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A Geo-Electric Survey of Potential Aquifer Inome Parts of Amaigbo, in Imo State, Using Vertical Electrical Sounding and Well Log Data

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The method employed was an electrical resistivity survey which was carried out to study the subsurface layer with a view of determine the depth of potential aquifers, the thickness of an aquifer, and to determine the potential aquifer for groundwater exploration. Using the Schlumberger array technique, Vertical Electric Sounding (VES), along with Self Potential well logging was carried out at six (6) VES stations in Amaigbo using the ABEM SAS 1000 terrameter and ABEM SAS 1000 logger respectively. The field data obtained have been analysed using the computer software (IP2win) which automatically interprets the apparent resistivity. The VES result revealed the heterogeneous nature of the subsurface geological sequence. Result from the Geo-electric section showed that the aquifer resistivity of the study ranges from 352Ωm to 7514Ωm, with potential groundwater depths ranging from 45m to 119m which shows that the study area is perfect for groundwater development. The data from the SP well logs correspond to the VES data obtained.

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1. INTRODUCTION

Water is the oldest, fundamental and abundant natural resources to maintain the existence of all living things on earth. Water just like air is the naturally resource we cannot do without for survival. Water is essential for all commercial, domestic, industrial, land agricultural purposes. Sourcing of water started from tapping from rainfall and local stream, rivers and lakes, to digging of wells and drilling of boreholes. As life ages, there is continuous search and thirst for a better life, good health and of course, a secured source of water [1].

This aging of life comes with advancement in technology, that embolden the intent and quest for water for all purpose in life, drifting from ordinary search for water to prospecting for portable, clean, accessible, secured source of water [2].

The sources include groundwater or subsurface water source, surface Water, precipitation or rain water.

Surface water such like river, lakes, streams was the first choice of man as a source of water, but with recent cases of pollution being inadvertently introduced by man through industrialization, urbanization, improper waste disposal and agricultural malpractices pose challenges for this type of water supply system (Bernard, 2003).

The subsurface or ground water is the portion of atmospheric precipitation that has percolated into the earth trapped under the surface of the ground in the tiny pore spaces between rocks, sand, and gravel. This makes water to be trapped almost everywhere beneath the earth's surface, not just from a single widespread aquifer but in millions of aquifer system Amaechi et al. [3].

Uma [4], confirmed the existence of three (3) major aquifer systems (shallow, middle and deep) occurring in the area as confined, unconfined and semi-confined forms. The study of subsurface lithologies can help ascertain causes of borehole failures, evaluate the aquifer parameters, map our prospective aquifers and determine the pollution potentials of the aquifers through borehole logs and water chemistry analysis, [5].

Over the years, a lot of different geophysical methods have been used to exploit the groundwater which is in abundance. This method includes Gravity. Seismic, Electrical Resistivity, Magnetic Resonance and magneto-telluric methods [6,7]. The method to be adopted during groundwater investigation is a function to depth of investigation and cost effect, as all these methods varies in use and cost.

However, the most frequent used is Electrical Resistivity and specifically Vertical Electric Sounding Molue, and Emegbetere, 2005; [8].

Vertical Electrical Sounding (VES) which is extensively used to for the location of aquifers Keller and Frischkknecht [9]; Zhody et al. [10]. It can also be used to determine other hydraulic parameters of an aquifer such like hydraulic transmissivity and conductivity Onyekwelu et al. [11].

VES must be carried out, on the surface before drilling, sinking or construction of a functional borehole**.** There have been a thorough researches by several researchers and geophysicist including Onwumesi et al. [12], confirming the effectiveness and efficacy of vertical electrical sounding for groundwater prospecting, containment plumb predication and freshwater and saline water boundary predication.

The groundwater in the study area is believed to be very shallow and very vulnerable therefore calling for a deeper investigation using the Electrical resistivity method as recommended by Nnamdi et al.[13].

The search for groundwater faces a lot of uncertainties to minimize and to avoid failures, it is pertinent that the right exploration is utilized in the delineation of subsurface water.

1.1 Objectives and Aim

To carry out a VES and obtain well log data in Amaigbo as to determine some potential aquifers in some areas with high borehole failures.

1.2 Justification of the Study

With the surging human population in Amaigbo, there has been an ever-increasing demand for portable water within the area. Groundwater and aquifer depth should be extensively studied, in knowledge as to supplement surface water or other sources of water. Thereby avoiding over exploitation by indiscriminate drilling of boreholes which consequently resulting to borehole failure and deterioration of groundwater in the area.

The cases of borehole drilling failures, contamination and abandonment reported in parts of Amaigbo have made this study imperative, to assist water resource planners, developers or geophysicist to accurately gauge the yield of the borehole in the area as to optimize the sinking of functional boreholes in the future.

1.3 The Study Area

The study area, Amaigbo is in Orlu senatorial zone of Imo State of south-eastern region of Nigeria. It lies within latitudes 5° 43' 48" N and longitudes 7° 6' 54" E. It is composed of both Niger delta basin and Anambra basin (Ogwashi-Asaba formation). The stratigraphic succession detailing the geology of the study area is shown in Table 1.

2. METHODOLOGY

The VES study is simply the shooting of electric current deep into the subsurface area to determine some of the potential aquifers. The Schlumberger configuration was used to carry out the VES within the study area. The input electrodes inject current (I) sourcing from a 12V battery, and the output electrode accurately defines the potential difference (V) which is determined by the terrameter, to further calculate the Resistance (R).

The resistance (R) was determined using the Ohm's law, that is, R= V/I. The Resistance (R) is multiplied by the Geometric factor (G) to determine the apparent resistivity (ρ). The apparent resistivity is further calculated using the formular below;

$$\rho = 2\pi G\left(\frac{v}{I}\right)$$

The sounding curves as shown in Figs.1-6 are generated using the IP2win software which plots the apparent resistivity (ρ) against AB/2 (the half electrode separation). The apparent resistivity for Schlumberger array can further be calculated as given that the MN/2 as the half potential electrode spacing.

$$\rho = \pi\left\{\frac{\left(\frac{AB^2}{2}\right) - \left(\frac{MN^2}{2}\right)}{MN}\right\}\frac{V}{I}$$

Potential electrodes (output electrodes) are installed at the centre of electrode array with small separation measured with a tape, which is typically less than one-fifth of the distance spacing of the current electrodes. The potential electrode remains constant while the current electrodes are increased in distance in the same position during the survey until the observed voltage becomes too small to measure. A spacing of 3m distance apart was maintained throughout the investigation for the six (6) VES point station.

3. RESULTS AND DISCUSSION

This study intends to give an elaboration of the geo-electric curves, the types of curves encountered in the area, the depth to potential aquifer in the study area as well as correction of the vertical electrical sounding result with the geophysical well logging result obtained from the research area.

3.1 VES Implications of Umuanu

Fig. 1. shows the Vertical electrical sounding result from Umuanu community reveals five layered subsurface formation with varying resistivity values of 288Ωm to 7514Ωm and thickness range of 1.3m to 119m. The first layer which cover top soil of the Earth material and has a resistivity value of $3101\Omega m$ and 1.3m thick. The second layer with a resistivity value of 4425Ωm and $3.95m$ thick indicates a consolidated layer and it is interpreted as unsaturated lateritic sand. The third layer of the formation with resistivity value of 2888Ωm consist of dry-sand mixed with gravel. The fourth layer with resistivity value of 7514Ωm reveals a saturated sand mixed with gravelly material that can hold and transmit water. The last layer whose bottom was not determined has a resistivity value of $3174\Omega m$ which is interpreted as saturated fine-sand with undefined depth and thickness.

3.2 VES Implications of Umuleke

Result of this location shows six Geo-electric units as observed in Fig. 2. and shown in (Table 3). The survey is displayed with resistivity range of 200Ωm to 491Ωm and thickness range of 1.5m to 25m.The first layer consist loose top soil of the Earth material and has a resistivity value of $134\Omega m$ and 1.5m thick. The second layer has resistivity value of 372Ωm with layer thickness of 2m and is interpreted as lateritic sand formation. The third layer of the formation has resistivity value of 491 Ωm and is interpreted as consolidated lateritic sand. The fourth layer of Umuleke geoelectric section with resistivity value of 325 Ωm with thickness of 12.5m is interpreted as partially saturated sand material. The fifth layer has a resistivity value of 352Ωm and $25m$ thick. The high resistivity indicates that the layer is made up of non- conductive material and it is interpreted as water saturated coarse-sand which is the potential aquifer unit of interest. The last layer whose bottom was not determined has a resistivity value of $200\Omega m$.

3.3 VES Implications of Amaju

This location shows five- Geo-electric units as seen in the curve in Fig. 3. The location is shown with resistivity variation of 31.7Ωm to 940Ωm and thickness range of 3.37m to 22.4m. The first layer which is mostly top soil of the Earth material and has a resistivity value of $31.7\Omega m$ and 3.37m thick. The second layer has resistivity vale of 940Ωm with layer thickness of 3.7m and is made up lateritic sand. The third layer with resistivity and thickness of 125Ωm and 31.2m is interpreted as partially saturated fine –sand formation. The fourth layer has a rise in resistivity value of 234Ωm with thickness of 22.4m which indicates layer of low conductivity; hence, it is interpreted as water saturated sands which is the potential aquifer unit. The last layer whose underneath was not determined has a resistivity value of $781\Omega m$.

3.4 VES Implications of Umudike

There are evident six geo-electric units sounding encountered in this location Fig. 4. The sounding has a resistivity range of 456Ωm to 3388Ωwith average thickness range of 5m to 40m. The first layer is about 5m thick, which is the top soil that is made up of blackish earth origin with resistivity of 456Ωm. The second and the third layer with layer thickness of 15m and 25.1m and resistivity values 1361 Ωm and 2202 Ωm is interpreted to contain unsaturated dry lateritic sand and coarse sand formation. The fourth and the fifth layer which has resistivity value of 3388 Ωm and 2237Ωm with thickness of 14.9m and 40m are seen as water saturated sand which are the prospective aquifer unit. The sixth layer whose base could not be recognized has.

3.5 VES Implications of Umudurumba

Six geo-electric units sounding are encountered in this location Fig. 5. The sounding has a resistivity range of 134Ωm to 491Ωm with varying thickness range of 1.5m to 25m. The first layer is about 1.5m thick, which is the top soil that is made up of earth origin with resistivity of 134Ωm. The second and the third layer has varying resistivity value of 372 Ωm and 491 Ωm with varying thickness of $2m$ and 19m, is interpreted to contain unsaturated fine-sand formation. The fourth and the fifth layer has resistivity value of 325$\Omega m$and 352Ωm respectively with thickness of 12.5m and 25m seen as water saturated sand which is the prospective aquifer unit. The sixth layer whose base could not be defined has a resistivity 200Ωm.

3.6 VES Implications of Umuchoke

Geo-electric section result of this survey area indicates six subsurface units as seen in Fig. 6. The survey is displayed with resistivity range of 314Ωm to 2723Ωm and thickness range of 3.36m to 14.9m. The first layer consists loose top soil of the Earth material and has a resistivity value of $314\Omega m$ and 3.36m thick. The second and the third layer has resistivity value of 817.1 Ωm and 25 Ωm with layer thickness of 11.6m and 10m is interpreted as lateritic and fine -sand formation. The fourth and the fifth layer has a resistivity value of 1240Ωm and 2723Ωm with thickness value of 20.1m and $14.9m$ thick. The resistivity indicates that the layer is made up of non- conductive material and it is interpreted as water saturated coarse-sand which is the potential aquifer unit of interest. The last layer whose bottom was not establish has a resistivity value of $1696\Omega m$.

Table 1. Stratigraphic succession in the study area (Adegoke et al., 2017)

Period	Age	Formation	Lithology
Quaternary	Recent	Meander belts	Sand, gravel and clay
Tertiary	Miocene -recent	Benin	Medium-coarse grain, poorly unconsolidated sand with clay lenses and stringers.
	Oligocene	Ogwashi-Asaba	Consolidated sands and ignite sands.

Table 2. Summary of geo-physical log chart aquifer depth intervals

S/NO	Borehole Location	Aquifer Depth intervals from well log chart (m)
1	Umuanu	58-62, 90-119
2	Umuleke	55-69
3	Amaju	68-98
4	Umuduramba	70-95
5	Umudike	48-60
6	Umuchoke	42-60

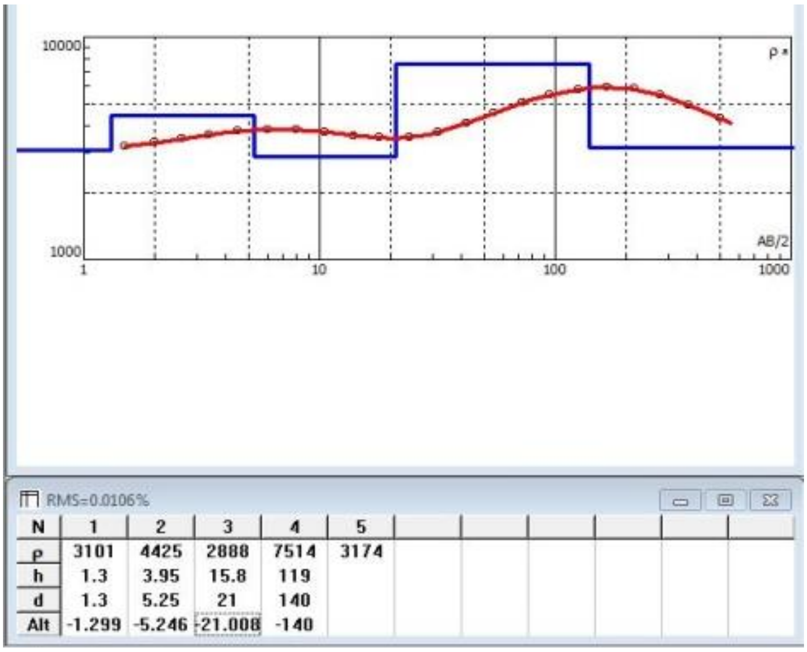


Fig. 1. VES of Umuanu

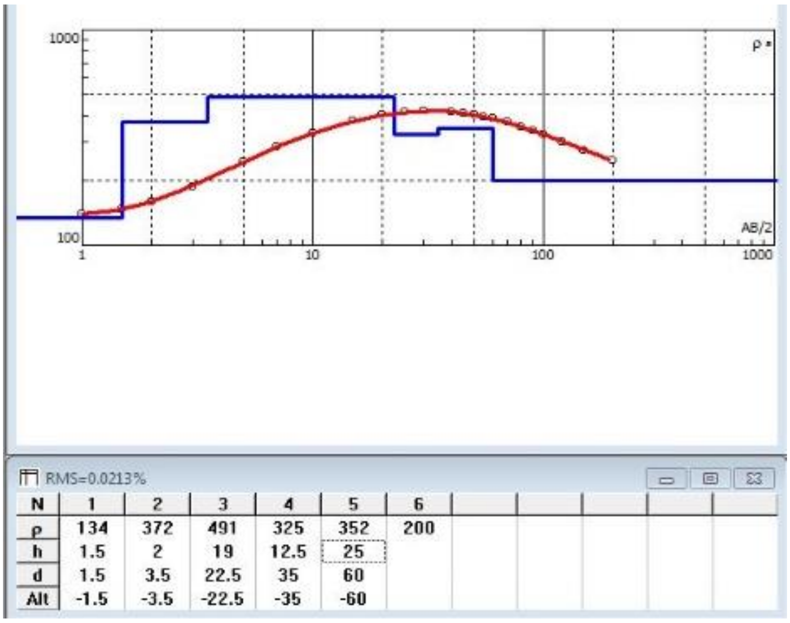
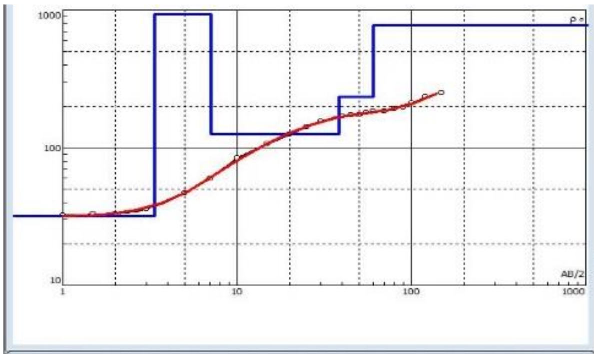


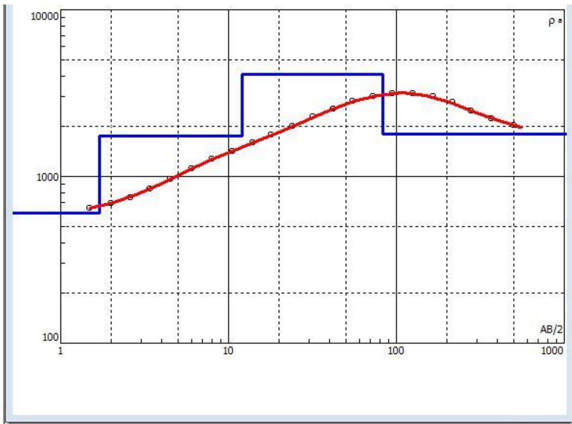
Fig. 2. VES of Umuleke



RMS=1.51%

N	1	2	3	4	5
ρ	31.7	940	125	234	781
h	3.37	3.7	31.2	22.4	
d	3.37	7.07	38.3	60.7	
Alt	-3.367	-7.071	-38.27	-60.69	

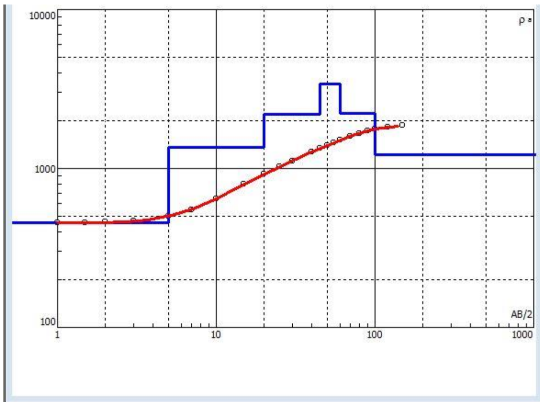
Fig. 3. VES of Amaju



RMS=0.11%

N	1	2	3	4
ρ	600	1758	4081	1796
h	1.7	10.3	70.5	
d	1.7	12	82.5	
Alt	-1.7	-12	-82.5	

Fig. 4. VES of Umudurumba



RMS=0.0103%

N	1	2	3	4	5	6
ρ	456	1361	2202	3388	2237	1226
h	5	15	25.1	14.9	40	
d	5	20	45.1	60	100	
Alt	-5.001	-20.01	-45.15	-60	-100	

Fig. 5. VES of Umudike

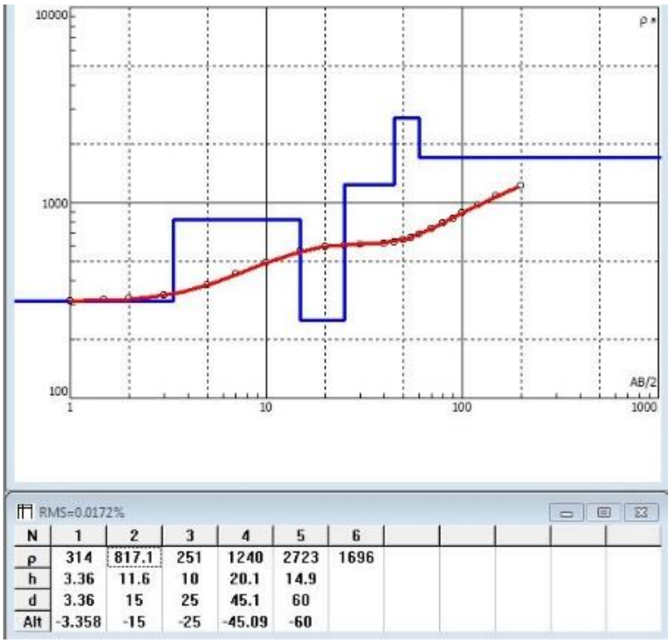


Fig. 6. VES of Umuchoke

3.7 Geophysical Log Chart of Umuanu

Fig. 7. display the geophysical log chart of Umuanu. The borehole was logged and drilled to depth of 119m. From the figure, it is marked that there are pockets of aquifers interval encountered during logging process considering the short and long normal which give more responsible information on freshwater interval composition. A look at the Long Normal Resistivity curve shows that fresh water column occurs at depths of 58m to 62m, and 90m to 117m.

3.8 Geophysical Log Chart of Umuleke

Fig. 8. shows the well-log chart carried out in Umuleke community. The borehole was logged and drilled to depth of 69m. From the figure, it is obvious that pockets of fresh water aquifers are encountered during logging process considering the short and long normal give more reliable information on the aquifer composition. A look at the Long Normal Resistivity curve shows that there is sand/ clay intercalation between depth of 19m-20m and 20m to 32m. Yet, freshwater interval occurs at depth between 55m to 69m as shown in the log chart.

3.9 Geophysical Log Chart of Amaju

Amaju Geophysical log chart is shown in and Fig. 9. The figure consists of borehole logged to depth of 98m. The log chart displays intercalation of clay and sand formation at depth between 58m and 60m with aquifer depth interval 68m to 98m. The aquifer depth section contains medium to coarse sand formation as shown in the kick of the long normal resistivity signature to the right hence, the well section can yield portable ground water for economic purpose.

3.10 Geophysical Log Chart of Umudike

Geophysical well log chart of Umudike is shown in Fig. 10. with the aquifer depth summary in Table 3. The spontaneous potential log and the resistivity log chart curve indicate a conductive clay formation from the depth of 12m to 21m with fine-sand and clay intercalation between depth of 21m to 48m. Underneath this depth is a clay formation which occurs from 48m through depth of 52m while the aquifer depth starts from depth of 52m

3.11 Geophysical Log Chart of Umuduramba

Umudurumba log chart is shown in Fig. 11. with drilled depth and logged depth of 96m. The log chart shows a thick clay boundary with the resistivity and spontaneous log kicking to the left from the depth of 58m to 72m. Nevertheless, the aquifer interval starts from 72m through the depth of 96m. to the log depth of 60m.

3.12 Geophysical Log Chart of Umuchoke

Fig. 12. shows the result from the chart of Umuchoke. It is seen from the chart that a conductor casing was used to prevent collapse of saturated topsoil during drilling and as such, the log chart starts at 9m. However, from the chart, the aquifer interval starts from 42-60m.Table 4 shows the summary of the logging for aquifer depth.

These are borehole charts represented near each VES point stations are listed below

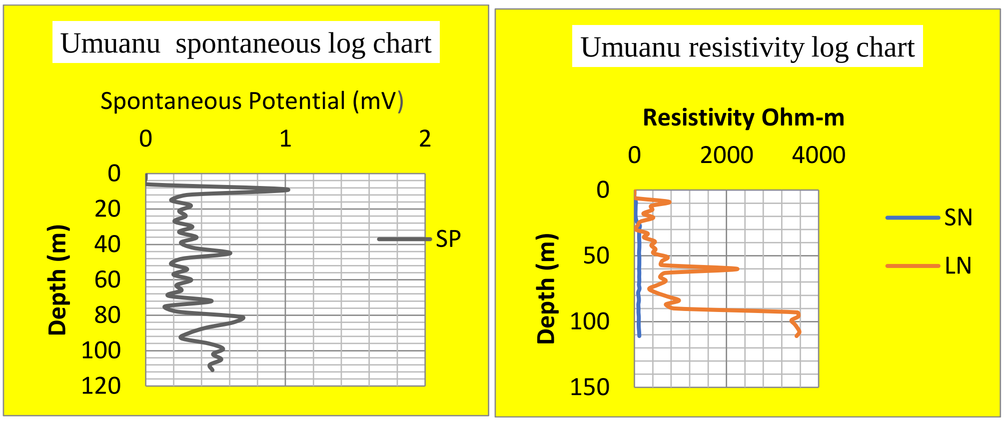


Fig. 7. Umuanu log Chart

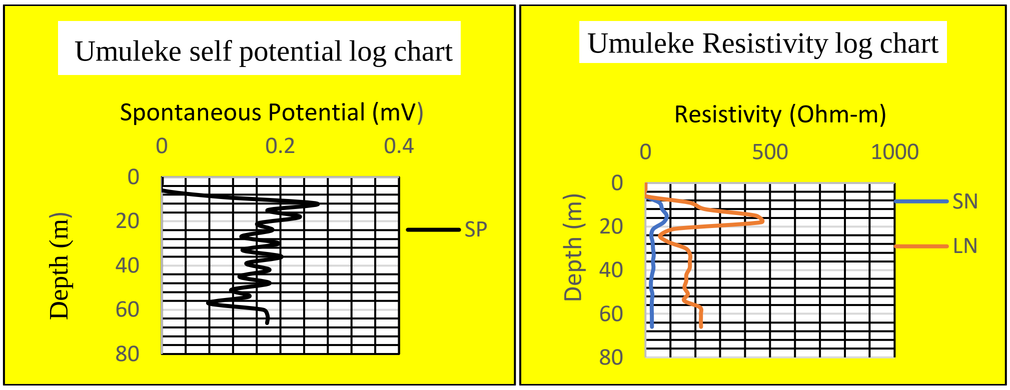


Fig. 8. Umuleke log Chart

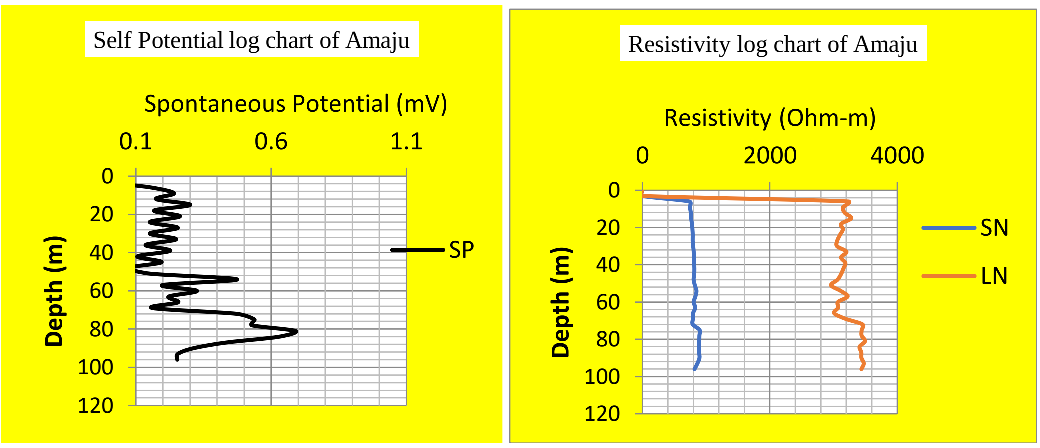


Fig. 9. Amaju log Chart

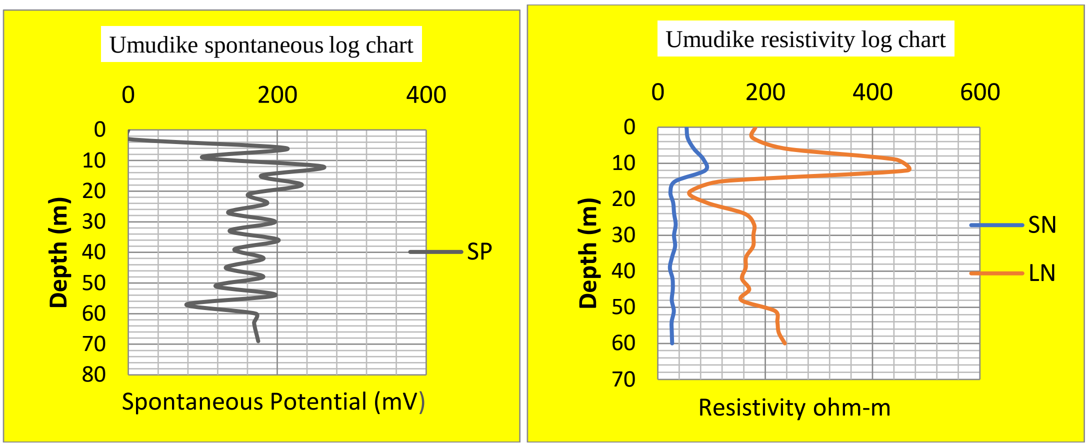


Fig. 10. Umudike log Chart

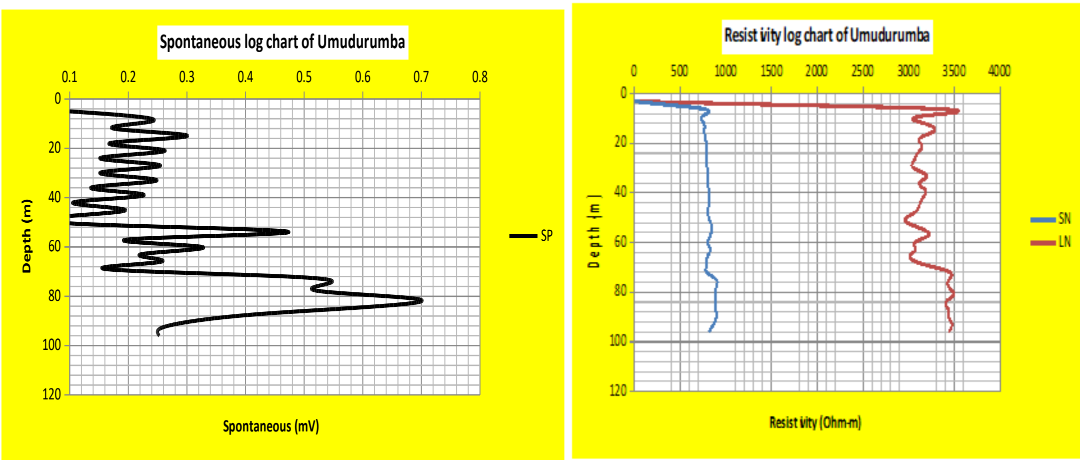


Fig. 11. Umudurumba log Chart

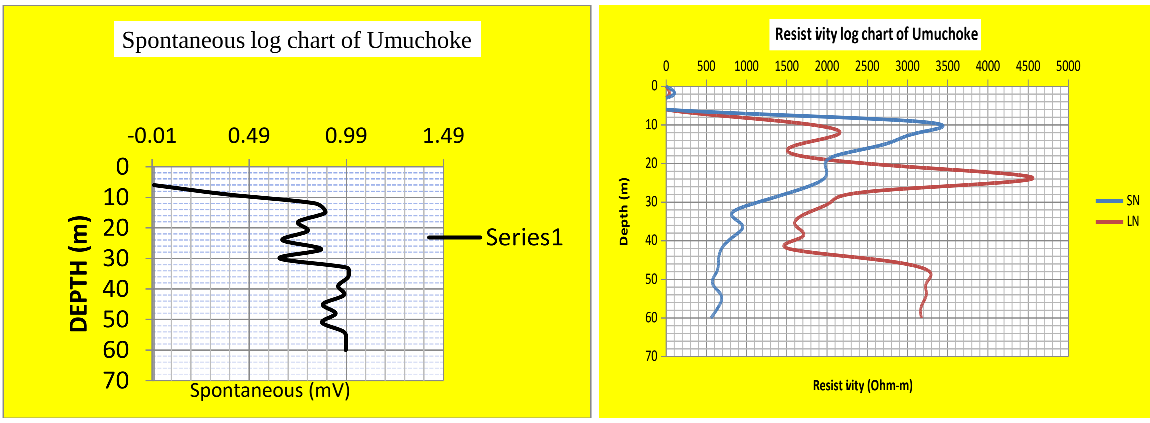


Fig. 12. Umuchoke log Chart

Table 3. The summary of the VES layers depth and thickness

VES Locations	Electric Resistivity (ohm-meter						Thickness (meter)					RMS(%)
	$\rho 1$	$\rho 2$	$\rho 3$	$\rho 4$	$\rho 5$	$\rho 6$	$h1$	$h2$	$h3$	$h4$	$h5$	
Umuanu	3101	4425	2888	7514	3174		1.3	3.95	15.8	119		0.01106
Umuleke	134	372	491	325	352	200	1.5	2	19	12.5	2.5	0.021
Amaju	31.7	940	125	235	781		3.37	37	31.2	22.9		1.51
Umudurumba	600	1758	4081	1796			1.7	10.3	70.5			0.11
Umudike	456	1361	2202	3388	2237	1226	5	20	45.1	60	46	0.0103
Umuchoke	314	817.1	251	1240	2723	1696	3.36	116	10	20.1	24.6	0.0172

Table 4. Resistivity ranges of materials Hunt [14]

Materials	Resistivity Range (ohm-metre)
Clay soil wet to moist	1.5 - 3.0
Silty Clay and Silty Soils	3-15
Well fractured and slightly fractured	150-300
Sands and gravel with silt	About 300
Sand and gravel with silt layers	300-2400
Slightly fractured bedrock with dry sand	300-2400
Sand and gravel deposits: Coarse and dry	> 2400
Massive and hard rock	> 2400

3.13 Correlation Between VES and Geophysical Well Logging

Result of depth to aquifer in the study area from the vertical electrical sounding corresponds to the aquifer depth obtained from the geophysical well logging result. Result of the Geophysical well logging validate the electrical resistivity survey carried out in the study area which is an approximation confirming the best interval for screen placement for the borehole drilled within the area for optimal yield and good groundwater development [15-17].

4. CONCLUSIONS

This research was aimed at investigating the aquifer potential in parts of Amaigbo in Nwangele Local Government area of Imo State with the vertical electrical sounding technique using the Schlumberger method and with geophysical well log data. The result obtained from the field data shows the Geo-electric parameters which include: aquifer depth, aquifer thickness, and aquifer resistivity of the study area. The aquifer depth and resistivity values at different depth were used to identify the potential depth of the aquiferous layers. Also, result obtained from the long normal resistivity log and the spontaneous potential log charts were used to identify the aquifer section of the drilled borehole located close to the survey area. From the result obtained the following conclusions are drawn.

The result of the vertical electrical sounding result obtained from the resistivity curve obtained from the study area indicates three to four geo-electric layers with KHK, KHA, AK, AKQ, KHAK, and AKHK curve-type.

Result from the sounding resistivity logs showed that the aquifer resistivity of the study ranges from 352 Ωm to 7514 Ωm, which confirms the range of fresh water resistivity.

Result from the survey and the geophysical well logging revealed that the potential aquifer within the study area lies between depths of 45m to 119m which shows that the study area is extremely good for groundwater development.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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