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Determination of Aquifer Characteristics from Geo-electrical Sounding data in parts of Anambra State, Nigeria

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ABSTRACT: The execution of water borehole project is quite expensive, there is therefore need for surface resistivity measurements before drilling to gain sufficient knowledge on the subsurface geo-hydrological conditions of an area. In this study, geophysical investigation of groundwater is aimed at delineating the aquiferous units in the central part of Awka by determining their depths, thicknesses, resistivities and the potential borehole depth at various locations within the area employing the technique of Vertical Electric Sounding (VES) using the Schlumberger array. Ten (10) sounding stations were obtained. The data was interpreted using conventional partial curve matching and computer aided iteration techniques. The vertical electrical sounding curve types identified in the study area includes K, H, QH, HK, and QK. The HK-type sounding curves were predominant in the study area. About four to six geo-electric layers comprising the top soil, shaly- sand, sand, dry sand, water saturated sandstone, and shale were delineated with the shale usually occurring as the last layer. Lithologic log for the borehole located near one of the sounding station at Awka revealed that some of the geologic units were either suppressed or merged into a single geo-electric unit probably due to similarities in electrical resistivity. 3-D surface map of the aquifer characteristics were produced, it was observed that the aquifer properties ranges from 0.0262 to 0.7187cm/s, 1.2995-48.0092cm^2/s, 139.14-3813.22 Ohm-m, 9,294.55-189,135.71 Ohm-m^2, 0.0130-0.4801 Ohm^{-1} for hydraulic conductivity, transmissivity, resistivity, transverse resistance and longitudinal conductance respectively within the study area.

KEYWORDS: Vertical electrical sounding, geo-electric section, transmissivity, hydraulic conductivity, resistivity, aquifer characteristics.

INTRODUCTION

Due to the failure of government to provide portable water sources in Awka, Anambra State and in addition to lack of portable surface water sources, lately there has been a greater interest in the exploitation of groundwater supplies. However, many problems exist as a result of insufficient knowledge of the subsurface geophysical conditions in many parts of Awka. The development of groundwater involves the sinking of boreholes at sites, which most times are chosen arbitrarily. In several cases, this has resulted in abortive boreholes, extremely low yield and total failure of some supply well within this study area. This has therefore underline the importance of taking proper precautions in order to reduce the risks of spending large sums of money in sinking abortive boreholes. Quantitative description of aquifers has become vital in order to address several hydrological and hydro-geological problems. Fluid transmissivity, transverse resistance, longitudinal conductance, hydraulic conductivity and aquifer depth are fundamental properties describing subsurface hydrology. As a result, many investigation techniques are commonly employed with the aim of the estimation of spatial distribution of the above mentioned hydraulic parameters [1].

There are many number of geophysical exploration techniques which can give insight on the nature of the water bearing layers and these include geoelectric, electromagnetic, seismic and geophysical borehole logging [2]. These methods measure properties of formation materials, which determine whether such formation may be sufficiently porous and permeable to serve as an aquifer. The electrical resistivity method and seismic refraction method are the surface geophysical methods commonly used for groundwater exploration [3].

Objectives Of The Study

Vertical Electrical Sounding (an Electrical Resistivity Survey Method) using a Schlumberger array was used to achieve the following which are the primary objectives of the study:

i. To determine the thickness of the aquiferous layers at various locations within Awka metropolis.

ii. To develop a geo-hydrological database for the study area that will guide government and individuals in groundwater development on the characteristics of the aquifers, the distribution of the aquifers as well as the depths boreholes could be drilled for sustainable water supply.

Materials And Methods

Study Area

The study area is Awka, Anambra State, Nigeria located between Latitude 6º12'- 6º16' N and Longitude 7º04' - 7º07' E and lies within the tropical wet climate zone having two distinct seasons: wet season (April- October) and dry season (November – March). The mean temperature which prevails over this region varies between 27 ºC - 28ºC which most times peak to 35ºC between January and April. This region also witnesses a mean annual rainfall of about 2000 mm with maximum monthly rainfall during the peaks ranging from 270 mm – 360 mm [3].

Field Procedure

An electrode made of stainless steel was driven into the soil at each end of the spread A and B. Both electrodes were then connected to the current sender of the Terrameter. The electrodes M and N were also driven into the soil and connected to the voltage receiver. At each position of A and B, the current was sent, and the potential difference between M and N was measured. Also, the distances AB and MN were measured.

Following the placing and connection of all electrodes, resistance measurements were made beginning with the smallest spacing and progressing outward. When the ratio of the distance between the current electrodes to that between the potential electrodes becomes too large, the potential electrodes must also be displaced outwards otherwise the potential difference becomes too small to be measured with sufficient accuracy [4].

The aim is to determine the depth of current penetration as a function of current electrode spacing. The ABEM Terrameter SAS 1000C performs automatic recording of both voltage and current, stacks the results, computes the resistance in real time and digitally displays it [5]. From the field data, the apparent resistivity, which is a function of AB/2 (half the current electrode spacing) was calculated and interpreted with computer software (One dimentional Interpex Version3).

The Root Mean Square error was less than 10%. The apparent resistivity values obtained in the field was plotted against half current electrode spacing in a bi-logarithmic graph. The curves of best fit were traced and the data obtained from the smooth curve was noted. Qualitative and quantitative interpretations of the field curves were carried out by inspection to obtain the type of curves. Resistivity measurements were made with a Terrameter SAS 1000 system.

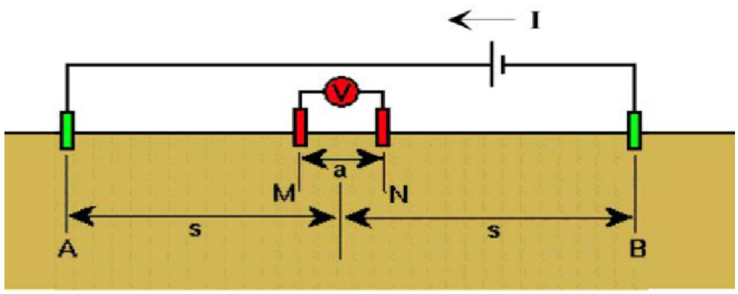

Fig.1: Sketch diagram of Schlumberger Configuration

Ten (10) vertical electrical sounding (VES) points were conducted at various locations within the study area in order to study the variations in the resistivity distribution of the soil with depth. GPS device was used for measuring the spatial location (latitude and longitude) and elevation for the VES points.

Table 1: GPS readings to show the elevations and coordinates of each VES Sounding point

VES	ELEVATION (M)	LATITUDE	LONGITUDE
1	115	6º14.224'N	7 º05.478'E
2	43	6º13.629'N	7 º05.458'E
3	47	6º15.572'N	7 º06.572'E
4	91	6º13.486'N	7 º05.843'E
5	74	6º12.635'N	7 º03.677'E
6	106	6º14.536'N	7 º05.832'E
7	52	6º13.321'N	7 º05.285'E
8	101	6º12.534'N	7 º03.459'E
9	139	6º13.943'N	7 º05.351'E
10	78	6º14.380'N	7 º05.963'E

AQUIFER CALCULATIONS

Hydraulic conductivity is symbolically represented as *K*, which depends on the intrinsic permeability of the material and on the degree of saturation. Saturated hydraulic conductivity, K_{sat}, describes water movement through saturated media.

$$K_c=1/p \quad (1)$$

Where K_c is the calculated hydraulic conductivity and p is the resistivity of the saturated layer

Expressing K in m/day or cm/s and b in m, the transmissivity (T) is found in units m^2/day or cm^2/s.

$$T=Kb \quad (2)$$

The transmissivity (T) of aquifer is related to the field hydraulic conductivity (K) by the equation above. In a porous medium according to [6]:

$$T_C = K_C b \quad (3)$$

Where T_C = Calculated transmissivity (m^2/day) from VES data, K_C = Calcluated hydraulic conductivity (m/day) from VES data. b = Thickness of saturated layer (m).

Transverse Resistance T_r (Ohm-m^2) and Longitudinal Conductance (Ohm^{-1}) L_c are parameters used to define target areas of good groundwater.

$$T_r = h\,p \text{ and } L_c=h/p \quad (4)$$

Where h is aquifer thickness and p resistivity value of the aquifer.

The calculated hydraulic conductivity (K_c), calculated transmissivity T_c, transverse resistance, and longitudinal conductance values estimated from the VES results are presented in Table 4.

RESULTS, INTERPRETATIONS AND DISCUSSIONS

QUALITATIVE INTERPRETATION

Qualitative interpretation of the vertical electrical sounding curves obtained from the study area showed four to six geo-electrical layers. [7] reported that the distribution of resistivities of different subsurface layers in a three layered earth model can be classified based on curve shapes into H-type ($\rho_1>\rho_2<\rho_3$), K-type ($\rho_1<\rho_2>\rho_3$), A-type ($\rho_1<\rho_2<\rho_3$) and Q type ($\rho_1>\rho_2>\rho_3$); they can be combined to produce

HA-type ($\rho_1>\rho_2<\rho_3<\rho_4$),

HK-type ($\rho_1>\rho_2<\rho_3>\rho_4$),

KH-type ($\rho1<\rho2>\rho3<\rho4$),

QH-type ($\rho_1>\rho_2>\rho_3<\rho_4$) and so on in four to six layer cases. Therefore based on the aforementioned assertions, the vertical electrical sounding curve types identified in the study area includes K (2), H (1), QH (2), HK (3), QK(2). Therefore, HK type is the most dominant sounding curve type in the study area.

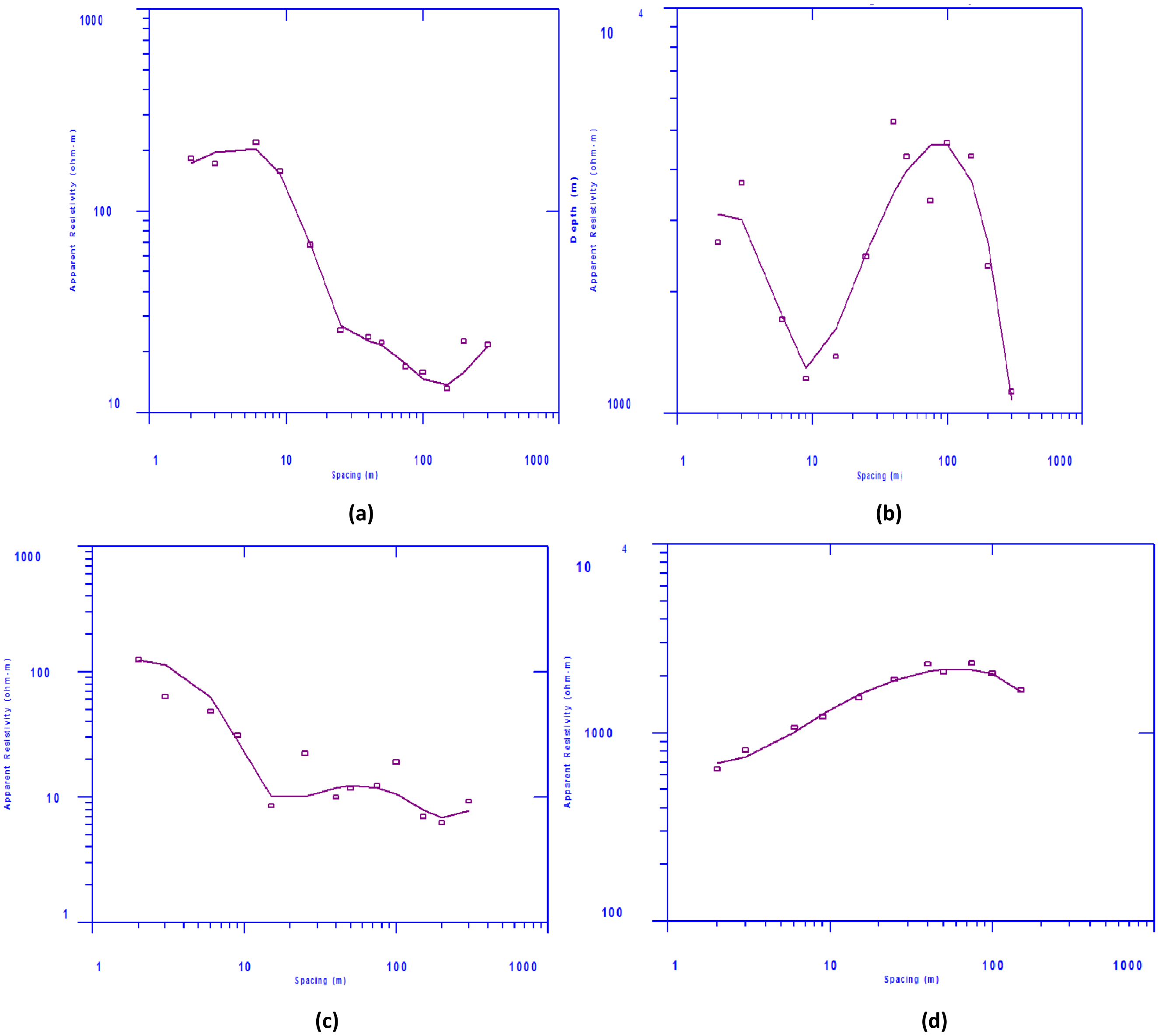

Figure 2: Computer modelled geoelectric curves at VES point (a) 1, (b) 2, (c) 3 and (d) 4

QUANTITATIVE INTERPRETATION

The quantitative interpretation of the curves highlights the geological units encountered, their various depth and thickness and the respective resistivity as shown in Tables 2. The sounding encountered five geo-electric units in VES1 (see Table 2-3). The first layer is about 2.7 metres thick, which is the top soil that is made up of laterite with resistivity of about 182.70Ω-m. The second layer of about 3.7 metres thickness with higher resistivity of about 219Ω-m is interpreted as sand. Third layer with thickness of about 5.1 metres contains shallow saturated shale with resistivity of about 158Ω-m. The next layer is about 180.7 metres thick with moderate resistivity of about 13.20Ω-m and interpreted as shale. The fifth layer, whose base could not be reached has a high resistivity (521.7Ω-m) and is interpreted as water saturated sandstone layer, which is the prospective aquifer unit (the unit of interest).

Table 2a: Summary of the Aquifer formation of layer parameters

Location	Layer 1			Layer 2			Layer 3		
	App. Resistivity (Ω-m)	Thickness (m)	Depth (m)	App. Resistivity (Ω-m)	Thickness (m)	Depth (m)	App. Resistivity (Ω-m)	Thickness (m)	Depth (m)
VES 1	182.7	2.7	2.7	219	3.7	6.4	158	5.1	11.5
VES 2	3103.12	3.5	3.5	1220.19	6.2	9.7	4650.16	90.7	100.4
VES 3	125.70	2.5	2.5	8.54	10.3	12.8	82.01	8.9	21.7
VES 4	640.41	2.3	2.3	2320.17	38.4	40.7	1894	65.2	105.9
VES 5	425.23	2.2	2.2	3.41	23.6	25.8	38.14	24.6	50.4
VES 6	393.01	2.4	2.4	144.16	2.3	4.7	2050.22	45.3	50
VES 7	232.92	2.7	2.7	875.54	6.7	9.4	4090.16	36.9	46.3
VES 8	597.02	2.2	2.2	858.21	6.3	8.5	10.22	29.7	38.2
VES 9	235.21	2.8	2.8	42.54	2.4	5.2	1986.1	98.1	103.3
VES 10	682.1	1.96	1.96	13.85	10.67	12.63	122.11	15.64	28.27

Table 2b: Summary of the Aquifer formation of layer parameters

Location	Layer 4			Layer 5			Layer 6		
	App. Resistivity (Ω-m)	Thickness (m)	Depth (m)	App. Resistivity (Ω-m)	Thickness (m)	Depth (m)	App. Resistivity (Ω-m)	Thickness (m)	Depth (m)
VES 1	13.2	180.7	189.2	521.7	-	Base not Reached			
VES 2	3813.22	49.6	150	210.72	-	Base not Reached			
VES 3	6.27	165.7	187.4	422.41	-	Base not Reached			
VES 4	124.98		Base not Reached		-				
VES 5	532.52	55.8	106.2	183.21	79.5	185.7	10.12		Base not Reached
VES 6	1235.37	106.1	156.1	8.02	-	Base not Reached			
VES 7	1004.04	59.5	105.8	106.52	-	Base not Reached			
VES 8	139.14	66.8	105.0	1221.09	-	Base not Reached			
VES 9	893.2	92.9	196.2	107.04	-	Base not Reached			
VES 10	564.28	14.91	43.18	320.86	77.85	121.03			

In VES 2, the sounding at this station intercepted five geo-electric units (see Table 2-3). The first layer is about 3.5m thick and is the top soil that is made up of laterite with a resistivity of about 3103.12Ω-m. The second layer of about 6.2 metres thickness with higher resistivity of about 1220.19Ω-m is interpreted as shaly-sand. Third layer with thickness of about 90.7 metres contains dry sand with very high resistivity of about 4650.16Ω-m. The next layer is about 49.6 metres thick with resistivity of about 3813.22Ω-m and interpreted as water saturated sand layer which is the prospective aquifer unit. The fifth layer whose base could not be reached has a very low resistivity (210.72Ω-m) and is interpreted as shale (clay).

Table 3: Summary of geo-electric layers

Location	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
VES 1	Top soil	Sand	shallow saturated shale	Shale	Saturated sand	
VES 2	Top soil	Shaly-sand	Sand	Water saturated sand	Shale	
VES 3	Top soil	Shale	Shallow saturated shale	Shale	Water saturated sand	
VES 4	Top soil	Sand	Water saturated sand	Shale	-	
VES 5	Top soil	Shale	Shaly-sand	Sand	Water saturated sand	Shale
VES 6	Top soil	Shale	Sand	Water saturated sand	Shale	
VES 7	Top soil	Shaly-sand	Sand	Water saturated sand	Shale	
VES 8	Top soil	Sand	Shale	Water saturated sand	Sand	
VES 9	Top soil	Shale	Sand	Water saturated sand	Shale	
VES 10	Top soil	Shale	Shaly sand	Sand	Water saturated sand	Shale

Similarly in VES 3, five geo-electric section were delineated in this location (see Table 2-3). The uppermost layer which is mostly laterite has a resistivity value of about 125.7Ω-m and about 2.5 metres thick. The underlying layer has a very low resisitivity value of about 8.54Ω-m and about 10.3 metres thick. It is interpreted as shale. Beneath the layer is another layer with thickness of about 8.9 metres contains sand with high resistivity of about 82.01Ω-m. The next layer which has resisitivity value of 187.40Ω-m and thickness of 165.7 meters. It is interpreted as shale. The last layer whose bottom was not reached has a resistivity value of 422.41Ω-m and was interpreted as water saturated sandstone which is the prospective aquifer unit. Four geo-electric sections were delineated in VES 4, six geo-electric units in VES 5, five geo-electric units in VES 6,7, 8, 9 and 10. The topmost layers have a resistivity value of 640.41Ω-m, 425.23Ω-m, 393.01Ω-m, 232.92Ω-m, 597.02 Ω-m , 235.21 Ω-m for VES 5,6,7, 8, 9 and 10 respectively.

Other results for VES 4-10 is properly presented in Table 2-3.

Geo-Electric Correlations Within The Study Area

The geo-electric correlation sections show vertical and lateral variations in layer resistivity and thickness, which is a revelation of the lateral and vertical lithological changes in the study area. Profile were taken; one A-B through VES locations 10, 4, 7, 2 and 5 in the northwest-southeast direction (Fig.3).

Five subsurface layers were identified as: topsoil, the sand, shaly-sand, water saturated sand and the shale. In Fig.3, the aquifer unit recognized has resistivity values between 183.21 to 3813.22 Ohm-m and the depth to the top of the water saturated sand, which is the propective aquifer unit of interest ranges from 40.7 to 106 meters. The water bearing sandstone depth varies from one region to the other. Beneath this aquiferous region, the profile reveals a layer identified as the shale, which is the last layer whose bottom was not reached.

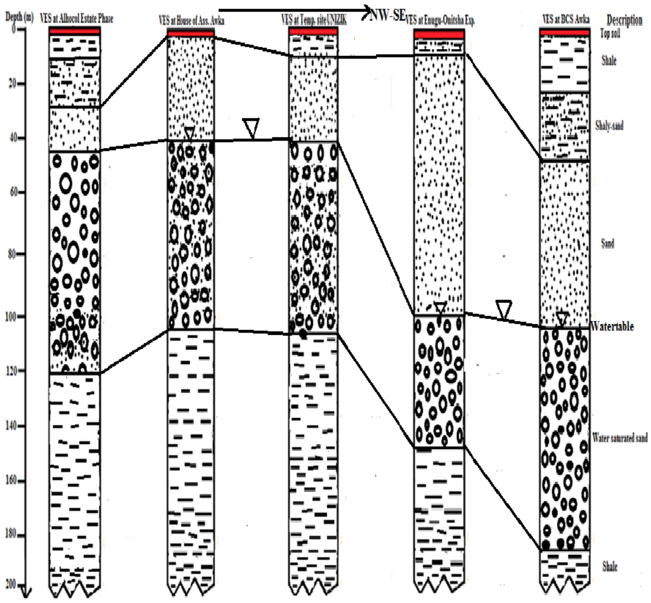

Fig.3: Geo-electric correlation along NW-SE Profile A-B

CORRELATION OF SOUNDING RESULT WITH GEOLOGY

Vertical electrical sounding data interpretation results obtained from the area showed four to six geoelectrical layers, which has been interpreted as: top soil, sand, shaly sand, dry sand, water saturated sand and shale. For better delineation of the underlying geology, results from two (2) vertical electrical soundings (VES 9 and 10) conducted in close proximity to two water boreholes have been correlated with known borehole log (Fig.4). Based on the borehole lithological logs, the correlation showed that the topsoil thickness in the lithologic section is 7.9m and 14.6m while in geo-electric section, it is 2.8m and 2.2m respectively. In the underlying layers, the geo-electric units show suppression and merging of some lithologic units from the borehole. This is due to the fact that geo-electric units are not the same as lithologic units. A given lithologic unit with variations in resistivity will give rise to so many geo-electric units. Also, different lithologic units with similar resistivities would be merged as one geo-electric unit.

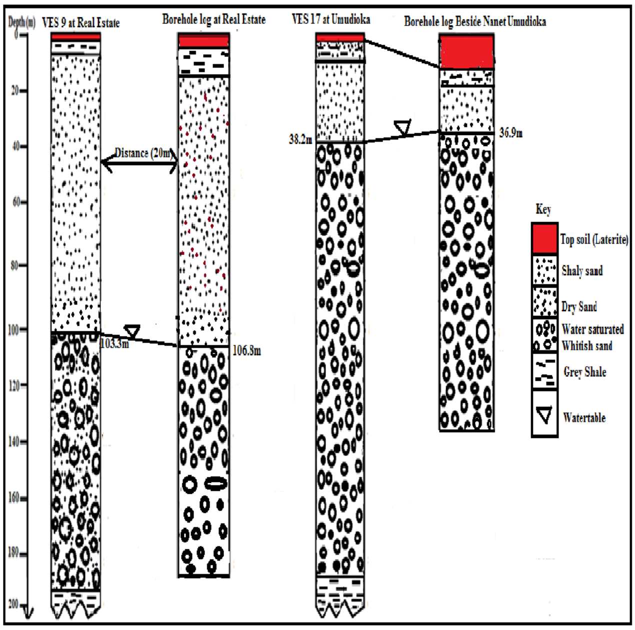

Fig.4: Correlation of Geoelectric and lithologic sections within the study area

AQUIFER CHARACTERISTICS

The hydraulic characteristics of aquifers are important properties for both groundwater and contaminated land assessments and also for safe construction of engineering structures [7]. Application of field hydrogeological method in aquifer parameter estimation is time consuming and capital intensive. In the alternative, surface geophysical method may provide rapid and effective techniques for groundwater exploration and aquifer evaluation. Table 3 shows the values of the aquifer parameters. Fig. 6 shows the distribution of the aquifer thickness computed from the resistivity soundings interpretation ranging from 49.6m at VES 2 to 112.6m at VES 3. The aquifer thickness map revealed that the maximum aquifer thickness is at eastern part of the study area, while the western part of the study area has the minimum thickness.

Table 3: Aquifer parameters estimated from geophysical data

VES NO	b (m)	ρ (ohm-m)	Transverse Resistance (Ohm-m^2)	Longitudinal Conductance (Ohm^{-1})	K_c(cm/s)	T_c (cm^2/s)
1	110.8	521.7	57,804.36	0.2124	0.1917	21.2383
2	49.6	3813.22	189,135.71	0.0130	0.0262	1.2995
3	112.6	422.41	47,563.37	0.2666	0.2367	26.6524
4	65.2	1894.34	123,488.80	0.0344	0.0528	3.4425
5	79.5	183.21	14,565.20	0.4339	0.5458	43.3911
6	106.1	1235.37	131,072.76	0.0859	0.0809	8.5835
7	59.5	1004.04	59,740.38	0.0593	0.0996	5.9262
8	66.8	139.14	9,294.55	0.4801	0.7187	48.0092
9	92.9	893.2	82,978.95	0.1040	0.1121	10.4008
10	77.85	320.86	24,978.95	0.2426	0.3117	24.2658

Maximum aquifer thickness area is characterized by a thick and prolific aquiferous zone, tapped by many productive boreholes and wells. This is due to the composition of the aquifer zone, consisted of unconsolidated medium to coarse grained sands and gravel.

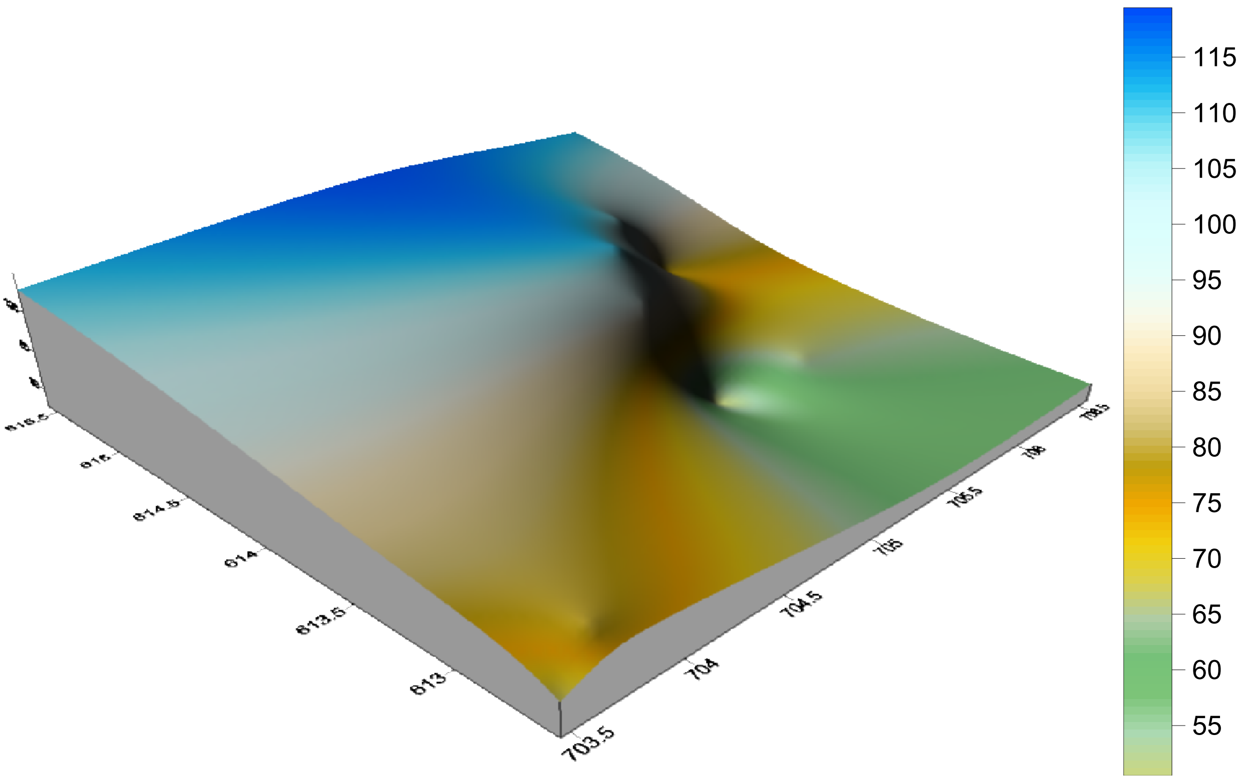

Fig. 5: 3-D Aquifer thickness map of the study area

The calculated hydraulic conductivity (Kc) values estimated from the VES results ranges from 0.0262 to 0.7187 cm/s (Table 3 and Fig.6). Hydraulic conductivity depends on the intrinsic permeability of the material and on the degree of saturation. The maximum hydraulic conductivity values are observed at the extreme north and southern portion of the study area while the transmissivity values (Table 3 and Fig. 8) vary between 1.2995 and 48.0092 cm^2/s, suggesting a high quality reservoir [9].

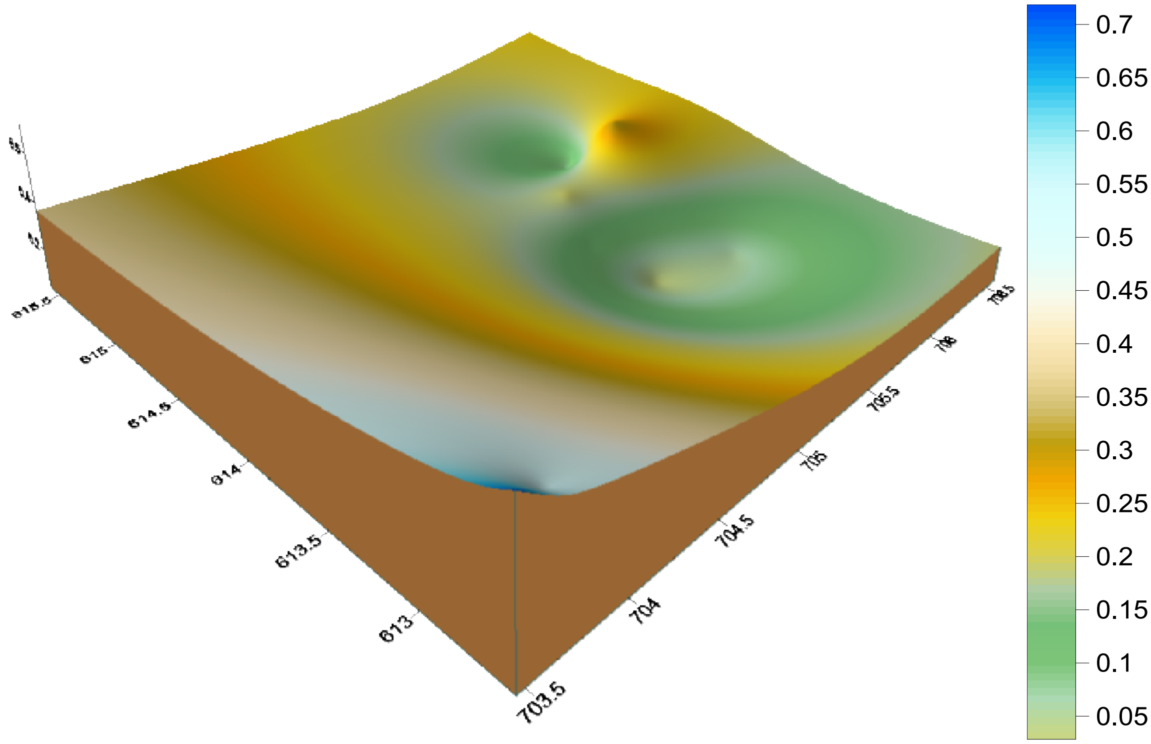

Fig. 6: 3-D Hydraulic conductivity map of the study area

The knowledge of transmissivity distribution is a fundamental source of information for establishing a hydrogeological model [6].

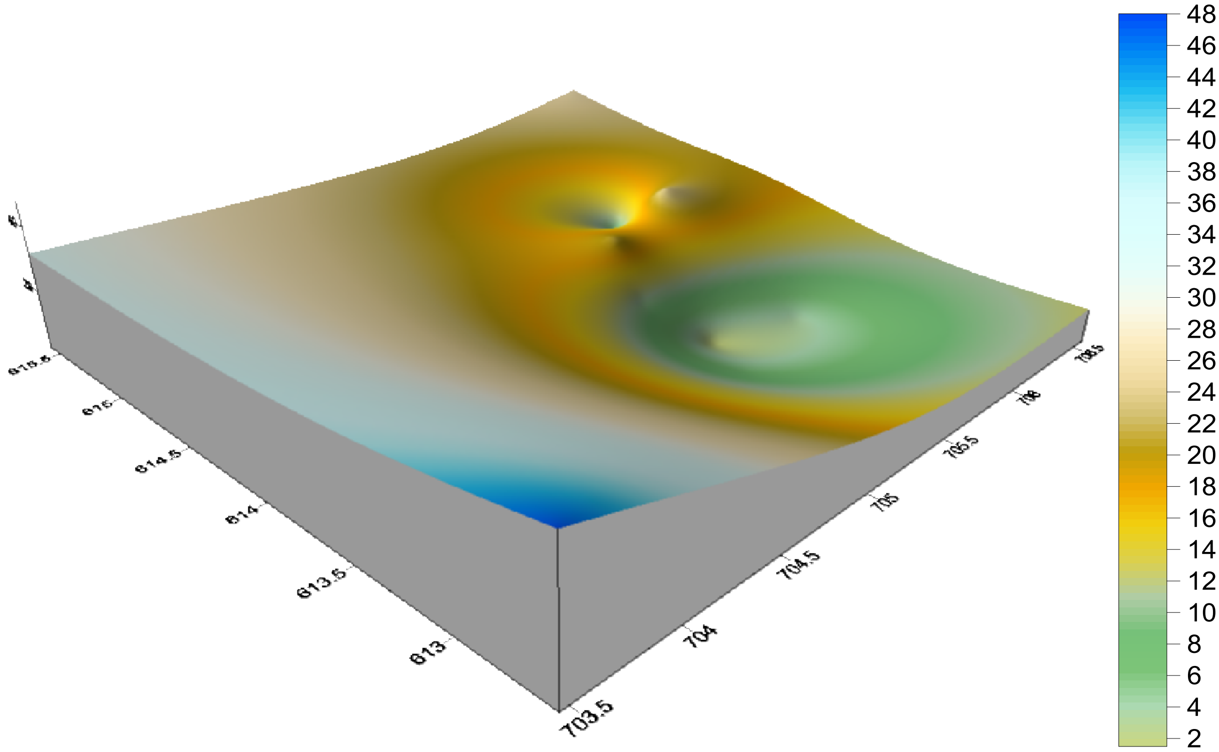

Fig.7: 3-D Transimissivity map of the study area

Transverse resistance is correlated with aquifer transmissivity and is one of the parameters used to define target areas of good groundwater potential. Higher values of transverse resistance indicate aquiferous zones with high transmissivity. VES 2 has the highest transverse resistance and therefore indicates area with good groundwater potential. The transverse resistance in this study is found to be higher than he transverse resistance in the study conducted by [10] in Northwest Bangladesh `which is found to vary between 480 and 5,375 ohm-m^2. Longitudinal conductance is closely related to transverse resistance, the 3-D map of transverse resistance and longitudinal conductance is shown in figure 8 and 9.

However, [1] in a study on estimation of aquifer hydraulic parameters from surficial geophysical methods: A case study of Keritis Basin in Chania (Crete – Greece) reported longitudinal conductance to be within 1.673 -10.500 ohm^{-1} which is slightly higher than values obtained in this study.

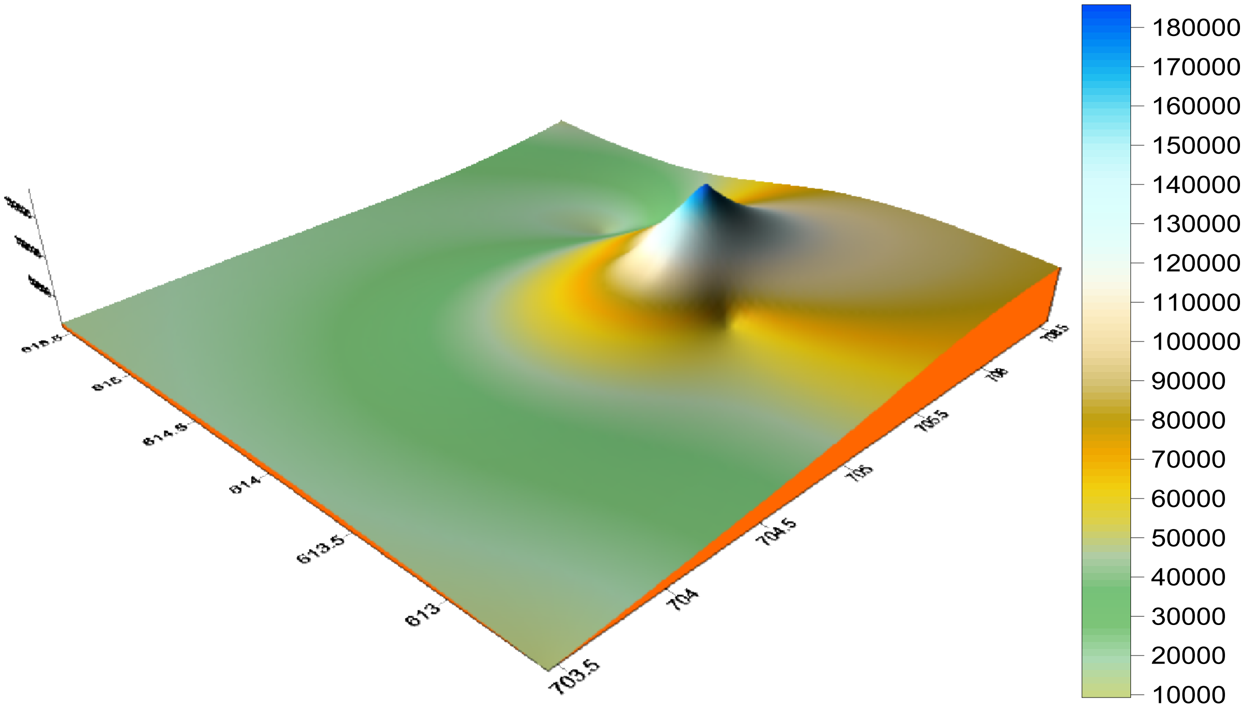

Fig. 8: 3-D Transverse Resistance map of the study area

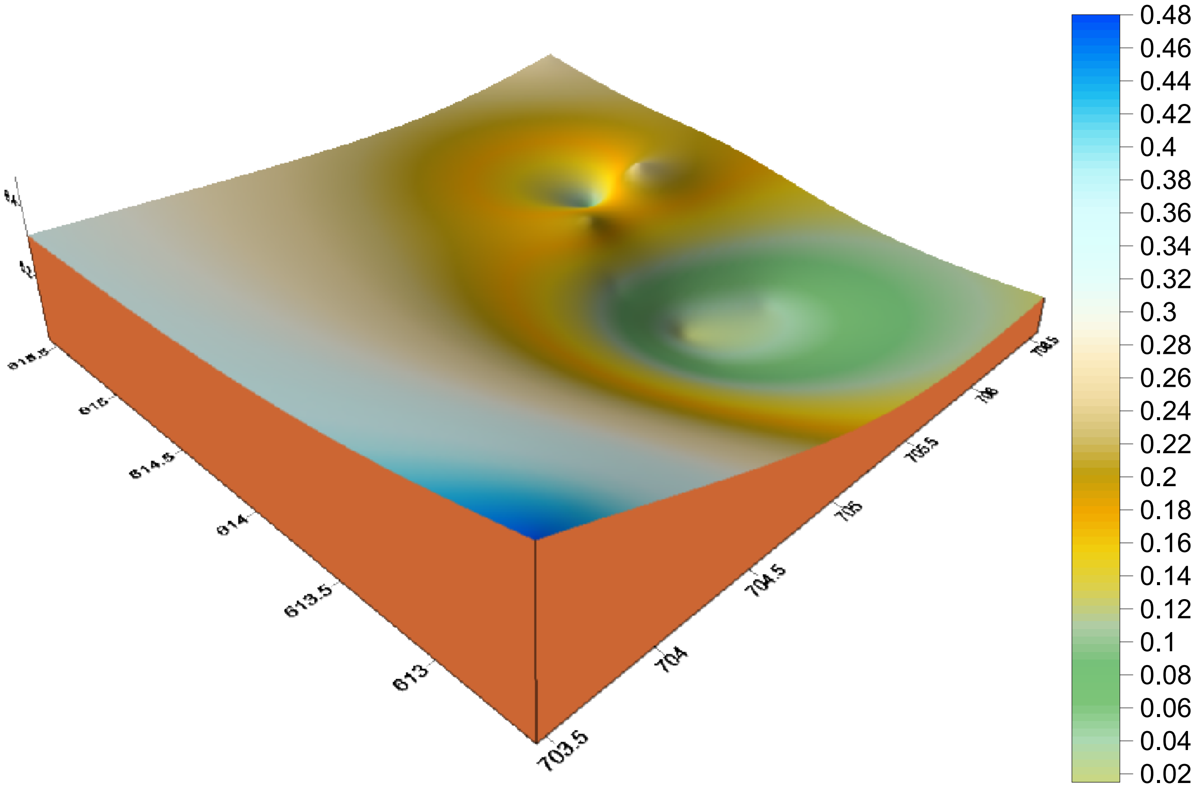

Fig. 9: 3-D Longitudinal Conductance map of the study area

CONCLUSION

The research presented the hydro-geological knowledge of the Study area in other to create awareness on the productive aquifer for sustainable groundwater development. Vertical electrical sounding data interpretation results obtained from the area showed four to six geoelectrical layers, which has been interpreted as: top soil, sand, shaly sand, dry sand, water saturated sand and shale. Lithologic log for the borehole located near one of the sounding station at Awka revealed that some of the geologic units were either suppressed or merged into a single geo-electric unit probably due to similarities in electrical resistivity.

Fluid transmissivity, transverse resistance, longitudinal conductance, hydraulic conductivity and aquifer depth which are fundamental properties describing subsurface hydrology were determined for the study area. 3-D surface map of the aquifer characteristics were produced, it was observed that the aquifer properties ranges from 0.0262 to 0.7187cm/s, 1.2995-48.0092cm^2/s, 139.14-3813.22 Ohm-m, 9,294.55-189,135.71 Ohm-m^2, 0.0130-0.4801 Ohm^{-1} for hydraulic conductivity, transmissivity, resistivity, transverse resistance and longitudinal conductance respectively within the study area.

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