Investigating the Relationship between Water Table and Topographic Variations within Owerri Metropolis

Nwosu, L. I.[1]; Nwachukwu M. A.[2]; Emujakporue, G. O.[3]; Ibekwe K.E.[4], Nwosu B.O.[5]
[1,3,4]Department of Physics University of Port Harcourt, Nigeria
[2,5]Department of Environmental Management, Federal University of Technology, Owerri, Nigeria

***Abstract: -* Twenty (20) Vertical Electrical Soundings (VES) were carried out in different locations in Owerri Metropolis, Imo state of Nigeria in order to investigate the relationship between water table and topographic variations for sustainable groundwater development. OHMEGA - 500 resistivity meter was used to acquire the field data through vertical electric sounding (VES) with maximum electrode spread of 700 m. At each VES location, coordinate and elevation were measured using the Global Positioning System (GPS). The field data were interpreted using the Advanced Geosciences Incorporation (AGI) 1D inversion software. The results revealed 12 geoelectric layers that could be constrained to about 6 lithological units. A near surface (water table) aquifer composed mainly of medium to coarse sand with low resistivity values was observed in Owerri West Area. The resistivity values ranged from 0.6Ωm to 1100.8Ωm. The depth to the water table varied across the area with surface elevation and it ranges from 16.80m to 85.6m. The aquifer thickness also varied from 13.23m to 111.56m and often not terminated. Areas of high aquifer thickness such as Awaka, Amakohia, and New Owerri have high groundwater potential and are good for siting water boreholes with high yield expectations. The study revealed that areas of topographic highs like Owerri North with elevation above 200ft generally have high value for depth to water table while areas of topographic lows in Owerri Municipal and Owerri West have shallow water table suggesting higher aquifer vulnerability to contamination. Finally, the modelled relationship between water table and elevation across Owerri Metropolis is $y = 0.38464406179 + 0.97247494717x - 0.00428862105x^2$, where y is the depth to water table and x is the elevation**

***Key words:* Resistivity, Elevation, Water table, Topographic, Chi-Square test**

I. INTRODUCTION

Water is one of the indispensable resources on earth which is essential for the sustainability of life. It is required for drinking, irrigation, livestock management and other uses. Rural dwellers mostly depend on surface water like rivers, streams, brooks and in some cases, unprotected shallow dug wells which are vulnerable to contamination. These sources of water could run dry with time. Sometimes, there are serious cases of water borne diseases resulting from consumption of water from these sources. In the study area, groundwater is presently the only source of water to the people. In the past was the Owerri Otamiri water scheme as the primary source of water in Owerri metropolis but this public water supply by government has been abandoned over the past 10 years subjecting Owerri metropolis with a whooping population of about 401,873 people into crises of water supply with its adverse health implications. As a result, people resorted to private water supply taking advantage of the near surface water table aquifer. This has resulted to proliferation of shallow substandard water wells by individuals, households and organizations without considering the quality of water produced. This proliferation of private shallow wells usually called boreholes has become household name and project that roadside drillers are ready to execute using manual drill “Tripod” and “Seismic” tools.

Because of the cheap cost charged by the shallow borehole drillers and the selfish urge by the people to own their private water supply, an assignment the drillers could accomplish within few hours with installation of inferior casing, inferior pump, and without gravel packing for filtering. These wells are terminated at very shallow depths few feet below water table and at relatively cheap cost, often as cheap as one hundred thousand naira (about 300 US Dollars). The operators use inferior casing materials that are made for surface installation. These shallow private wells are predominantly 100 – 140 feet deep, often located too close to domestic septic tanks and highly vulnerable to surface contamination by microbes such as coliform (Nwachukwu *et al*., 2010).

In the process of this hand drilling of shallow substandard private wells in Owerri metropolis, several abortive, failed contaminated and abandoned wells exist in the area. This development does not go well with conservation and sustainability of water resources in the area. It is possible to cause total pollution and condemnation of the shallow aquifer of the area in the near future, thereby making water supply from groundwater impossible or dangerous to future generations of the area presently hosting five institutions of higher education in Imo State Nigeria.

This study will enable quick estimation of prospective well depth in situations where geophysical exploration or electrical resistivity measurement is not feasible. Individuals could obtain elevation information of their site and apply the mathematical relationship to obtain water table depth. The ultimate is standard water well development which implies standard depth, use of standard material and standard well completion producing water of good quality or potable water. According to Nwachukwu *et al.* (2012), standard water well can be estimated as WT + X = 300 (TCD), where WT = water table depth, X = penetration below the water table and TCD = Total cased depth. Manual drilling using tripod and seismic drilling tools can hardly achieve this TCD, due to the limited ability of applicable mud pump to lift drill cuttings and the limitation on well diameter which prevents the use of standard casing material;

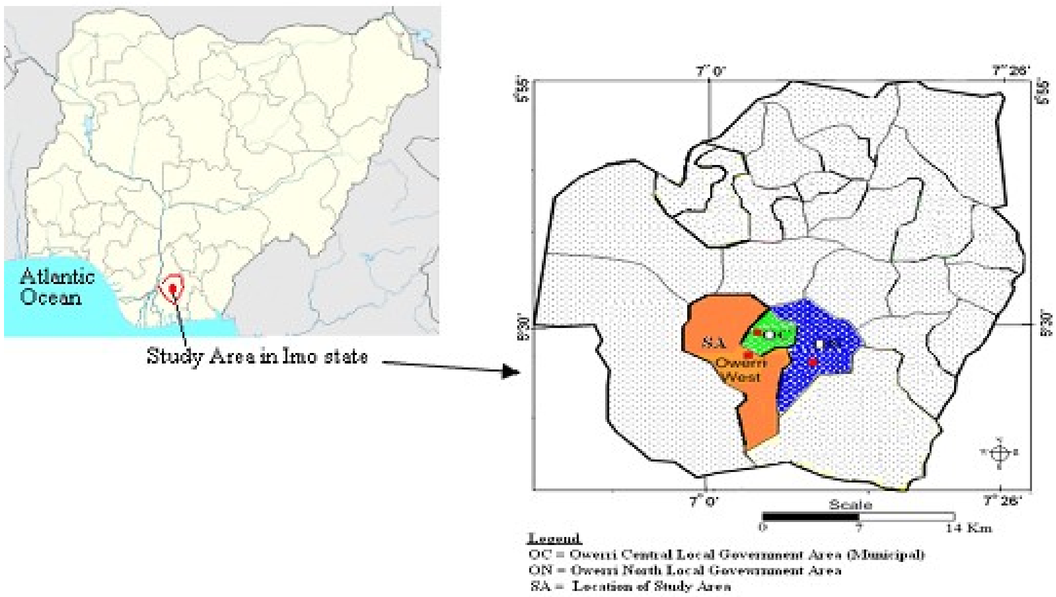

Figure1. Map of Nigeria showing Imo state and Map of Imo state showing Owerri metropolis

II. LITERATURE REVIEW

Groundwater is a more reliable source of potable water than surface water for more than half of the world population (Alabi *et al*., 2010; Anomohanran, 2011). It is that part of precipitation that sips into the ground and percolate downwards through unconsolidated materials and openings in bedrock until it reaches the water table. This unconsolidated sediment or layer that is capable of yielding water in usable quantities when needed is referred to as aquifer (Alabi *et al.*, 2010).

Nwosu and Ndubueze (2017) used Vertical Electrical Sounding (VES) to investigate water table Variation with surface elevation for mapping drill depths for groundwater exploitation in Owerri Metropolis, Imo State, Nigeria.

Several groundwater resource investigations have been completed in so many places using the geophysical methods of exploration which are increasingly being used for subsurface data acquisitions. Ozegin *et al*. (2008) used combined electromagnetic method and vertical electrical sounding to establish groundwater viability in Oke-Agbe High School field located in Akoko North-west local government area of Ondo state Nigeria. Other works on groundwater potential evaluation include those of Olayanju (2011), Onabanjo (2001), Offodile (1983) and Isife *et al*. (2000). A study by Egwebe *et al*. (2004) estimated the aquifer potential at Ivbiaro, Ebesse Edo State using the geo-electrical direct current resistivity technique. The interpretation of the data indicated a depth of 96-147m to the aquifer (sand) within the sand /shale sequence of the Mamu Formation. Onimisi *et al.*(2014) used Vertical Electrical Sounding survey for Groundwater exploration in Parts of Anyigba and its environs, in the Anambra Basin of Nigeria and observed that the aquifer units in the study area consist of the partly saturated sandstone and fully saturated sandstone units. This study is aimed at investigating the relationship between water table and topographic variation across Owerri Metropolis in Nigeria.

Owerri Metropolis is a Local Government Area in Imo State, Nigeria (Figure. 1). It has an estimated population of about 401,873 as at 2006 and is approximately 100 square kilometres (40 sq mi) in area. Owerri is bordered by the Otamiri River to the east and Nworie River to the south. It lies between Latitude 5°29′06″N to 5.485°N, and Longitude7°02′06″E to 7.035°E.

The study area is underlain by the Benin Formation**(**Figure 2**).**This formation which is Paleocene to Miocene in age consists of coastal plain sands with minor clay and gravel beds and sandstone in some locations. Thickness of the Formation is about 800m at its depocenter (Nwachukwu *et al*., 2010).

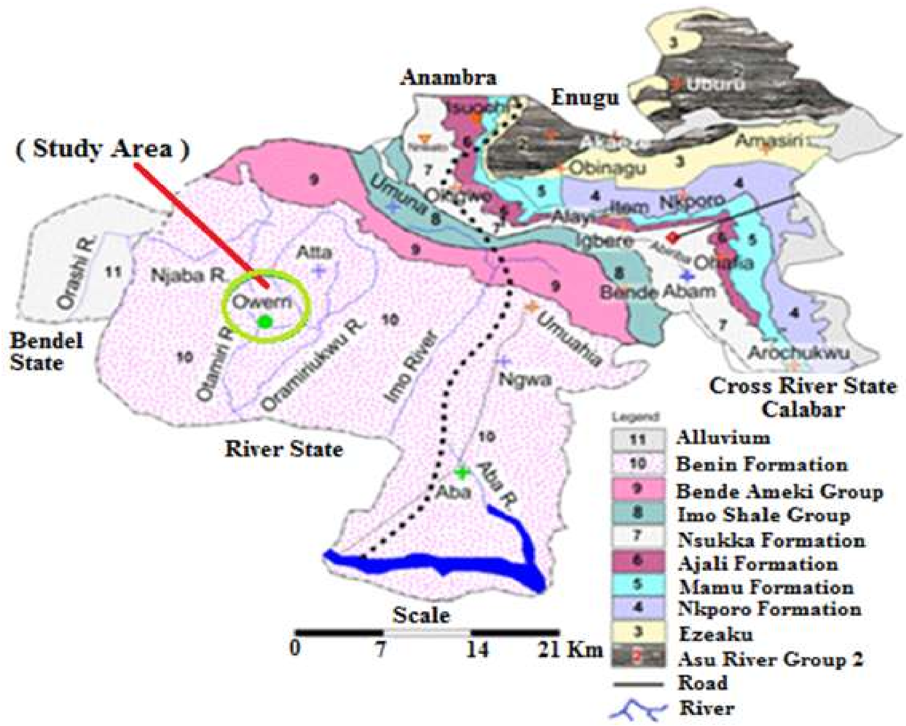

Figure 2: Geologic Map of Imo River basin, showing the Study Area (after Nwachukwu, 2010)

III. MATERIALS AND METHODS

The field procedure adopted in this study is Vertical Electrical Sounding (VES) using the Schlumberger electrode configuration and a total of 20 VES stations were occupied within the study area with maximum electrode spread of 700m. Four electrodes consisting of two current electrodes A and B, and two potential electrodes M and N were placed along a straight line on the land surface such that the current electrode spacing AB is greater than or equals five times that of the potential electrode MN. This technique involves the measurement of variations in ground apparent resistivity with depth at a fixed point of expanding spread.

The Ohmega-500 electrical resistivity meter was placed in between the potential electrode M and N and its terminals P1 and P2 were then connected to the terminal M and N respectively using the ABEM sounding set. The current electrode A and B were connected to the C1 and C2 respectively using the ABEM sounding current cables wound on two separate metal reels mounted on the stand. After setting up the equipment, the electrodes which are about 0.7m long were driven to a reasonable depth into the ground using a hammer.

During the data acquisition, necessary precautions were taken to avoid current leakage and creep which can substantially reduce the attainable accuracy and sensitivity and thus the depth of penetration. The potential electrodes were fixed while the current electrode spacing was expanded in opposite direction on a straight line for subsequent measurements. However, the potential electrode spacing was increased whenever the value of measured resistance became too small to be reliable while the length of the configuration was generally increased. At each VES location the elevation and coordinates were measured using the Global Positioning System (GPS).

The field data was first subjected to manual computation and finally to computer processing techniques. The interpretation of the field data was carried out by applying the Advanced Geosciences Incorporation (AGI) ID resistivity analytical software. The Analytical result presented by the AGI ID software and the Schlumberger Automatic analysis package revealed 12 layers with their various resistivity and depth and are later constrained to a certain number of layers depending on the significant value of the thicknesses.

Empirical Modelling

In this model, relationships between the depth to water table and elevation are derived by looking at the available data on the variables and selecting a mathematical form which is a compromise between accuracy of fit and simplicity of mathematics. In this research, a least square quadratic polynomial approximate method was adopted to fit a polynomial function P(x) for the dataset (x, y) having a theoretical solution:

$$y = f(x) \qquad 1$$

where

y is the depth to water table and

X is the elevation

A high-degree polynomial regression is used due to the fact that a linear regression cannot fit all the data used in this study well. The equation is of the form:

$$y = \alpha_0 + \alpha_1 x + \alpha_2 x^2 \quad 2$$

Chi – Square Test

Chi – Square distribution is one of the most widely used theoretical probability distribution in inferential statistics in statistical significant test. The best known situations in which the Chi – Square distribution is used are the common Chi – Square test for goodness of fit of an observed distribution to a theoretical one. In this work, the observed values and expected values were compared and subjected to statistical analysis using Chi – Square to test if there were significant differences between the two.

$$\chi^2 = \Sigma(\text{Observed data} - \text{Expected data})^2/\text{Expected data})^2 \quad \chi^2_{0.05,\, n-1} \quad 3$$

where n = 20 (number of VES data points) and $\chi^2_{0.05}$, n-1 is the χ2 tabulated which gives 30.144 as standard for comparism.

III. RESULTS AND ANALYSIS

Typical modelled results are shown in figures 3 to 6 for the VES stations sited at Awaka, Chukwuma Nwoha Foundation road, Orji and Nworie River bank respectively while Tables 1 to 4 display their corresponding analytical results presented by the AGI 1D Software and the Schlumberger automatic analysis package. Table 5 is the summary of the modelled results for all the VES stations. Figure 7 shows the surface elevation map of the study area while Figure 8 is the water table contour map showing the variation of depth to water table in the study area.

Table 1: Awakaanalytical result presented by the AGI 1D Software and the Schlumberger automatic analysis package

LAYER S/No.	DEPTH (m)	RESISTIVITY (Ohm-m)	LITHOLOGY	COLOR
1	0.5	441	Topsoil	Mixed Blue
2	2.0	1412	Siltstone	Green
3	5.1	751	Sand	Light Blue
4	7.7	221	Sand	Blue
	12.5	324	Sand	Mixed blue
6	13.3	3142	Sand/Gravel	Red
7	34.7	6502	Sandstone	Red
8	50.3	2068	Siltstone	Yellow
9	110	57.6	Sand (Prospective Unit)	Blue

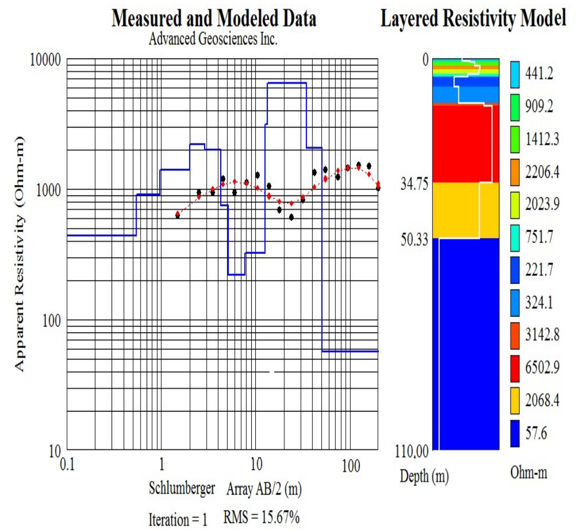

Figure 3: Model result for VES located at Awaka Owerri North

Table 2: Chukwuma Nwoha, Foundation road VES analytical result in constrained geo-electric sub-layers

LAYER	DEPTH (m)	RESISTIVITY	LITHOLOGY	COLOR
1	1.2	296.3	Topsoil	Light Blue
2	1.475	3884.1	Lateritic soil	Orange
3	4.085	15357.2	Sandstone	Red
4	8.50	1128.2	Siltstone	Green
5	16.80	78.6	Saturated sand (aquifer)	Blue
6	34.03	201.1	Sand	Light blue
7	88.00	1421.8	Sitstone	Yellow

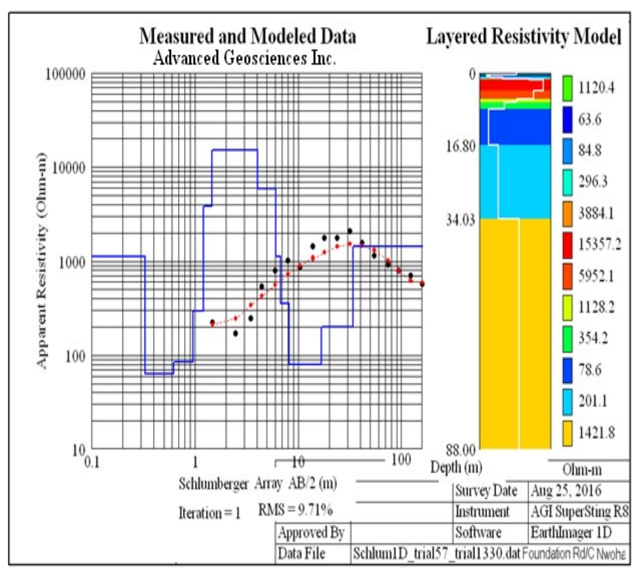

Figure 4: VES model result of Chukwuma Nwoha,

Foundation road

Table 3: Orji VES analytical result in constrained geo-electric sub-layers

LAYER	DEPTH (m)	RESISTIVITY (Ωm)	LITHOLOGY	COLOR
1	1.9	865.32	Topsoil	Yellow
2	6.06	331.7	Sandy clay	Green
3	11.06	223.1	Sandy clay	Light blue
4	14.61	454.8	Lacteritic sand	Green
5	23.59	2485.4	Siltstone	Red
6	42.91	2084.1	Siltstone	Orange
7	68.75	186.5	Saturated aquifer	Blue

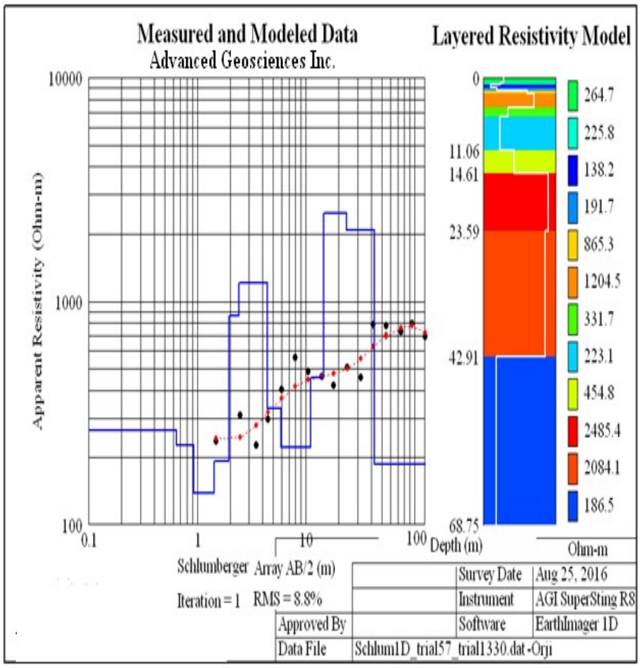

Figure 5: VES model result of Orji

Table 4: Nworie lane VES analytical result in constrained geo-electric sub-layers

LAYER	DEPTH (m)	RESISTIVITY (Ohm-m)	LITHOLOGY	COLOR
1	3.195	7531.8	Topsoil	Red
2	8.7	934.8	Sandy soil	Green
3	11.56	4754.7	Sandy soil	Yellow
4	22.7	9816.6	Sandstone	Red
5	42.91	6258.3	Siltstone	Orange
6	57.45	2361.2	Sand	Green
7	110.00	37.5	Sand (aquifer)	Blue

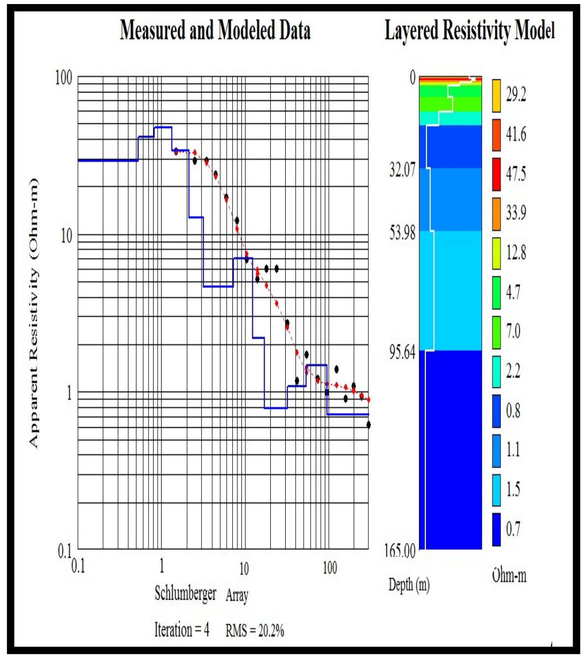

Figure 6: VES model result of Nworie River bank

Areas around Owerri North such as Awaka, Toronto and Orji have high elevation. Also areas around Irete, National Library are characterized by high elevation. Nworie River bank lies in-between topographic high areas corresponding to Nworie River valley. Topographic low areas include Obinze, Nekede, Federal University of Technology Owerri (FUTO), Eziobodo in Owerri West. Otamiri River drains through this low elevation (Figure 7) areas from Egbu, Naze, Nekede and Obinze. A very low water table was observed at Avu Junction, Obinze, Ihiagwa and Nworie River bank. Medium water table was also observed at Nekede, Eziobodo, Port Harcourt road and Imo State Universiy {IMSU} junction. More so, high water table was observed around owerri North (Figure 8).

The area around Obinze is characterized by topographic high ground and drainage pattern is the flow towards the Eastern part into Otamiri River channel which lies in the valley from Egbu through Nekede and towards South East of the study area. In correlating the groundwater drainage and surface water drainage, the results obtained and observed show that the flow pattern of groundwater is similar to that of surface drainage.

The result of the mathematical relationship between water table and elevation in the study area is shown in table 6. The model shows a positive correlation between water table and elevation. The outcome of the Chi – Square test for n = 20 (Table 7), shows that there is no significant difference between the observed and the expected values which is an indication that the result for the model is valid.

Analysis of VES Results

Table 5: Summary of the relevant field data and the aquifer parameters

S/No	Location	Elevation (ft)	Coordinate E (Degree)	Coordinate N (Degree)	Depth to Water Table (m)
1	Awaka	450	07º05.185/	05º28.584/	57.6
2	Foundation Rd. Aladima (IMSU)	126	07º02.916/	05º29.545/	16.8
3	Orji	413	07º08.239/	05º07.987/	43.0
4	Toronto Junction	418	07º05.101/	05º29.527/	43.0
5	New Owerri	140	07º00.839/	05º.29.344/	26.0
6	Amakohia	258	07º02.214/	05º23.006	39.0
7	Ugwu Orji Owerri	460	06º51.907/	06º07.749/	64.5
8	Naze	225	07º03.769/	05º27.071/	50.0
9	Nekede (AforamaMkt)	213	07º.01.067/	05º26.750/	30.0
10	Oforola	120	06º54797/	05º24.899/	17.0
11	Umuguma	245	06º58.189/	05º27.793/	47.8
12	Obinze Junction	202	06º57.855/	05º24.032/	48.6
13	National Library	103	07º00.726/	05º28.315/	23.0
14	EziobodoOwerri West	86	06º59.943/	05º22.605/	26.2
15	Nekede Police Primary School	243	07º00.724/	05º24.895/	60.5
16	Nworie River Bank	165	07º01.348/	05º29.338/	23.8
17	Industrial Court Owerri	221	07º01.758/	05º29.356/	85.6
18	Avu Junction (PH – Rd)	175	06º58.756/	05º26.040/	64.0
19	INEC Commissioners Quarters	286	07º00.918/	05º28.649/	40.1
20	Ihiagwa (FUTO Building)	227	06º59.618/	05º23.092/	56.2

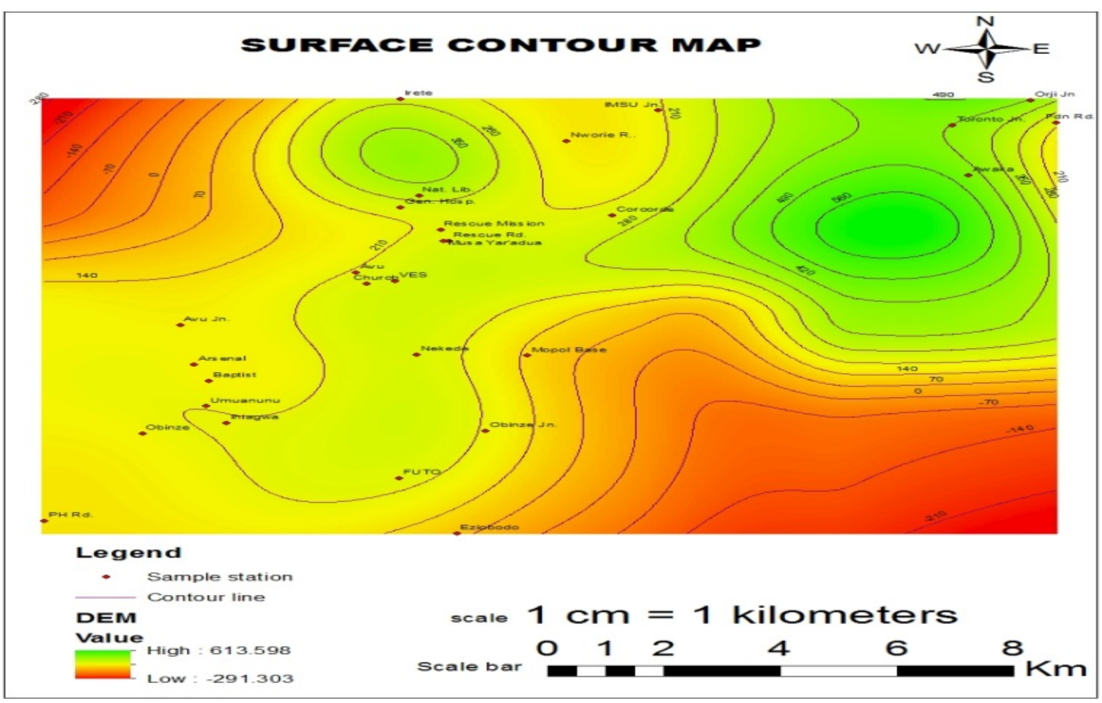

Figure7: Surface Elevation Contour Map

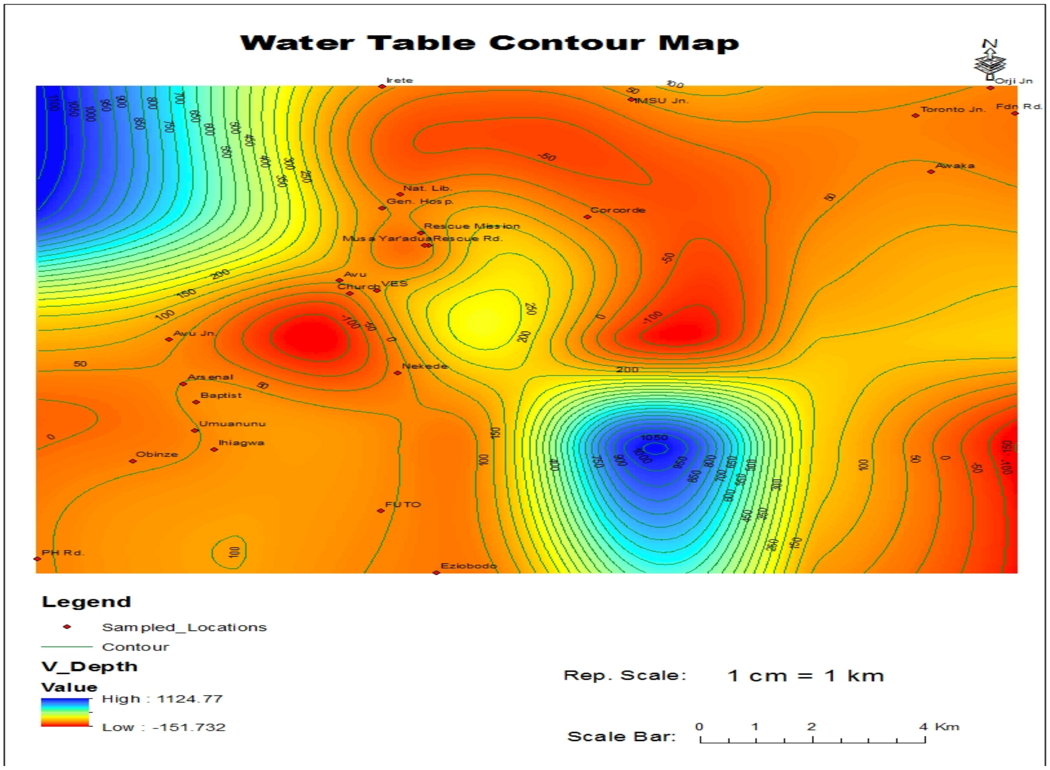

Figure8: Water table Contour Map

Table 6: Table of values for the water tables and the elevations: Elevation (x) and water table (y)

X(ft)	X(m)	y(m)	Y^2	X^2	X^3	X^4	XY	YX^2
450	137.16	57.6	3317.76	18812.87	2580373	353923912	7900.416	1083621
126	38.4048	16.8	282.24	1474.929	56644.34	2175414.6	645.2006	24778.8
413	125.8824	43	1849	15846.38	1994780	251107716	5412.943	681394.3
418	127.4064	43	1849	16232.39	2068110	263490510	5478.475	697992.8
140	42.672	26	676	1820.9	77701.43	3315675.3	1109.472	47343.39
258	78.6384	39	1521	6183.998	486299.7	38241831	3066.898	241175.9
460	140.208	64.5	4160.25	19658.28	2756249	386448101	9043.416	1267959
225	68.58	50	2500	4703.216	322546.6	22120245	3429	235160.8
213	64.9224	30	900	4214.918	273642.6	17765534	1947.672	126447.5
120	36.576	17	289	1337.804	48931.51	1789718.9	621.792	22742.66
245	74.676	47.8	2284.84	5576.505	416431.1	31097408	3569.513	266556.9
202	61.5696	48.6	2361.96	3790.816	233399	14370283	2992.283	184233.6
103	31.3944	23	529	985.6084	30942.58	971423.82	722.0712	22668.99
86	26.2128	26.2	686.44	687.1109	18011.1	472121.37	686.7754	18002.31
243	74.0664	60.5	3660.25	5485.832	406315.8	30094348	4481.017	331892.8
165	50.292	23.8	566.44	2529.285	127202.8	6397283.9	1196.95	60196.99

221	67.3608	85.6	7327.36	4537.477	305648.1	20588701	5766.084	388408.1
175	53.34	64	4096	2845.156	151760.6	8094910.4	3413.76	182090
286	87.1728	40.1	1608.01	7599.097	662434.6	57746276	3495.629	304723.8
227	69.1896	56.2	3158.44	4787.201	331224.5	22917291	3888.456	269040.7
4776	1455.725	862.7	43622.99	129109.8	13348648	1.533E+09	68867.82	6456431

Mathematical Analysis Using Empirical Model

In this model, relationships between variables are derived by looking at the available data on the variables and selecting a mathematical form which is a compromise between accuracy of fit and simplicity of mathematics. In this research, a least square quadratic polynomial approximate method was adopted to fit a polynomial function P(x) to a set of data (x, y) having a theoretical solution as given by equation 1 above:

$$y = f(x) \tag{4}$$

A high-degree polynomial regression is used due to the fact that a linear regression cannot fit all the data used in this study well. The equation is of the form as given by equation 2 above:

$$y = \alpha_0 + \alpha_1 x + \alpha_2 x^2 \tag{5}$$

That is, n = 2. Therefore, the computation was carried out using the following:

$$\Sigma y = n\alpha_0 + \alpha_1 \Sigma x + \alpha_2 \Sigma x^2$$

$$\Sigma xy = \alpha_0 \Sigma x + \alpha_1 \Sigma x^2 + \alpha_2 \Sigma x^3 \tag{6}$$

$$\Sigma x^2 y = \alpha_0 \Sigma x^2 + \alpha_1 \Sigma x^3 + \alpha_2 x^4$$

Solving for a_0, a_1 and a_2 respectively in equation 5, we have

$$a_0 = \frac{\Sigma y \Sigma x^4 + (\Sigma x^3 \Sigma x^2 - \Sigma x \Sigma x^4)\, J - \Sigma x^2 \Sigma x^2 y}{2\Sigma x^4 - (\Sigma x \Sigma x^4 - \Sigma x^2 \Sigma x^3)\, K - (\Sigma x^2)^2} \tag{7}$$

$$a_1 = \frac{\Sigma xy \Sigma x^4 - \Sigma x^3 \Sigma x^2 y}{\Sigma x^2 \Sigma x^4 - (\Sigma x^3)^2} - a_0 \left\{\frac{\Sigma x \Sigma x^4 - \Sigma x^2 \Sigma x^3}{\Sigma x^2 \Sigma x^4 - (\Sigma x^3)^2}\right\} \tag{8}$$

$$a_2 = \frac{\Sigma x^2 y - \Sigma x^3}{\Sigma x^4} a_1 \tag{9}$$

Table 7: Shows the validation of the Mathematical Model

Elevation X(ft)	Elevation X(m)	Water Table from VES y(m)	Water Table from Math Model Y^2(m)
450	137.16	57.6	53.1
126	38.4048	16.8	21.4
413	125.8824	43	54.8
418	127.4064	43	54.7
140	42.672	26	34
258	78.6384	39	50
460	140.208	64.5	52.4
225	68.58	50	46.9
213	64.9224	30	35.4
120	36.576	17	30.2
245	74.676	47.8	49.1
202	61.5696	48.6	44
103	31.3944	23	26
86	26.2128	26.2	22.9
243	74.0664	60.5	48.9
165	50.292	23.8	38.4
221	67.3608	85.6	86.4
175	53.34	64	60.1
286	87.1728	40.1	52.6
227	69.1896	56.2	47.1

Table 8: Table of Values for the chi – square test

Y_1(m)	**Y_2(m)**	**$Y_1 - Y_2$**	**$(Y_1 - Y_2)^2$**	**$(Y_1 - Y_2)^2/Y_2$**
57.6	53.1	4.5	20.25	0.381355932
16.8	21.4	-4.6	21.16	0.988785047
43	54.8	-11.8	139.24	2.540875912
43	54.7	-11.7	136.89	2.502559415
26	34	-8	64	1.882352941
39	50	-11	121	2.42
64.5	52.4	12.1	146.41	2.794083969
50	46.9	3.1	9.61	0.204904051
30	35.4	-5.4	29.16	0.823728814

17	30.2	-13.2	174.24	5.769536424
47.8	49.1	-1.3	1.69	0.034419552
48.6	44	4.6	21.16	0.480909091
23	26	-3	9	0.346153846
26.2	22.9	3.3	10.89	0.475545852
60.5	48.9	11.6	134.56	2.751738241
23.8	38.4	-14.6	213.16	5.551041667
85.6	86.4	-0.8	0.64	0.007407407
64	60.1	3.9	15.21	0.253078203
40.1	52.6	-12.5	156.25	2.970532319
56.2	47.1	9.1	82.81	1.758174098
				34.93718278

Mathematical Relations

The modelled relationship between water table and elevation across Owerri Metropolis is given by equation 10. This was obtained by substituting the computed values of a_0, a_1 and a_2 given by equation 7, 8 and 9 into equation 5.

$$y = 0.38464406179 + 0.97247494717x - 0.00428862105x^2$$

where

y is the depth to water table

x is the elevation

Table 6 shows values for the water tables and the elevations for the surveyed area while Table 7 is the validation of the Mathematical Model result. The results of the chi – square test analysis is shown in Table 8.

IV. DISCUSSION

The results of the VES interpretation show that the study area has 7 to 9 geoelectric layers and the lithology ranges from topsoil, siltstone, sand, sand/gravel and sandstone. The maximum depth of probing varies from 67.8 to 110.0 metres.The resistivity values ranged from 0.6Ωm to 1100.8Ωm. The depth to the water table varied across the area with surface elevation and it ranges from 16.80m to 85.60m. The aquifer thickness also varied from 13.23m to 111.56m and often not terminated. Areas of high aquifer thickness such as Awaka, Amakohia, and New Owerri have high groundwater potential and are good for siting water boreholes with high yield expectations.

Analysing Figures 7 and 8, the results show that areas around Owerri North such as Awaka are topographic high areas with corresponding high depth to water table while areas around Owerri West such as Eziobodo are topographic low areas and have shallow water table. The same is applicable to areas around Imo State University.

V. CONCLUSION

Generally, it can be concluded from the results that depth to water table varies with surface elevation. Water table is shallow in topographic low locations and deep for topographic high places. Deep wells are therefore prescribed in topographic high locations for sustainable groundwater development. Relatively high surface elevation areas such as Nekede, Avu, Orji and Awaka, the drill depth of 100m or more is recommended. Thus the cost of drilling standard water well should be relatively higher in Owerri North than other areas in the study area. Also, there is a mathematical relationship between water table and elevation in the study area. From the Chi – Square test for n = 20, there was no significant difference between the observed and the expected values which shows a valid result for the model in the area.

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