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Hydrogeophysical Approach in Aquifer-Trend Determination around the Western Part of the Lower Imo River Basin Southeastern Nigeria

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ABSTRACT

This geophysical investigation of groundwater is aimed at delineating the aquiferous units around the western part of the Lower Imo River Basin by determining their depths, thicknesses, resistivities and the potential borehole depth at various locations within the area employing the technique of Vertical Electrical Sounding (VES) using the Schlumberger array. Twenty two sounding stations were established. Four to six geo-electric layers comprising the top soil, clayey sand, dry sandstone, saturated sandstone, shaley sand and sandy shale were delineated with the later usually occurring as the last layer. The third and fourth layers underlying dry sandstone form the aquiferous unit. This unit was found to have an average resistivity value range of 10.7–6060Ωm and an average thickness of 32 m. Longitudinal Conductance increases towards the Southeast with a high closure around Umuduru Egbe Aguru. Conversely, Transverse Resistance increases towards the Northwest with a very high closure around Dikenafai and Mgbee axis. These confirm the difficulties often experienced during ground water exploitation in these localities. The Northern part of the study area has high thickness of aquifer units ranging from 50-80m. Similarly too, high depth to water table and consequent high possible Total Drill Depth (TDD) were mapped within the Northern part of the area. The reverse is the case for the South being dominated by the highly prolific Benin Formation. It was advised that care ought to be taken in drilling and casing at shallow aquiferous areas to maintain proper sanitary condition so as to reduce the risk of groundwater contamination.

Introduction

Water is essential for life. It had been and will continue to be a hot topic in both the political and scientific arena for years to come (Miller, 2006). The importance of groundwater as a supply source to the socio-economic development of a country is tremendous. Groundwater is water contained within the open spaces between soil, sand, gravel and within fractures in rock. The water comes from rain and melting snow which soaks through the ground and seeps into formations called aquifers. It usually moves slowly from high places towards low places and ultimately discharges into a nearby surface water body. The fact remains that some 74% of the earth consists of water. But 99.4% of this water cannot be used because it's either saline or locked up in glaciers or ice sheets. Less than 0.01% is present in rivers and lakes. The remaining water is present in soils and rocks as groundwater (Adagunodo, 2011). In Nigeria, Federal, state and local Government including individuals and politicians are busy drilling boreholes with little or no consideration to hydrogeology, fluid mechanics and its relationship with the host rocks and lithologic Formations. It has been observed that most drillers tend to drill boreholes in areas that are being recharged by lacerates landfills, polluted surface Rivers, even at times in old cemeteries/ graveyards and abandoned sucker pits and sewage systems. There is a serious lapse in groundwater development in Nigeria with a lot of abortive boreholes being drilled. Drilling boreholes is now, all-comers-affairs. Therefore there is need for proper studies of underground formations. Since the development of electrical resistivity surveying method in 1900's, it has been applied to solve problems associated with groundwater exploration, mapping fractures and cavities, engineering investigations, environmental studies among others (Kearey et al (2002), Keller and Frischknecht, (1966), Khalil (2009), Telford et al (1970)). Vertical Electrical Sounding, VES, using Schlumberger array has gained wide applications owing to its cost effectiveness and easy data acquisition and interpretation, among numerous advantages, compared to other resistivity measurements (Ibeneme et al 2013b). This method has been a veritable tool to mapping aquifer in all geologic terrains in the country and beyond. A number of authors have recently attempted the prediction of aquifer hydraulic properties in Nigeria from surface electrical resistivity soundings (Onuoha and Mbazi, 1988; Mbonu et al., 1991; Ekwe, et al., 2006; Igboekwe et al., 2006; Onu and Ibezim,2004; among others). Various hydrogeophysical and hydrogeeological works have been carried out in areas close to the study area by numerous workers. These include Uma and Egboka, 1985, Opara, 1997, Adishi, 1994, Ibe and Uzoukwu, 2004 Uma, 1989. Uma and Egboka, 1985 worked on the water resources of Owerri and its environs. They studied critically the aquifer systems of the area and result showed that the unconsolidated sands and their interfingering clay underlying the area gave rise to their aquifer systems. The first and second aquifer layers are unconfined and semi-confined respectively. The second having high field capacity. They showed that water table is less than 20m from the ground surface in the South but ranges from 25-35m deep Northwards. They also verify the aquifer parameters such as hydraulic conductivity K, transmissivity T, and Storativity S, the results showed that hydraulic conductivity ranges between 0.72 x 10^2 cms^{-1} to 24 x 10^2 cms^{-1}. The corresponding transmissivities range between 1.37$m2s^{-1}$ to 7.40$m2^{-1}$. Adishi, 1994 Carried out

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studies on the weathering layer parameters of Ihiagwa, Owerri using resistivity and Seismic refraction methods. He estimated the average thickness and average velocity of the weathered layer. Also he deduced its electrical resistivity. Opara, 1997 worked on the aquifer systems of the Niger Delta using resistivity and geophysical well logging methods. He affirmed the multilayered aquifer system and estimated the average depth to the saturated water level as 6m and this decreased coastwards. The aim of the study is to use the electrical resistivity sounding methods to define the geometry of the aquifers in the study area and delineate sites for drilling of productive boreholes and estimate aquifer hydraulic parameters with a view to mapping the different aquifer systems in the area and evaluating their trend.

The Study Area

The area lies within latitudes 5^{o}38’N to 5^{o}50’N and longitudes 7^{o}00’E to 7^{o}24’E. It is located towards the northern part of Imo State. The area is bounded to the northwest by Anambra State, to the northeast by Okigwe and to the south by Owerri. The main rivers that traverse the study area are Njaba, Orashi and Ogidi Rivers which are tributaries to the Imo River. The terrain of the study area is characterized by two types of landforms viz: high undulating ridge and flat topography. These undulating ridges and flat lands are somewhat related to the bedrock underlying the area. Borehole lithologic logs reveal that the undulating Hills and ridges are underlain by a succession of thick unconsolidated sandstones and relatively thin clay units belonging to the Benin Formation.

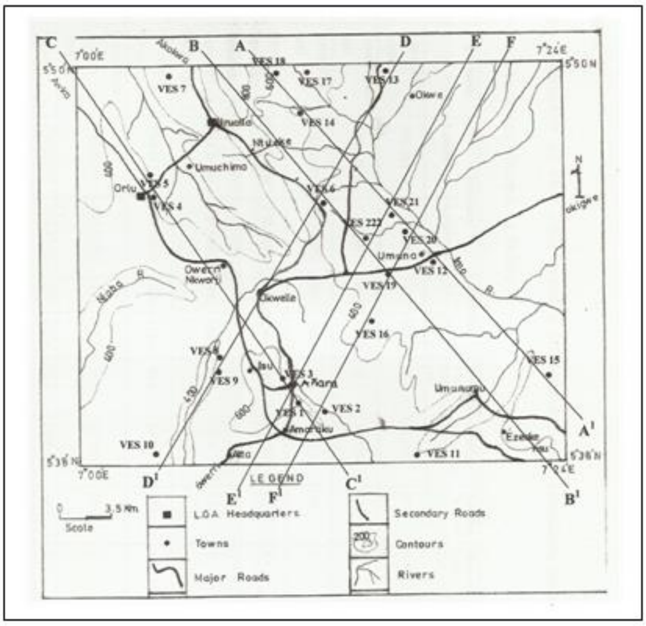

Figure 1. Location Map of the Study Area showing VES points

The ridges trend in the north-south direction and have elevation ranging from about 90-240m above sea level (Figure 3). In between these ridges and valleys of the Orashi River, Njaba River and their tributaries further south, the ridges give way to clearly flat topography. The flat southern part is underlain by thick unconsolidated sand and minor clay lenses and stringers. The area has two seasons, namely rainy and dry seasons. The mean annual rainfall is between 200m and 2250m and the annual rainfall is usually heavy. On a monthly basis, the rainfall amount at any location is not uniform but exhibits a marked seasonality. The date of the onset of the rainy season is usually between February and March and ends around October and November, whereas the onset of the dry season is between November and December and ends between March and April (Iloeje 1991). The rainfall distribution consists of two minima and two maxima. The first minima are in November and December while the second minimum is in August which is usually associated with August break. From February, total rainfall increases sharply to primary maxima in June and July. The second maximum is in September which increases sharply and subsequently decreases in November and December (NIMET 2012). The area comprises of true rainforest, characterized by an abundance of plant species. A storeyed sequence of canopies may be found in most part of the forest.

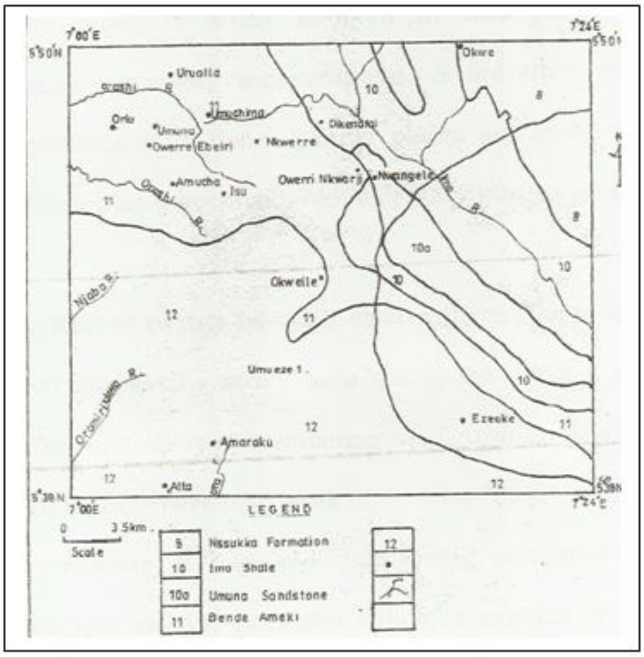

Figure 2. Geologic Map of the Study Area

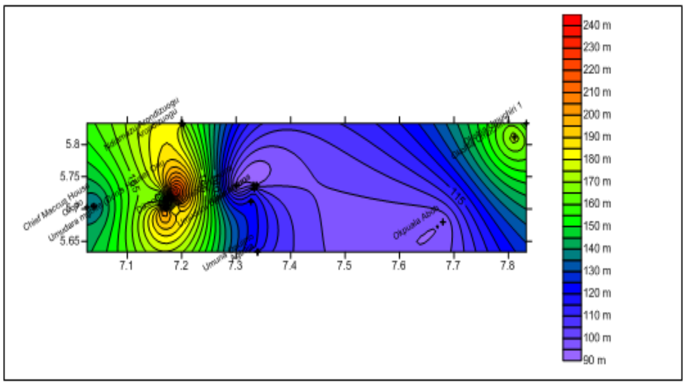

Figure 3. Elevation map of the area in meters above sea level

Geology of the area

The area is part of the Benin Formation (Figure 2). The geology of the Benin Formation has been given by Short and Stauble 1967, Reyment 1965, Hospers 1965 among others. The Benin Formation is made up of friable sands and minor intercalation of clay. The sand units are mostly coarse grained, pebbly, poorly sorted and contain lenses of fine grained sands (Short and Stauble, 1967, Onyeagocha, 1980). Benin Formation is one of the three recognized subsurface stratigraphic units in the modern Niger Delta. It is the fresh water bearing massive continental sand and gravel deposited in an upper deltaic environment. It was formerly designated as coastal plain sands (Reyment, 1965). As the study component in most areas form more than 90% of the sequence of the layers, permeability, transmissivity and storage coefficient are high.

The Formation starts as a thin edge at its contact with Ogwashi/Asaba Formation in the north of the area and thickens seawards. The Benin Formation conformably overlies the Ogwashi/Asaba Formation. The Ogwashi/Asaba Formation (Lignite series) is also predominantly sandy with minor clay units. The Formation is characterized by lignite seams at various levels. The lignite Formation has thickness of about 300m. This is underlain by the Ameki Formation with thickness of 1460m, which is in turn underlain by Imo shale and Nsukka Formations successively.

Table 1. Stratigraphic succession in the area (adapted from Uma and Egboka 1985).

Tertiary	AGE	FORMATION	LITHOLOGY
	Miocene-Recent	Benin Formation	Medium-coarse grained poorly consolidated sands with clay lenses and stringers.
	Oligocene-Miocene	Ogwashi Asaba	Consolidated sands with lignite seams at various layers.
	Eocene	Ameki Formation	Clayey sandstone and sandy claystones
	Paleocene	Imo shale	Laminated clayey shale
		Nsukka Formation	Sandstones intercalated with shales and coal beds

Data acquisition and instrumentation

A total of twenty two (22) VES were carried out. The maximum spread was 250-300m for AB/2 (m) and the data were acquired under favourable weather condition. A variety of electrodes arrangement is possible for resistivity measurement in the field, but Schlumberger array has been found to be convenient and reliable in most terrains. The theory behind the use of this method has been fully documented (Ibeneme et al 2013a). The instrument used for this study is the ABEM SAS 4000. This consists of a basic unit called the Terrameter SAS 4000 which can be supplemented as desired with SAS 3000C Booster and SAS log 200. SAS, which stands for Signal Averaging System, is a method whereby consecutive readings are taken automatically and the results are averaged continuously. The continuously update running average is presented automatically on the display unit. For this study an average of four readings were taken at each point. The tetrameter SAS 4000 can be operated in two modes: the resistivity surveying mode and the voltage measuring mode. In the resistivity surveying mode, it comprises of a battery powered, deep penetration resistivity meter with an output sufficient for a current electrode separation under good surveying condition. In the voltage measuring mode, the SAS comprises of self potential instrument that measures natural D.C potentials, and displays the result in millivolts (mV). The overall range extends from 0.01mv to 500v. Non-polarizable electrodes are available for self potential surveys. The tetrameter SAS 4000 consists of three main units housed in a single casing: the transmitter, the receiver and the microprocessor. The electrically isolated transmitter sends out well defined and regulated signal currents. The receiver discriminates noise and measures voltage correlated with transmitted signal current (resistivity survey mode) and also measures uncorrelated D.C potentials with the same discrimination and noise filtering (voltage measuring mode). The microprocessor monitors and controls operation and calculates results. In geological survey the equipment permits natural and induced signals to be measured at extremely low levels with excellent penetration and lower consumption. Moreover it can be used in a wide variety of application where effective signal/noise discrimination is needed.

Field Procedure

The vertical electrical sounding (VES) method using the Schlumberger electrode array was applied in this study. Current and potential electrodes made of stainless steel were used. The current electrodes were expanded to a maximum of 250-300m, while the potential electrodes are kept fixed and are only moved in order to get a reasonable value of the potential gradient. The soundings were conducted with conventional current electrode reels, a multicore potential cable and switching unit. Current and potential electrodes were made of non-polarizable electrodes, the current electrode spacing was increased in logarithmic steps while the potential electrodes were kept constant and were only varied to obtain a satisfactory reading to the potential drop. A total of 22 soundings were carried out in the study area. The data in form of earth's resistance measurement were converted to apparent resistivity value by multiplying it with the Schlumberger geometric factor as shown in equation 1

$\rho_a = (a^2/b - b/4)\,R$ …………………(1)

where

ρ_a = Apparent resistivity in Ohm-m

a = AB/2, the Half Current Electrode Separation in meters

b = MN, Potential electrode separation in meters

R = Instrument reading in Ohms

G is the Geometric Constant which is a function of the electrode configuration employed during the survey. The data collected in the field were presented by plotting the apparent resistivity (ρ_a) values against the electrode spacing (AB/2) on bi-log graph. Quantitative interpretation of the VES curves involved partial curve matching and computer iteration technique employing the method of Zohdy (1976) . As a good fit, (up to 95% correlation) was obtained between field and model curves, interpretation was considered as right.

Results and discussion

The results of the twenty two (22) Vertical Electrical Sounding (VES) are presented in Table 2 while their interpretation and subsequent analysis to suite the content of this work are as presented hereunder. The Resistivity of the delineated aquiferous zones in the study area varies from 10.7-6060 Ωm. Low resistive aquifer units were observed towards the eastern part of the study area (Figure 4). These areas geologically correspond to areas occupied by the Imo Shale Formation. Aquifers encountered in these areas are mainly perched aquifers entrapped within the sandstone member of the Imo Shale Formation (Umuna Sandstone).

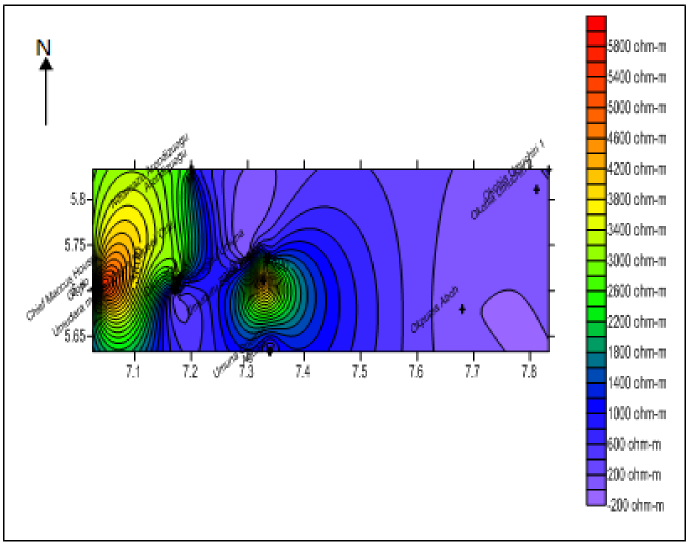

Figure 4. Variation of Aquifer Resistivity in the study area

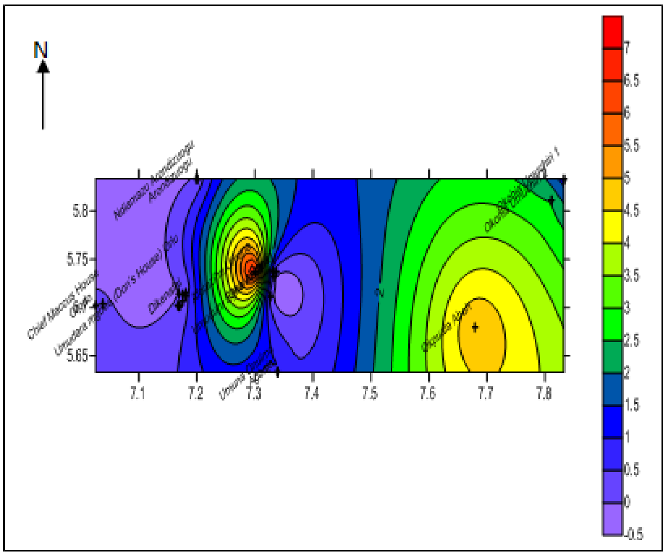

Figure 5. Variation of Longitudinal Conductance in the study area

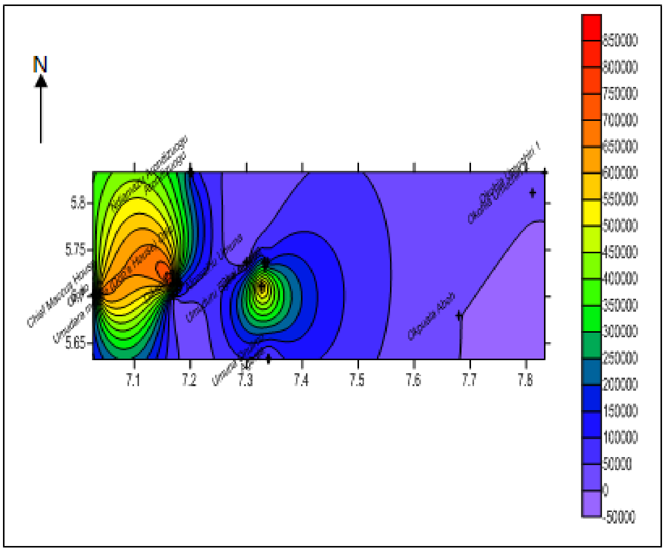

Figure 6. Variation of Transverse Resistance in the study area

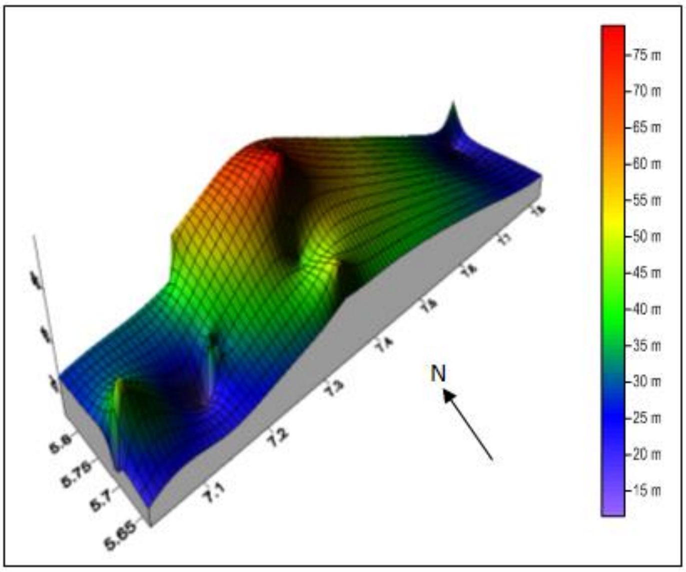

Figure 7. 3-D map of the Aquifer thickness distribution in the study area

The Longitudinal Conductance and Transverse Resistance vary in opposite directions (Figures 5 and 6). Longitudinal Conductance increases towards the Southeast with a high closure around Umuduru Egbe Aguru. Conversely, Transverse Resistance increases towards the Northwest with a very high closure around Dikenafai and Mgbee axis. These confirm the difficulties often experienced during ground water exploitation in these localities. The Northern part of the study area has high thickness of aquifer units ranging from 50-80m (Figure 7). Similarly too, high depth to water table (Figure 8) and consequent high possible Total Drill Depth (TDD) (Figure 9) were mapped within the Northern part of the area. The reverse is the case for the South being dominated by the highly prolific Benin Formation.

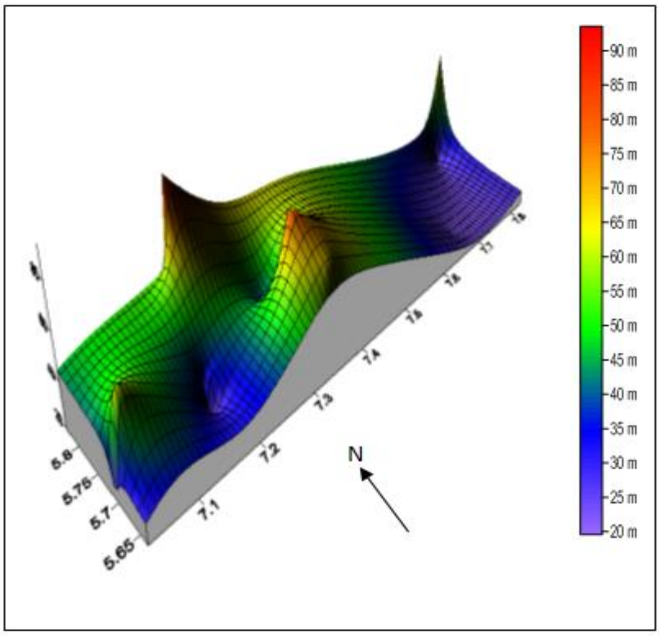

Figure 8. 3-D map of Depth to water table variation in the study area

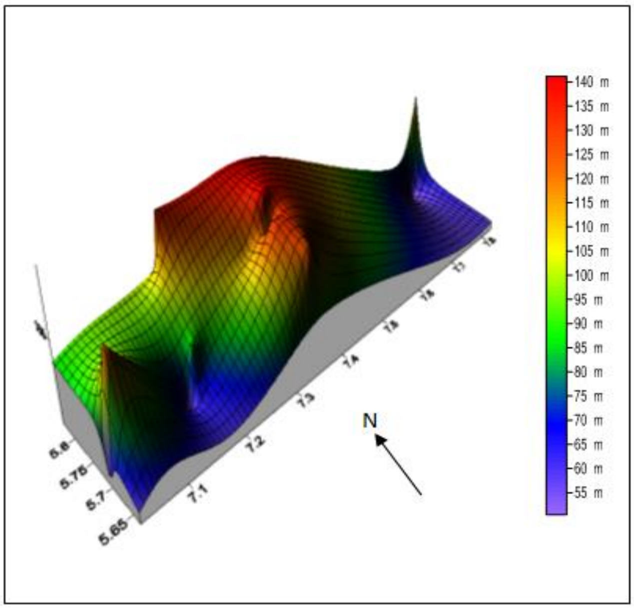

Figure 9. 3-D map of possible Total Drill Depth (TDD) in the study area

Conclusion And Recommendation

The western parts of the Lower Imo River Basin have good aquifer systems. It was observed that the shallow aquifer systems were obtained towards the south characterized by the dominant Benin Formation whereas the deeper aquifer systems were observed to occur in the areas underlain by the Ameki and Imo Shale Formations. Low resistive aquifer units were observed towards the eastern part of the study area.

Table 2. Summary of the VES results indicating real location names and other hydraulic parameters

VES	Location	Coordinates		Elevation		Depth to water table (m)	Aquifer Resistivity	Aquifer thickness	No of layers	Possible total drill depth (m)	Aquifer Material	Longitudinal conductance	Transverse resistance
		Latitude	Longitude	Ft	m								
1	Anara I	5°42.081’N	7°10.2118’E	671	204.5	21.6	111.00	23	5	60	Sand	0.059	49506
2	Anara II	5°42.125’N	7°10.2118’E	601	183.2	19.3	1120.0	15.9	6	55	Sandstone	0.058	39424
3	Anara III	5°42.125’N	7°10.049’E	651	198.4	26.0	1010.2	19	6	60	Sand	0.073	45955
4	Dump Site Ugwu Orlu	5°42.416’N	7°10.562’E	558	170.1	18.1	3190.0	51.9	4	85	Sandstone	0.028	226171
5	Umudara mgbee (Don’s House) Orlu	5°42.811’N	7°10.540’E	407	124.1	18.3	3190.0	51.9	4	85	Sandstone	0.028	2915.4
6	Dikenafai Ideato South	5°42.729’N	7°10.846’E	445	135.6	39.9	86.0	15.6	5	50	Sandy shale	0.527	233632
7	Umuokwara Akokwa, Ideato North	5°42.911’N	7°10.837’E	891	271.6	26.17	2980.0	38.5	4	90	Sandstone	0.064	86856
8	Uloano Ndugba Isu L.G.A	5°42.853’N	7°10.173’E	426	129.8	36.1	2310.0	10.9	6	50	Sandstone	0.030	977920
9	Chief Marcus House	5°42.243’N	7°02.285’E	434	132.3	63.1	6060.0	49.9	5	128	Sandstone	0.050	684780
10	Orodo Mbaitolu L.G.A	5°42.151’N	7°01.567’E	457	139.3	20.0	539.0	12.6	4	47	Sandstone	0.090	17571.4
11	Agbaja, Isiala Mbano	5°38.010’N	7°20.361’E	389	118.6	63.0	237.0	53	4	125	Sand/Sandstone	1.089	274.92
12	Umuna Onumo	5°38.001’N	7°20.361’E	360	109.7	50.4	1200.0	24.3	4	47	Sand/Sandstone	0.312	89640
13	Okohia Umuchiri I	5°49.972’N	7°49.972’E	510	155.4	72.9	260.0	37.1	4	120	Sandy shale	1.222	10375.2
14	Okohia Umuchiri II	5°48.673’N	7°48.673’E	571	174.0	22.4	60.0	16.9	4	50	Sandy shale	2.465	2381.58
15	Okpuala Aboh	5°40.784’N	7°40.784’E	312	95.0	20.7	10.7	31.2	4	63	Sandy shale	5.023	555.33
16	Umuduru Egbe Aguru	5°42.681’N	7°19.631’E	401	122.2	82.0	5070.0	42	4	133	Sandy shale	0.126	628680
17	Ndiamazu Arondizuogu	5°49.972’N	7°12.113’E	542	165.2	95.0	940.0	53	4	138	Shaly sand	0.193	120320
18	Arondizuogu	5°49.992’N	7°11.932’E	602	183.4	56.3	2340.0	36.6	4	105	Sandstone	0.053	217386
19	Okai umuna	5°43.921’N	7°20.002’E	372	113.4	52.2	2650.0	54.8	4	115	Sandstone	0.064	283550
20	Umuezeala Umuna	5°44.231’N	7°20.242’E	307	93.6	58.9	1010.0	71.1	4	140	Sandstone	0.155	131300
21	Umuezeala Ezifuoke Umuna	5°44.230’N	7°19.922’E	310	94.5	45.8	1900.0	81.2	4	135	Sandstone	0.112	241300
22	Aforezihu Umuna	5°44.230’N	7°18.021’E	301	92.0	39.5	30.5	61.5	4	112	Sandy shale	7.228	3080.5

These areas geologically correspond to areas occupied by the Imo Shale Formation which is characterized by its low capacity to release bound water. Similarly too, the hydraulic conductivity decreases towards the south indicating high groundwater productive potentials as one traverses southwards and vice versa. We hereby recommend that exploitation for groundwater in those areas delineated to have deeper aquifer units should be carried out with the aid of high powered hydraulic rig machine. The use of seismic rotary method is not in any way recommended in these areas. The seismic method can be used to exploit the shallow aquifer units. Also the design of the casing system of those shallow aquiferous areas must be carefully completed and properly grouted to avoid contamination of the groundwater system. The casing design must be carefully followed in both cases as to tap almost all the aquifer units (in case of areas with multi-aquifer systems).

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