in the weathered rocks within the valleys at Onicha Olona. It also shows that groundwater flow originates from faults within the rocky valleys and culminates into running surface waters around the ranch. A section of these running waters form the slow running Iyi Ishiekpe stream at Onicha Olona which has been one of the main sources of water for domestics use for many a people. Aquifers are delineated in Onicha Olona at depths of 120 m and more, while at Atuma Iga and Akwukwu-Igbo sustainable aquifers exist at depths of about 85 to 105 m due to reduction in topography from Onicha Olona to Akwukwu-Igbo. The static water level in Atuma Iga and Akwukwu-Igbo is about 80 m. Perched

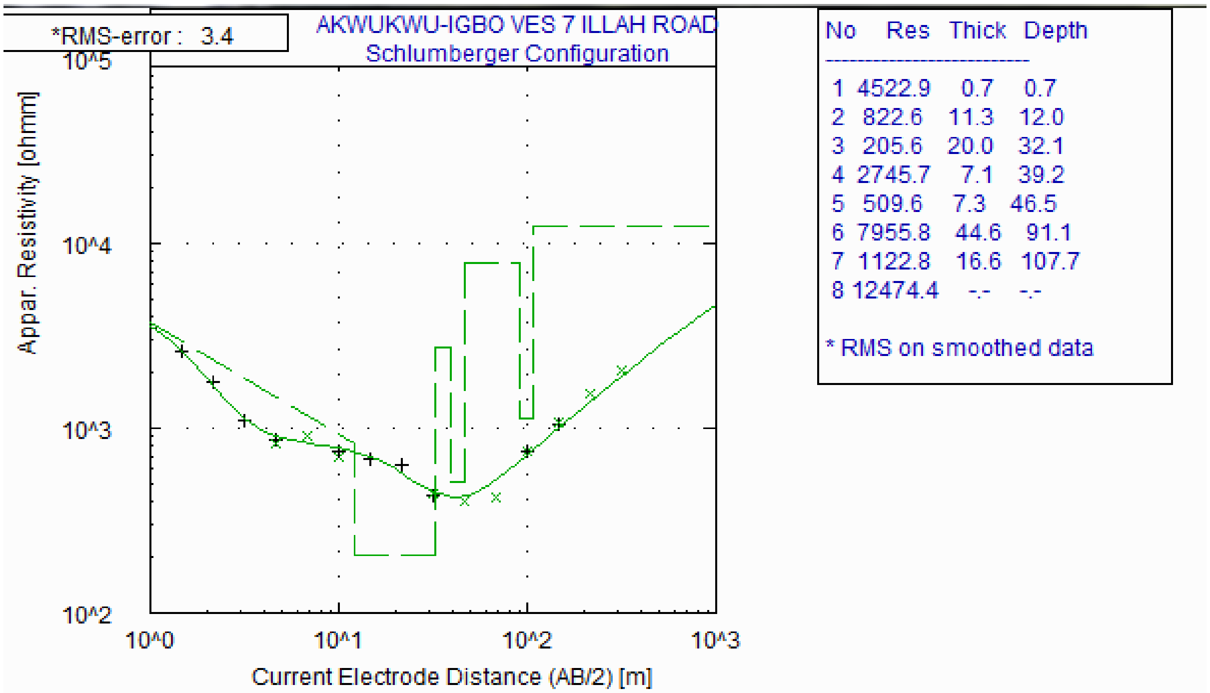

Figure 7. Typical Sounding Curve for Akwukwu-Igbo (VES 7) QHKHA - curve type.

Table 2. Geoelectric parameters and delineated lithology in the study area.

VES	Layer No.	Resistivity (Ωm)	Thickness (m)	Depth (m)	Delineated lithology	VES station and type curve
	1	185.5	0.7	0.7	Topsoil	
	2	30.3	1.7	2.4	Clayey Sand	
	3	830.1	9.8	12.2	Clay	**Onicha Olona**
	4	1302.7	7.5	19.7	Sandy Sand	(Along Mkpitime Rd)
VES 1	5	758.3	11.7	31.4	Fine Sand	
	6	132.4	25.5	56.9	Brownish Sandy Clay	$\ell_1>\ell_2<\ell_3<\ell_4>\ell_5>\ell_6>\ell_7<\ell_8$
	7	85.5	28.4	85.3	Fine to Medium Grain sand	HAK
	8	1297.6	---	-----	Medium to Coarse Grain Sand	
	1	150.9	0.7	0.7	Topsoil	
	2	50.9	0.6	1.3	Clayey Sand	**Onicha Olona**
	3	1058.5	8.6	9.9	Clay	(Atuma Iga Rd)
VES 2	4	1448.9	20.8	30.7	Sandy Sand	
	5	778.2	34.5	65.2	Fine Sand	$\ell_1>\ell_2<\ell_3<\ell_4>\ell_5>\ell_6<\ell_7$
	6	213.2	21.7	86.9	Brownish Sandy Clay	HAH
	7	3777.2	---	-----	Fine to Medium Grain sand	
	1	2956.5	0.5	0.5	Topsoil	
	2	250.3	4.5	5.0	Clayey Sand	**Onicha olona**
	3	3659.6	14.9	19.9	Clay	(Palm Guest House)
VES 3	4	1724.0	9.7	29.6	Sandy Sand	
	5	4523.9	15.9	45.5	Fine Sand	$\ell_1>\ell_2<\ell_3>\ell_4<\ell_5>\ell_6>\ell_7$
	6	3748.2	18.4	63.9	Brownish Sandy Clay	HK
	7	231.9	---	------	Fine to Medium Grain sand	

Table 2. Contd.

	1	1100000.0	1.0	1.0	Topsoil	
	2	5379.9	1.9	2.9	Granulated Sand & stones	**Onicha Olona**
	3	22817.9	39.3	41.2	Weathered rocks	(Olona Ranch)
VES 4	4	1498.0	22.5	63.7	Sand stones	
	5	751.0	13.8	77.5	Fine Sand	$\ell_1>\ell_2<\ell_3>\ell_4>\ell_5>\ell_6<\ell_7$
	6	346.5	9.5	87.0	Brownish Sandy Clay	QHK
	7	2402.0	---	------	Fine to Medium Grain sand	
	1	211.8	0.6	0.6	Topsoil	
	2	776.1	1.0	1.6	Clayey Sand	**Atuma Iga**
	3	316.7	2.2	3.8	Clay	(Obi's Palace)
VES 5	4	2587.7	13.2	17.0	Medium grain sand	
	5	399.1	17.0	24.0	Sandy Clay	$\ell_1<\ell_2>\ell_3<\ell_4>\ell_5<\ell_6>\ell_7$
	6	6717.8	54.5	78.5	Brownish Sandy Clay	QKHK
	7	410.0	---	----	Fine to Medium Grain sand	
	1	1971.1	0.5	0.5	Topsoil	
	2	639.6	1.2	1.7	Clayey Sand	**Atuma Iga/Akwuwu-Igbo**
	3	3029.2	2.6	4.3	Weathered rock/ Sand stones	(Market)
VES 6	4	478.4	10.0	14.3	Sandy Sand	
	5	2729.2	17.5	31.8	Fine Sand	$\ell_1>\ell_2<\ell_3>\ell_4<\ell_5>\ell_6>\ell_7$
	6	2244.0	21.8	53.6	Brownish Sandy Clay	HKHKQ
	7	473.4	---	-----	Fine to Medium Grain sand	
	1	4522.9	0.7	0.7	Topsoil	
	2	822.6	11.3	12.0	Clayey Sand	
	3	205.6	20.0	32.0	Clay	**Akwukwu-Igbo**
	4	2745.7	7.1	39.1	Sandy Sand	(Ministry of Works)
VES 7	5	509.6	7.3	46.4	Fine Sand	
	6	7955.8	44.6	91.0	Brownish Weathered Sand stones	$\ell_1>\ell_2>\ell_3<\ell_4>\ell_5<\ell_6>\ell_7<\ell_8$
	7	1122.8	16.6	107.6	Fine to Medium Grain sand	QHKHA
	8	12474.4	---	-----	Medium to Coarse Grain Sand	

aquifers are also delineated at 50 m in Atuma Iga and at 40 m in Akwukwu-Igbo. The study has thus, been successfully used to delineate the subsurface structure and increase the probability of drilling successful and sustainable boreholes in the area.

RECOMMENDATION

From the study, the subsurface formations contain rocks and the prolific aquifers exist only at very far depths. It is obvious that obtaining uncontaminated groundwater from viable aquifers in these towns, Onicha Olona, Atuma Iga and Akwukwu-Igbo requires government intervention as deep wells in the area can only be obtain by professional drillers and special drilling equipment. Indeed, only very few individuals may afford this feat. It is therefore recommended that Government and private sectors should as a matter of urgency assist these agro-based and fast developing towns in the provision of reliable and sustainable boreholes that will stand the test of time to improve the quality of life of the people.

ACKNOWLEDGEMENTS

Author gratefully acknowledge Prof Andy Egwunyenga and geophysics students for their concern, field commitments and immense contributions; The Vice Chancellor Prof. Eric Arubayi and Dean of Faculty of Science Prof S.H.O. Egboh both of Delta State University, Abraka for granting official permission to go for this study; His Royal Majesty, Obi Chukwuka Ogbudo of Atuma Iga, His Royal Highness, Obi David Azuka of Akwukwu-Igbo and the Obi of Onicha Olona for the hospitality and unflinching support received during the

study.

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