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Application of Vertical Electrical Sounding in Assesing Groundwater Hydraulic Characteristics in Owerri Metropolis, Imo State.

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ABSTRACT
A geoelectric survey involving vertical electrical sounding (VES) employing Schlumberger electrode configuration was carried out with the aim of determining aquifer characteristics in Owerri metropolis and evaluating the vulnerability of these aquifers. Thirteen (13) locations were investigated using ABEM Terrameter SAS 300B model. A maximum current electrode spacing (AB) of 1000 meters was used for the data acquisition. The VES data acquired were interpreted using 2D-inverse interpretation resistivity software. The layer parameters thus obtained were used to estimate aquifer hydraulic parameters by using Dar-Zarrouk model while aquifer vulnerability was determined with DRASTIC model. The range of results obtained from the analysis for each parameter are as follows: Aquifer resistivity (0.7Ωm to 21600Ωm), Depth to water table (4.7m to 179m), Aquifer thickness (0.8m to 109), Transverse resistance (49Ωm^2 to 1040472Ωm^2), Longitudinal conductance(0.000021Ωm to 100Ωm), Hydraulic conductivity (0.0350m/day to 538.93m/day), and Transmissivity (0.14m^2 /day to 37725.27m^2/day). From aquifer vulnerability rating, using DRASTIC index, the area of study is moderately (69.2%) to highly (38.2%) vulnerable to aquifer contamination. It is apparent from this study that vertical electrical sounding can be reliably employed to assess aquifer characteristics and the method is cost saving compared to the conventional methods of determining those parameters.

Key words: Vertical Electrical sounding, Aquifer, Hydraulic charateristics

I. INTRODUCTION

Water is a finite resource which is an essential component of life on Earth and vital services. Water supports human, animal and plant life while providing services fundamental for the livelihood and well-being of the population around the world (UNESCO, 2016). Through the hydrologic cycle, drinking water is provided to us in form of rain and surface water, for example, rivers, lakes, lagoons, and groundwater. The availability of drinking water is currently affected by rapid growth of population worldwide, increasing pollution, climate variability and unsustainable management, affecting the quantity and quality of groundwater resources (Estefania, 2017).

Nwosu et al. (2013) reported that groundwater is more potable than surface water and also has large storage capacity which is a big advantage over surface water. Because of this many people in various part of Nigeria use groundwater as source of water for their domestic activities. Groundwater supply has increased significantly in recent times and becomes the main water source, for all purpose, in rural and urban areas of West Africa especially in the dry season (Pimentel et al., 1997).

In Owerri metropolis, Imo State, groundwater is the major source of potable water used for all domestic activities. There are various boreholes drilled by governmental agencies, private firms, and individuals within Owerri metropolis to provide the populace with water for their domestic activities.

Due to the increase in population, and its consumption through domestic, agricultural and industrial purposes, exploitation of groundwater has been increasing over the last decades in Owerri Metropolis. There is constant demand for water and to meet this need many bore holes are being drilled in the area. These human activities do put pressure on water resources and much off water needs is sourced from underground aquifers. This informs the need to pay special attention on the hydraulic characteristics and contamination vulnerability of the aquifer system. Hence this study is a means to achieving these objectives .

Study Area

This study was carried out in Owerri Metropolis (latitude 5° 25' 56" N and longitude 6° 58' 49" E), Imo State, Nigeria. Fig.1: It is the capital city of the

It has an area of 295 km² and a population of about 1.4 million people according to the National Population Commission of Nigeria in 2016.

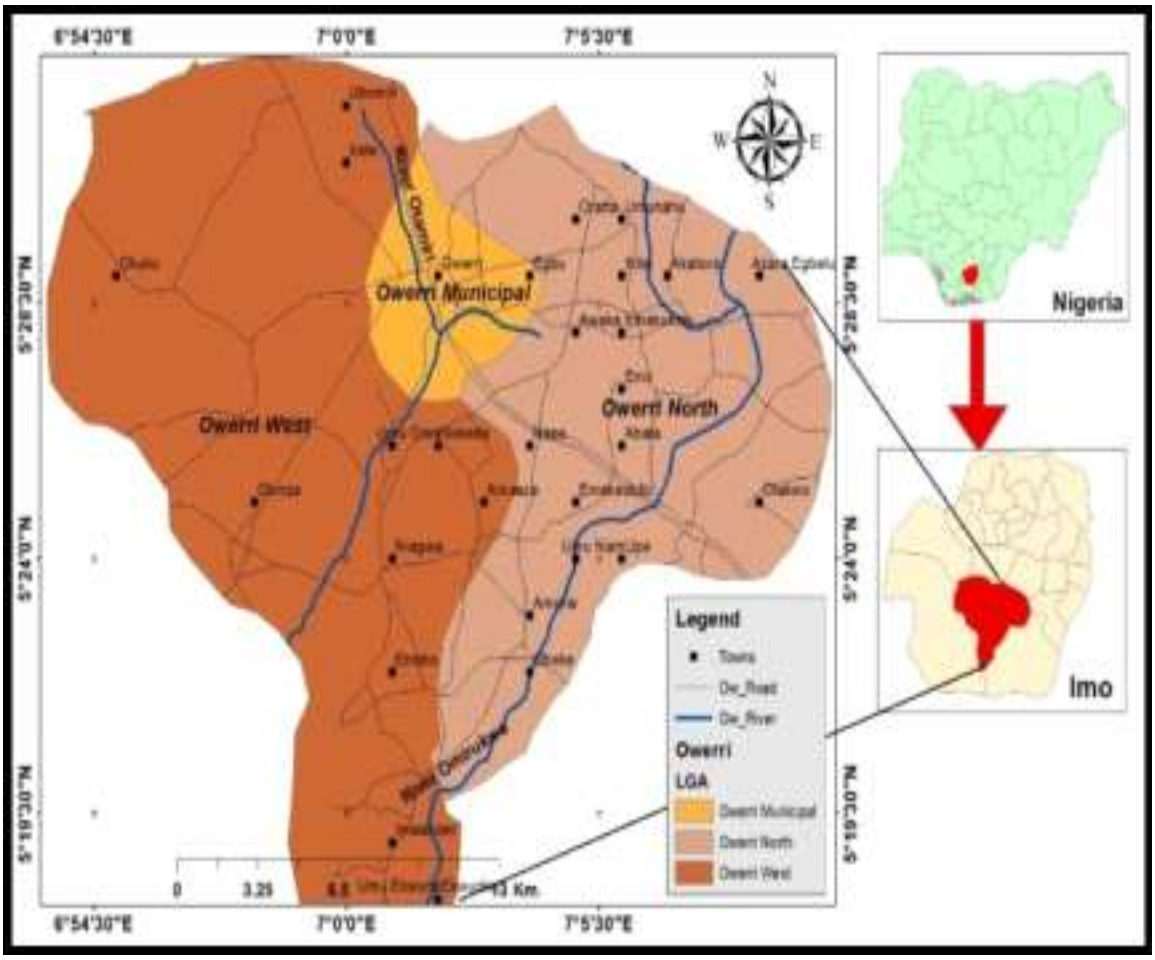


Fig1: Map of Owerri Metropolis showing the study area

Sample Collection

All the raw field data obtained in course of the investigation were collected, collated and subjected to analysis using the appropriate constants and FORTRAN Resistivity 2D Inverse Computer Program which is an iterative inversion-modeling program. The results obtained following the analysis (VES data) are then displayed as sounding curves which represents graphs of apparent resistivity versus half-current electrode spacing on double logarithmic graph sheets. It yields layered earth models comprising individual layers of specified thickness and apparent resistivity (Agagwuncha, 2021).

A representative sounding curve is shown in Figure 2 and 3. Consequent on these curves the geo-electric sections of the entire study area were generated .

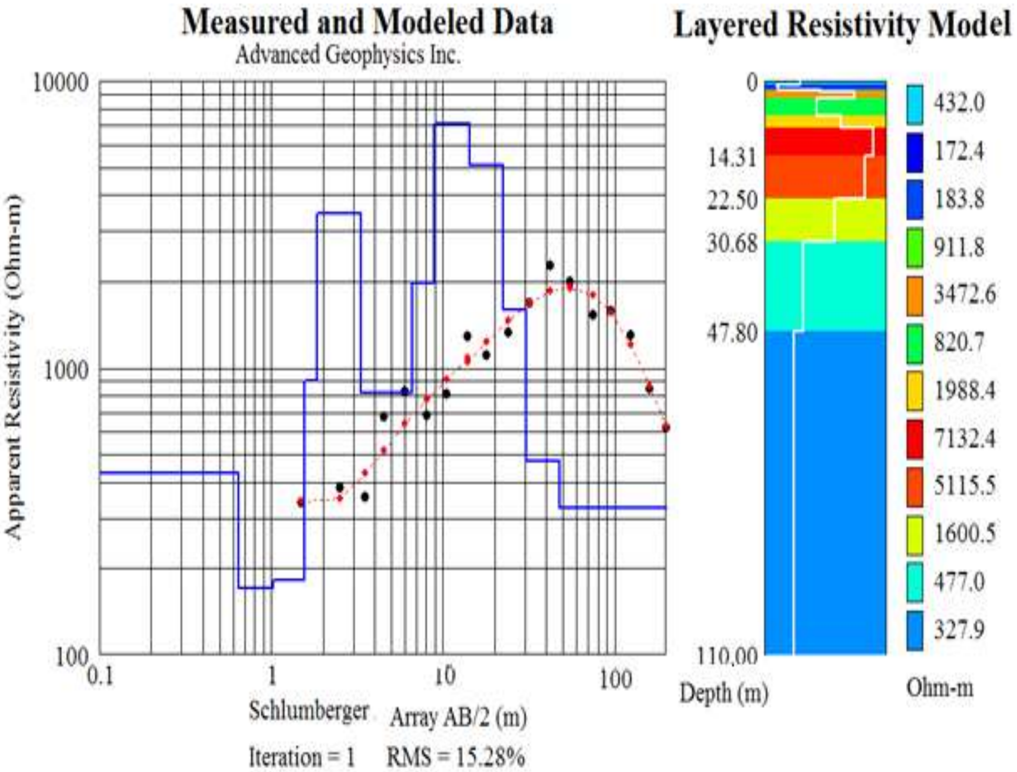
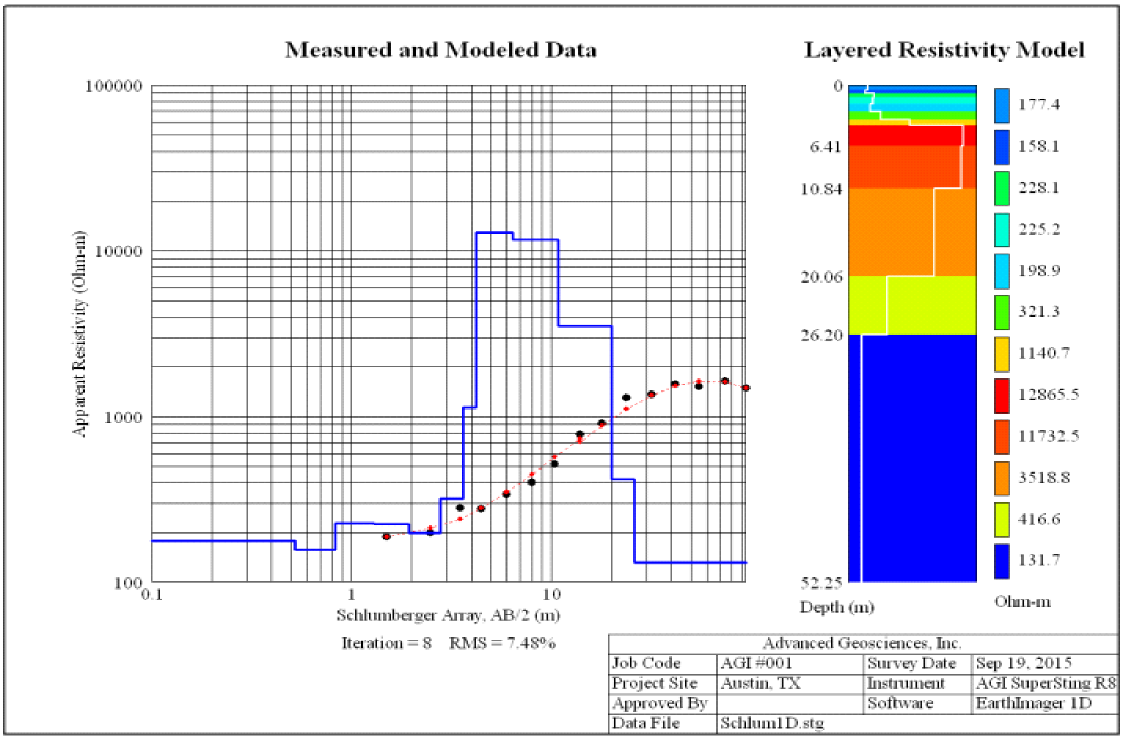


Fig 2:Profiles of VES at NAZE



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Project Site	Austin, TX	Instrument	AGI SuperSting R8
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Fig 3: Profile of VES at Orogwe

Sample Preparation.

The directions of each VES point was noted and in conjunction with the base map a VES profile map was generated, Figure 3. The geoelectric sections were then aligned and the composite data were introduced into Surfer 13 software and Dar-Zarrock parameters for interpretation, as appriopriate. The soft wares were designed to generate aquifer characteristics from the feedstock and produce2D and 3D maps. The aquifer characteristics generated include resistivity, depth to the aquifer, thickness, conductivity transverse resistance, longitudinal conductance, hydraulic conductivity, transmissivity and storativity. A summary of the results for each location is presented in Table 1, (Agagwuncha, 2021).

A 2D display or contour map of aquifer resistivity of the study area is shown in Figure 3 while the equivalent 3D display is presented in Figure 4 (after Agagwuncha, 2021)

Table 1: RESULT OF AQUIFER CHARACTERISTICS/PARAMETERS

VES No	**Location**	**Aquifer Resistivity (Ωm)**	**Aquifer Depth (m)**	**Aquifer Thickness (m)**	**Aquifer Conductivity $(\Omega m)^{-1}$**	**Transverse Resistance (Ωm^2)**	**Longitudinal Conductance (Ωm)**	**Estimated Aquifer Hydraulic Conductivity (m/day)**	**Estimated Aquifer Hydraulic Transmissivity m^2/day)**	**Estimated Aquifer Storativity**
1	Naze	3690	179	87.04	0.00027	321177.6	0.0236	0.1818	15.82	0.000261
2	Nekede	328	110	62.2	0.003	20401.6	0.1900	1.738	108.13	0.000187
3	Ihiagwa	2965.2	52.25	17.15	0.00034	50853.18	0.0058	0.2229	3.82	5.145×10^{-5}
4	FUTO-Obinze	26	165	108.8	0.038	2828.8	4.185	18.497	2012.5	0.000326
5	bank of Otamiri	3746.1	4.7	0.8	0.00027	2996.88	0.000021	0.1792	0.14	2.4×10^{-6}
6	Avu	41.8	135	109.1	0.0239	4560.38	2.61	11.878	1295.93	0.000327
7	Ohaji	3015	139	78	0.00033	235170	0.02587	0.2195	17.12	0.000234
8	Irete	2164.8	24.52	16.62	0.00046	35978.98	0.0077	0.2990	4.97	4.98×10^{-5}
9	Ohii	11	110	57	0.0909	627	5.18	41.266	2352.18	0.000171
10	Oforola	0.7	165	70	1.429	49	100	538.93	37725.27	0.00021
11	Amakohia	477.0	109	61.2	0.0021	29192.4	0.1283	1.226	75.02	0.000184
12	Awara	21600	144.7	48.17	0.000046	1040472	0.00223	0.0350	1.68	0.000145
13	Orogwe	416.63	26.20	6.14	0.0024	2558.11	0.0147	1.3908	8.54	1.8×10^{-5}
JMean		2960.17	104.95	55.56	0.1207	134158.88	8.644	47.39	3355.47	1.67×10^{-4}

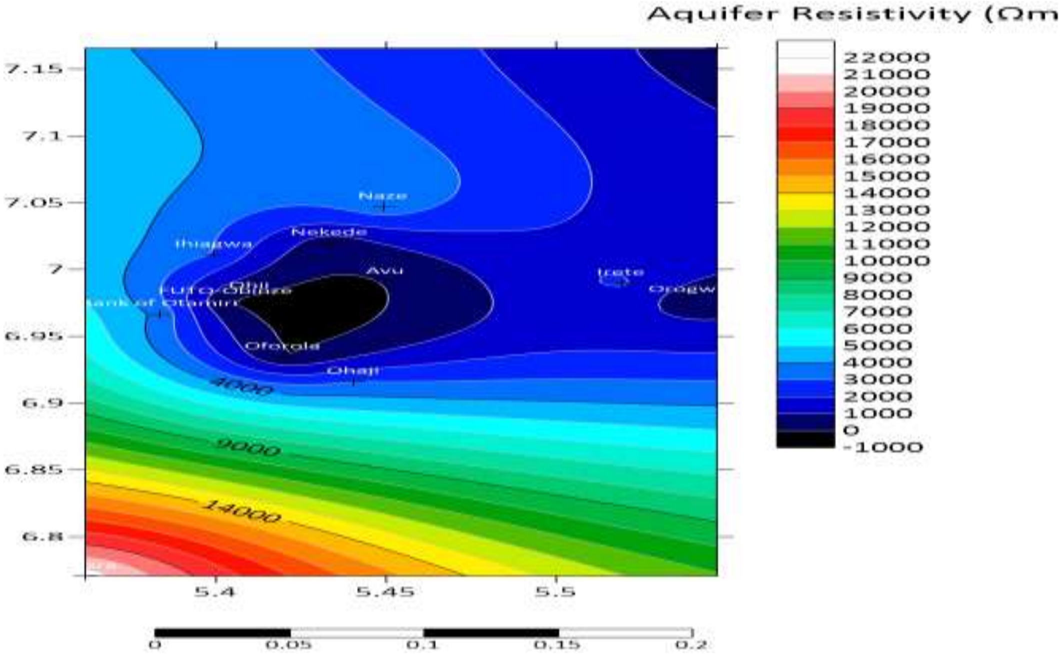


Figure 4: 2D display of aquifer resistivity distribution in the study area

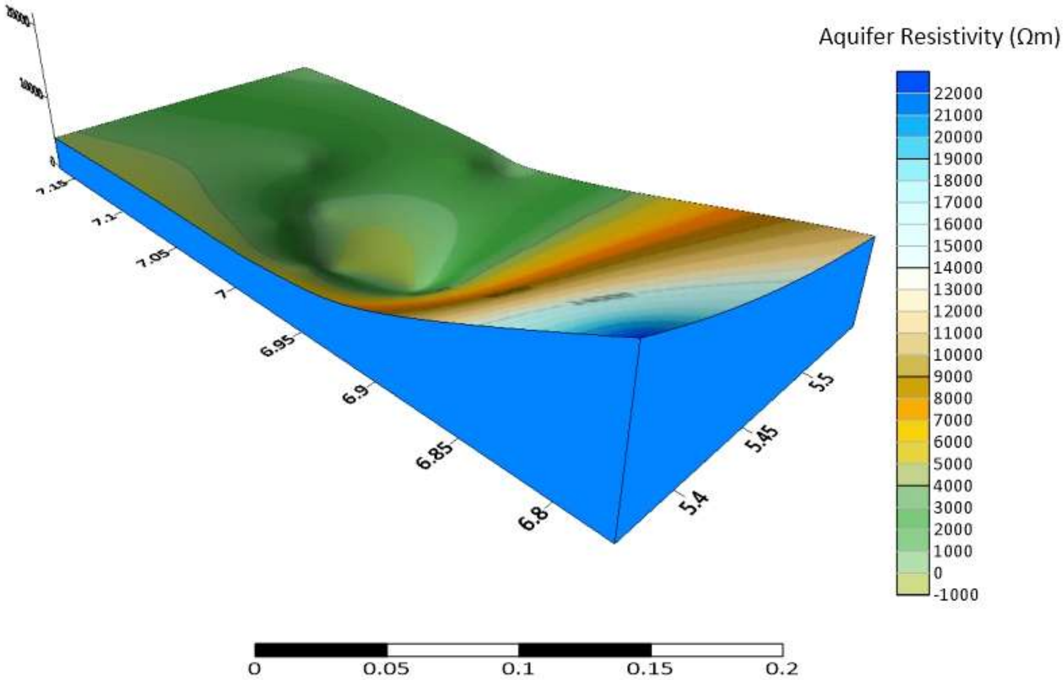
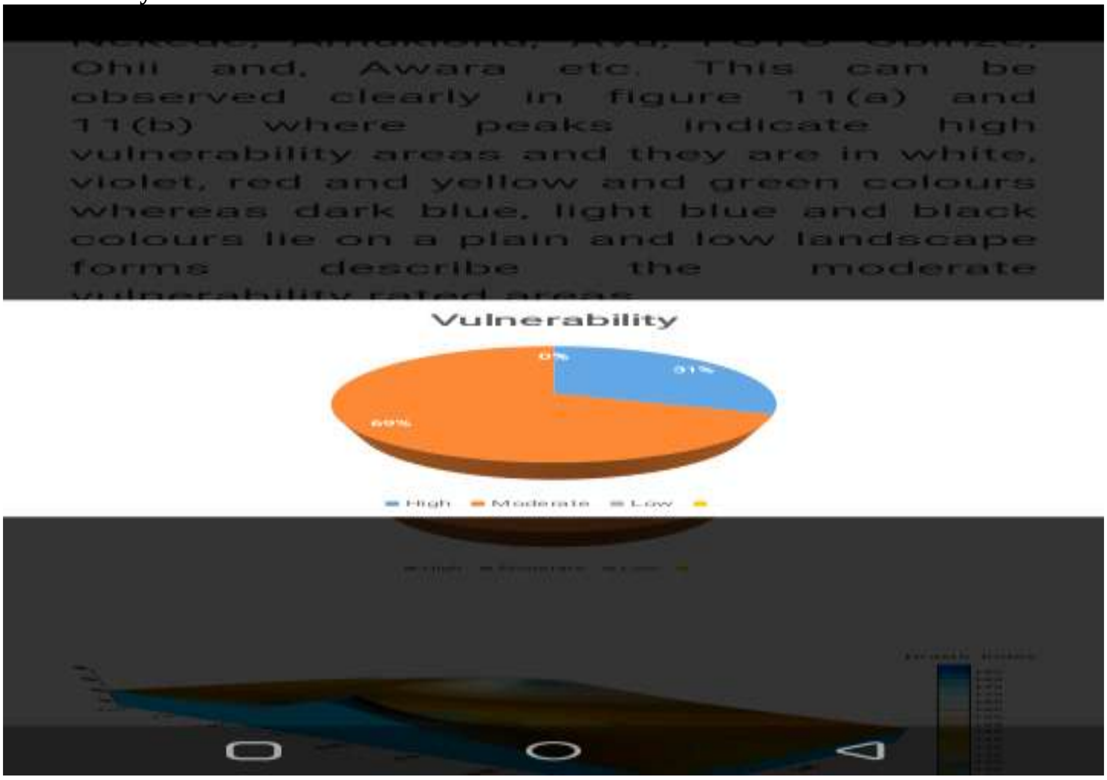


Figure 5: 3D display of aquifer resistivity distribution in the study area

The Vulnerability Assessment



Ohii and, Awara etc. This can be observed clearly in figure 11(a) and 11(b) where peaks indicate high vulnerability areas and they are in white, violet, red and yellow and green colours whereas dark blue, light blue and black colours lie on a plain and low landscape forms describe the moderate vulnerability rated areas.

Figure 6: Pie chart showing the percentage level of the vulnerability assessment.

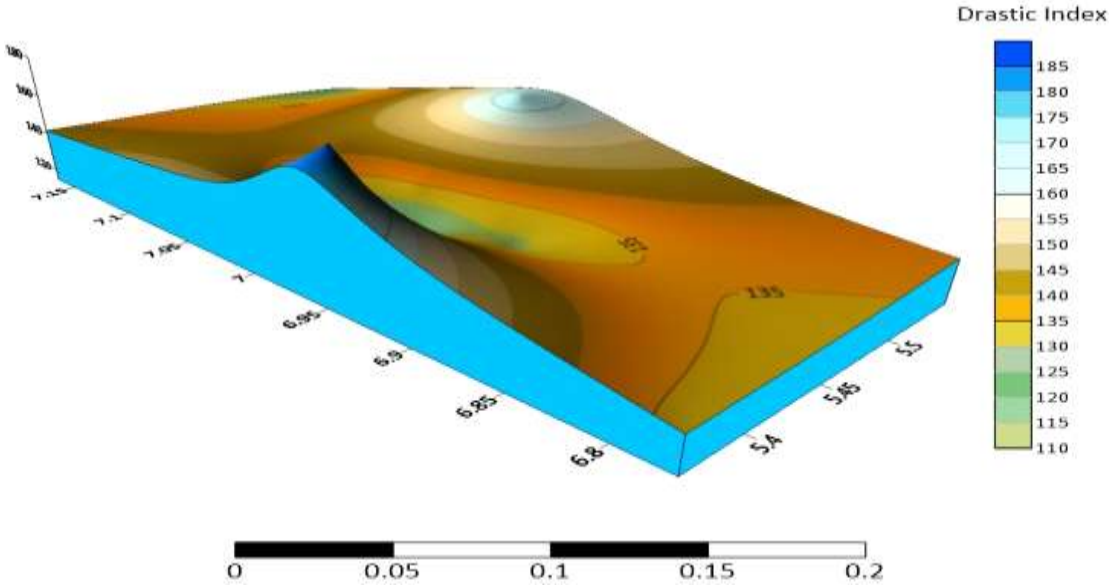


Figure 7: The 3D Model of the DRASTIC Index of the Study Area

AQUIFER HYDRAULIC CHARACTERISTICS

Aquifer Resistivity

It was observed that Amakioha, Avu, Oforola, FUTO Obinze, Ohii Orogwe and Nekede have lower resistivity values of about -1,000Ωm to 10,00Ωm with colour indications of black and navy blue, while places like Ihiagwa, Naze, Ohaji, Irete, and Bank of Otamirri have a relatively low resistivity between 2000Ωm to 8000Ωm while Amara have relatively high resistivity value of about 22000Ωm, indicated with the white colour; and areas indicated by green, yellow, and orange colours are other zones with high resistivity values above 9000Ωm.

Aquifer Conductivity

Aquifer conductivity is inverse of aquifer resistivity. This implies that the locations of high conductivity are direct opposite of resistivity of the area. Amakiohia, Orogwe, Naze, Ihiagwa, Nekede and FUTO have low aquifer conductivity values of about -0.1Ωm-1 to 0.1Ωm-1, situated at the East-Southern and the Northern axes, while places like Avu, Oforola, Ohaji, Ohii, FUTO Obinze, Bank of Otamirri which are marked with green, yellow, red and light blue colours, situated at the western and central parts have high aquifer conductivity values that range from 0.2Ωm-1 to 1.1Ωm-1.

Aquifer Depth

From the map of Depth to water table in Figure 4.3a obtained shows a varying distribution of aquifer depth in various parts of the study area. . The following towns and villages: Orogwe, Irite, and bank of Otamiri etc. fall within it. Places such as Naze, Awara, Oforola, Ohaji, Avu, FUTO Obinze, Ohii etc have their water table within 140m to 180m and they are represented with shades of red colour have moderately deeper aquifer; however, the areas that are represented with yellow and green colour have a relatively average aquifer depth and they are located at places like: Ihiagwa, Amakohia, Nekede etc.

Aquifer Thickness

From Figures 4.4(a) and 4.4(b), it shows how the various aquifers in the study area vary in thickness. Almost the whole parts marked with shades green colour have an aquifer thickness range of about 45m to 65m, places like Avu, Ohaji, Nekede, Ohii, Oforola, FUTO Obinze etc. In the central zone of the study area marked with shades of red and orange has an aquifer thickness ranging from 65m to 105m. Also white colour denotes a range of 110m and it is inundated at Avu which pose to possess the area with the highest aquifer thickness. Places like Irete, Orogwe, Ihiagwa and Bank of Otamirri, has the area with the lowest aquifer thickness with values ranging from -5m to 40m, these depict area that shows threshold of blue colour and the colour black.

Longitudinal conductance and transverse resistance

This was obtained using Dar-Zarrock parameters

The Longitudinal Conductance was estimated by dividing the aquifer thickness by the aquifer apparent resistivity. Figure 4.4(a) and (b): shows the distribution of it across the study area which indicates that an upward maximum values are found towards the central part of the maps and that the minimum values are scattered around the outermost parts. The longitudinal conductance values vary between 0.0058 m/day (VES 2) and 100 m/day (VES 5), with a mean value of 8.644 m/day. Longitudinal conductance(S) value decreases from the north western region of the study area towards the south and eastern part of the study area. The study reveals an increasing longitudinal conductance, towards the northwestern flank while the southeastern, northeastern and the entire southern part of the study is underlain with low conductive materials

The transverse resistance (R) is one of the parameters used to define target areas of good groundwater potential. It has a direct relationship with transmissivity such that highest transverse resistance values reflect most likely the highest transmissivity values of the aquifers or aquiferous zones and vice versa. Transverse resistance is the measured resistance along the horizontal profiling of an area of study. What that means is to determine how the resistance of an area or a ground surface varies from place to place as one moves/pulls away from his original position. Transverse resistance within and across the study area was estimated by simply taking into account the products of both the aquifer resistivity and aquifer thickness, Figures 4.6(a) and 4.6(b). The distribution of this transverse resistance shows that low transverse resistance values of -500000Ωm2 to 40,000Ωm2as shown with the black and shades of blue colours which found at the central and northern parts of the maps and it can be found in such towns as Amakohia, Ihiagwa, Nekede,, bank of Otamirri, Irete, Orogwe, Oforola, Ohii, Naze and FUTO Obinze which solemnly lies with the black region which shows it has the lowest transverse resistance but it began to increase towards the southern parts as indicated by the shades of green, yellow, red and purple colours in the maps with reading above 1,000,000Ωm2 to 500000Ωm2 and town within the area and its environs.

Hydraulic conductivity and transmissivity estimation

Hydraulic conductivity, K, is used to describe the ability of a material to conduct fluids under a unit hydraulic gradient (Fetter, 1994). In this research, the hydraulic conductivity was estimated from the product of the diagnostic constant and the aquifer conductivity. The hydraulic conductivity ranges within the study area ranges from -40 m/day to 40 m/day at Orogwe, Ihiagwa, and Naze; 40 m/day to 200 m/day in Irete, Ohii, Nekede, Avu, FUTO Obienze, Bank of Otamirri and Ohaji; 200 m/day to 520m/day Oforola.

From the map, and from all indications, it is observed that the study area is basically underlain by the Benin formation, a formation that is widely known to have the ability to contain a large volume of fluid including groundwater.

The central part Oforola and its environs which has a very high rate of transmissivity that ranges from 16000 m2/day to 38000 m2/day as shown in figure 4.8(a) and 4.8(b) marked with green, yellow, red, white and purple colours. On the other hand, places like Amakohia, Naze, Ohii, FUTO Obinze, Avu, Ohaji, Bank of Otamirri, Nekede, Amara, Irete and Orogwe with a colour indication of light blue and dark blue colours, also have a high transmissivity but not as high as the ones above; their values are within the range of 0m2/day to 16000m2/day. The area with the black colour has the poorest and lowest hydraulic transmissibility of -4000 to -2000.

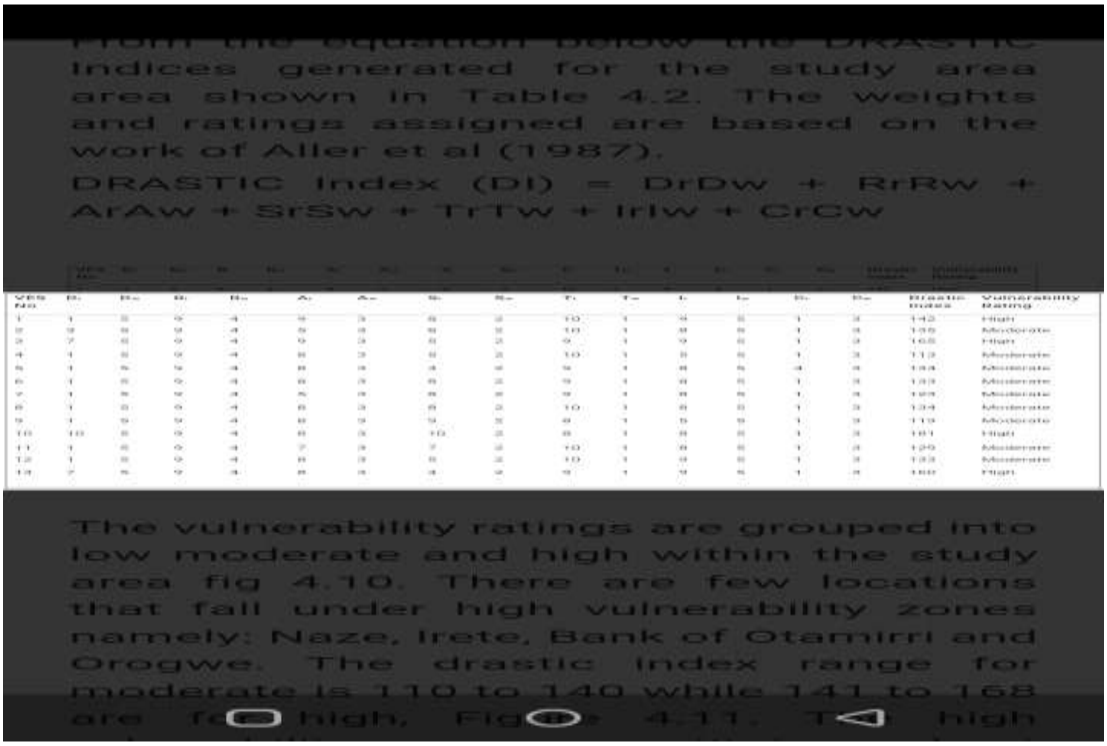
Aquifer Storativity

Aquifer Storativity coefficient is the amount of water an aquifer releases or takes into storage. The numerical value that is assigned to an aquifer is its storativity; and it is a dimensionless value. Storativity was determined from the rule of thumb according to Lohman (1972): S = 3 x 10-6h. The distribution of the aquifer storativity within the study area indicates that the area is characterized with very high storativity values; while some areas have a moderately high storativity values. Communities like: Avu, Bank of Otamirri, FUTO Obinze, Irete, Ohii and Orogwe are those areas that have a relatively higher storativity values ranging within the neighbourhood of 0.00025 to 0.00033 with colour indications of green, yellow, red, white and purple as can be seen in Figures 7(b). Then towns like: Ihiagwa, Oforola, Ohaji and Nekede etc are those places that have a relatively moderately high storativity values that fall within the neighbourhood of 0 0.00018 to 0.00025and they are marked with such colours like, dark blue and light blue. Awara depicts the area with the lowest storativity with a reading 0.000014.

Aquifer Vulnerability Assessment using DRASTIC Index

From the equation below the DRASTIC Indices generated for the study area area shown in Table 2. The weights and ratings assigned are based on the work of Aller et al (1987).

DRASTIC Index (DI) = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw



Indices generated for the study area shown in Table 4.2. The weights and ratings assigned are based on the work of Aller et al (1987).

DRASTIC Index (DI) = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw

The vulnerability ratings are grouped into low moderate and high within the study area fig 4.10. There are few locations that fall under high vulnerability zones namely: Naze, Irete, Bank of Otamirri and Orogwe. The drastic index range for moderate is 110 to 140 while 141 to 168 are fo[illegible] high, Fig[illegible] 4.11. T[illegible] high

Table 2: Aquifer DRASTIC Vulnerability Ratings

II. SUMMARY AND FINDINGS

This research work was intended to obtain vertical electrical soundings of the area, interpret them, draw the geo-electric sections using the DRASTIC model, FORTRAN Resistivity 2D Inverse Computer Program and Dar-Zarrouk tools to determine the depth to water table of the area, to compute the hydraulic characteristics of the study area and to draw the vulnerability map of the area.

Vertical electrical sounding (VES) was carried out in the selected areas. The maximum spread was AB/2=500m using the Schlumberger array. Raw field data were processed using appropriate constants and analysed using a FORTRAN Resistivity 2D Inverse Computer Program which is an iterative inversion-modeling program. The VES data was then presented as sounding curves which were obtained by plotting graphs of apparent resistivity versus half-current electrode spacing on double logarithmic graph sheets yielding layered earth models composed of individual layers of specified thickness and apparent resistivity.

Aquifer resistivities and other hydraulic characteristics obtained by the interpretations were modelled using surfer 13 to produce contour maps and 3D maps. The vulnerability map of the area was also obtained using DRASTIC index formulation.

III. CONCLUSION

This study provided data on the aquifer hydraulic conductivity (K), Transmissivity (T), aquifer thickness (h), depth to water table, and the Dar Zarrouk parameters: longitudinal unit conductance (S) and the transverse resistance (R) of the aquiferous zones.

Drilling of wells to determine aquifer hydraulic parameters is often prohibitively expensive, thus the use of Dar Zarrouk transmissivity technique outlined in this study in determining the aquifer transmissivity from resistivity data is a cost effective alternative. The advantage of using Dar Zarrouk parameters to estimate transmissivity is that the non-uniqueness of interpreting resistivity to compute the hydraulic characteristics of the study area and to draw the vulnerability map of the area.

The areas with a shallow aquifer are places like: Bank of Otamiri, Ohii and Orogwe wiuth that of the Bank of Otamiri lowest with 4.7m. This is easily understanble and so because the area is close to Otamiri river. The area with a moderate aquifer depth is Ihiagwa. While the areas with a deep aquifer are places like: Awara, Naze, Ohaji, Obinze, Avu, Amakohia, Nekede, Oforola, Naze and Irete.

The apparent resistivity in the area ranges from around 0.7Ωm to far above 21600Ωm. In terms of aquifer conductivity, the values obtained in the study area ranges from 4.6 x 10-5 (Ωm)-1 to 1.429 (Ωm)-1.

The transverse resistance within and across the study area was estimated by simply taking into account the products of both the Aquifer Resistivity and Aquifer Thickness. The distribution of this transverse resistance shows that low transverse resistance values of about 49 Ω/m2 to 4560.38 Ω/m2 found at Oforola, Ohii, Orogwe, FUTO-Obinze, Bank of Otamiri and Avu. While on the contrary, a high transverse resistance values of about 20401.6 Ω/m2 to 1040472 Ω/m2 are found at Naze, Awara, Nekede, Ohaji, Orogwe etc. all within the study area. The longitudinal conductance of the study area ranges from 0.000021 at Bank of Otamiri to 100 at Ohii. Areas that have relatively low longitudinal conductance include: Bank of Otamiri, Awara, Naze, Irete and Ihiagwa while the town that have relatively high longitudinal conductance are Oforola, Ohii, FUTO-Obinze, Avu etc.

The distribution of aquifer transmissivity within the study area shows that towns like: FUTO-Obinze, Avu, Oforola and Ohii have a very high rate transmissivity that ranges from 1295.93 m2 /day to 37725.27 m2 /day. While areas like Bank of Otamiri, Awara, Ihiagwa and Irete have relatively low transmissivity with values that ranges from 0.14 m2 /day to 8.54 m2 /day. In terms of the hydraulic conductivity, the results obtained showed that towns like: Awara have a low value of hydraulic conductivity of about 0.0350 m/day; but Oforola area have a very high hydraulic conductivity of about 538.93 m/day and this indicates that the area has the proficiency of yielding high volume of groundwater supply.

The result of the aquifer vulnerability assessment using DRASTIC model clearly reveal that the area is generally moderately vulnerable to groundwater contamination with the depth to water table and vadose zone inflicting the largest impact on the intrinsic vulnerability of the aquifer systems in the area. Only few areas showed high vulnerability.

Recommendations

1) Hydro-chemical evaluation should be carried out in the study area to obtain the water quality of the aquifer systems.

2) A well detailed geophysical data of the area should be done so as to enable authorities

concerned to enforce drill depth that will assure potable water for the area.

3) The relevant authorities should survey the manner in which domestic and industrial wastes are disposed in the study area.

4) Government should set up water schemes in different regions to enable a sustainable potable water supply

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