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(RESEARCH ARTICLE)

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Groundwater exploration using vertical electrical sounding techniques in parts of Etche Local Government Area of Rivers State, Nigeria

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Abstract

Vertical Electrical Sounding (VES) was carried out in parts of Etche Local Government Area, Rivers State, Nigeria to investigate availability of groundwater. An ABEM SAS 1000 terrameter was used. Schlumberger configuration was adopted for the sounding to acquire a 4 point data, with the use of ID Interpex software in order to know the subsurface variations in resistivity with respect to depth. The investigation revealed the subsurface, thickness of lithology, prolific aquiferous zones, the resistivity curve portrays an overall increase in resistivity trend ranging from 228.7Ωm - 5872Ωm. The resistivity trend in the form of $\rho_1 < \rho_2 < \rho_3 < \rho_4 < \rho_5$, indicates the presence of conductive materials present at a shallow depth of the point of survey. The highest resistivity value is observed in the fifth layer and it is believed to have gravely sized particles. A stratigraphic layer with gravely sized particles in this area revealed a good aquifer quality with reasonable quantity of aquifer fluid contained within the interconnected pore spaces. This zone of the studied area contains rock units from the geoelectric section such as silt, medium sand, coarse sand and gravel. The fifth layer is the prospect zone for aquifer delineation. A geoelectric section drawn from the resistivity data shows that the first layer is silt, the second layer is fine sand, the third layer is medium sand, the fourth layer is silty sand, the fifth layer is fine sand and the sixth layer is medium sand. The sixth layer is believed to be the prospect zone for aquifer characterization. A suitable data from drilled boreholes should be introduced to this study so as to have a profound knowledge and views about the grain size, sphericity, roundness and parking. These characteristics will be useful to determine the dominant grain size existing in these aquifers and characterize them appropriately.

Keywords: Geophysical investigation; Resistivity; Groundwater; aquifer; Etche; Rivers State

1. Introduction

The increase in the need for potable source of groundwater for both domestic and industrial consumption has necessitated the use of geophysical method (using the Vertical Electrical Sounding method) for groundwater exploration during the late decades with high success rate in delineating depth to various discontinuities existing at the subsurface as well as depth to potential aquifer formations as earlier reported by [1].

In recent years, exploration in the underground sources of water has led to a need for more intensive studies of the geometry and properties of aquifers. Geophysics has played a useful part in such investigations for many years and improvement in instrumentation and development of other geophysical methods resulting in widening of its applications [2]. It is still used to determine the number of subsurface layers existing in a given area consisting

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considerable interest in the possibilities of estimating aquifer properties such as permeability and porosity from measurements of geophysical properties. Geophysical methods such as gravity, magnetic and electrical methods detect differences in physical properties within the earth's crust.

Recently, resistivity imaging surveys have been used to map groundwater contamination and it is widely used for environmental surveys [3].It has also been successfully used in engineering and hydrological applications [2]. The vertical electrical sounding (VES) has also found application in modeling of subsurface features and in evaluating the suitability of an area for heavy Engineering construction such as a dam. [4] used the (VES) in delineation of salt and fresh water interface in basement terrain for location of geologic structures such as faults, joints, cracks, fractures patterns [5]believes that geologic Formation whose fractures have produced secondary porosity and permeability serves as potential water bearing Formation.

Parts of Etche are faced with the condition of near scarcity of potable water. This condition can sometimes be so severe especially during the dry season after a heavy draw down resulting to the residents going kilometers to neighbouring communities in search of potable water, some of these communities are devoid of surface water like streams, rivers, ponds, etc. However, there are few water boreholes in these areas that are not pumping or at some level of malfunctioning. The reason could be attributed to the lack of geological/geophysical information about the groundwater potentials within these areas prior to citing of the borehole. The scope of this work only consider the determination of the depth to groundwater table, the thickness and the resistivities of the subsurface layers and the general geologic sequence of the area.

The significance of this is to enable the indigenes of the study areas to have an idea of the subsurface layers and their respective thicknesses, the depth to groundwater table, the thickness of the aquifer in the area and possibly have an idea on what is responsible for some failed water boreholes drilled in area.

1.1. Description of the Study Area

It is located within Longitude 07^{0}14'0''E and latitude 05^{0}0'0''N (Figure 1) in the Niger Delta. The location in which the vertical electrical sounding points were done includes Ndashi, Umuokom, Akporku, Okehi, Odufor, Egwi, Ulakwo and Opiro.

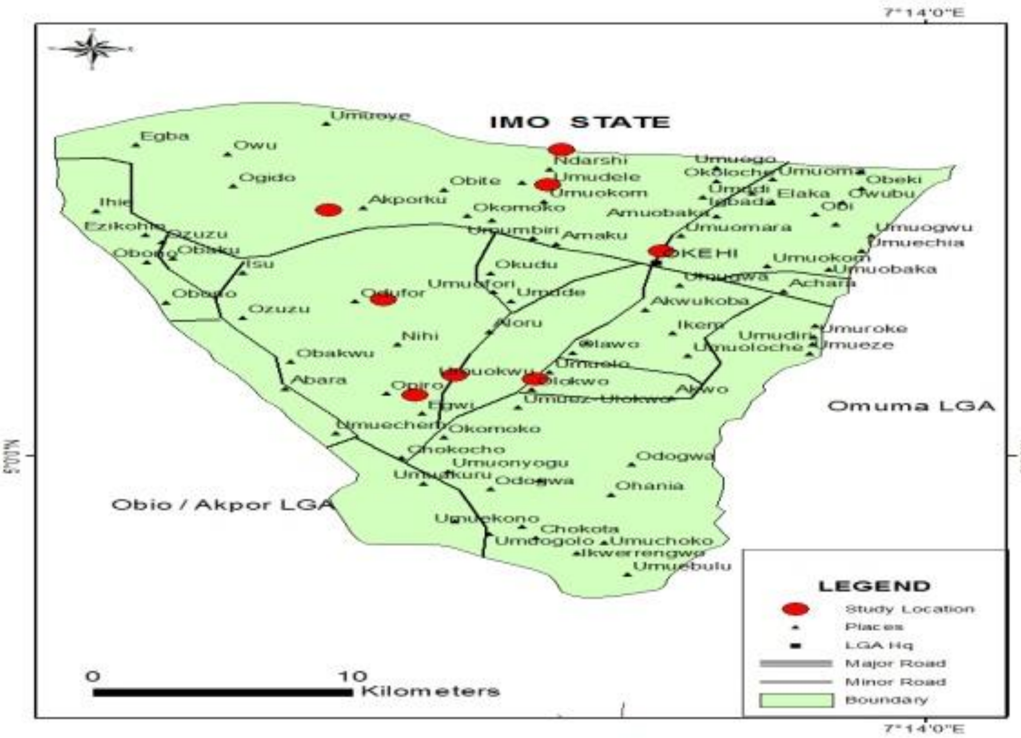

Figure 1 Location map of the studied area

1.2. Climate and Vegetation

The studied area, experiences a tropical climate characterized by two distinct seasons; the wet season (April to mid-August, September to mid-November) and dry season (November till March) usually with sparse rainfall in-between [6]. The rainfall exhibits a double maxima regime with peaks in July and September, with a little dry season in August. In the dry season, high evapotranspiration rate induced by dry conditions helps to increase water losses in the region [7]. The vegetation of the Niger Delta is classified into two (2) main regions namely; The swamp forest region and the rainforest region, The swamp forest is further subdivided into two (2) fresh water and salt water swamp which divides the Niger Delta into these vegetation regions. The characteristic vegetation of the salt water swamp forest is the presence of mangrove trees in its varieties. The secondary forest on the other hand represents the vegetation type derived from other activities that combined to degrade the original forest vegetation.

1.3. Hydrogeology of the Area

The quality and availability of groundwater in any environment is relative to rainfall in the area. Rainfall is required to recharge and replenish the groundwater and suitable rock type is needed to store the water, according to [8]. Rainfalls in these areas are high with an average annual rainfall ranging from 100mm in the inland area to over 2000mm near the coast. Unfortunately the runoff is high and is estimated to be up to 90%. Thus the geology of the area made the infiltration and percolation rate of rain water too small.[9] explains the hydrogeological assessment of groundwater resources involves primarily the mapping of surface lithologies and structures to help assess the subsurface lithologies deposition of sedimentary aquifers. This is akin to hydrogeological basin analysis; which differentiates groundwater migration laterally and downwards.

The study area belongs to Imo-Kwa-Iboe hydro geological basin of Nigeria. It is about 12,000 sq. km as earlier reported by [8] consists of a fairly rectangular basin elongated in the northwest — south, east direction. The basin is bounded by southern trunk of the River Niger, just south of Onitsha, to the northwest and the Atlantic coast, to south and southwest. The major aquiferous Formations are the Ameki Formations, but unfortunately the sand stone units of the Ameki Formation which forms a prolific aquifers is not conveniently distributed within its lateral extent, especially in the lower plains. In areas where the Imo-Shale dominates, the predominant shale lithology (Aquiclude) makes it difficult to have good aquifers. Availability of groundwater in the area depends on either the interception of the sandstone unit or sands of Ameki Formation which is limited in its lateral extent in the area or ground water occurs in fractured shale's which gives rise to secondary porosity and permeability.

2. Material and methods

The method used in carrying out this research is vertical electrical sounding (VES) and the type of array used in Schlumberger Electrode configuration. In the method, a direct current (D.C) from a charged car battery of 12 volts is connected to ABEM - Terrameter (signal Averaging system) SAS 1000 which regulates the voltage and used 20A. The current was injected into the ground through a pair of current electrodes which were connected to current cables and the potential electrode was also connected to potential cables. The potential difference was measured between a pair of potential electrodes. The current and potential electrodes are generally arranged in a linear array, with the potential electrodes inside, while the current electrode is outside the array, according to [10]. The principle of vertical electrical sounding (VES) was established in the 1920's. [1] affirms that the principle of vertical electrical sounding (VES) is based on the fact that the wider the electrodes separation, the deeper the current penetration. The potential electrodes are kept fixed until measures voltage decreases to low values as the potential gradient in the ground falls with increasing current electrodes separation. The ABEM-Terrameter (Signal Averaging System) SAS 1000 is positioned at the center of the linear array. However, there are some necessary precautions taken while carrying out this field work and these include: (i) avoid cross talking; this means to ensure that current and potential cables do not tangle with each other on either side of the linear array (ii) ensure that the line where the field operation is carried out is straight (iii) avoid carrying out the field operation on culverts, tarred roads and under high tension electric wires (iv) ensure that the connections of the current and potential electrodes are correct with their corresponding cables.

2.1. Field Operations/Data Acquisition Procedures

Having chosen a suitable site for the sounding, the necessary electrical connections were made. One vertical electrical sounding (VES) was probed into the ground. The maximum current electrodes separation was 740 meters i.e. 370 meters each way and the maximum potential separation was 55 meters.

The Schlumberger electrode configuration is such that the separation between the potential electrodes MN was smaller than the current electrodes AB. The current AB was passed through the two outer electrodes at a fixed distance apart. The resulting potential difference was measured between the potential electrodes.

A record of the current (1) and voltage (v) as well as MN/2 and AB/2 was made, the measurements were repeated with a fixed MN and AB was increased symmetrically until the response from the meter becomes too small, then MN was increased and the readings repeated with the previous AB/2 so that the reading overlaps.

The ABEM-Terrameter (SAS) 1000 resolves and records the resistivity value of each point on the linear array. The apparent resistivity data is acquired by the multiplication of the geometric constant (K) and the resistance recorded from the ABEM-Terrameter (SAS) 1000.

Where the Geometric constant K is;

$$K \equiv \left[\frac{\left(AB/2\right)^2 - \left(MN/2\right)^2}{2\left(MN/2\right)} \right] * \pi$$ ……………………………………equation 1

Where:

π=3.142
AB/2=Half-Current Electrode Spacing
MN/2=Half-Potential Electrode Spacing

2.2. Data Processing

The data processing begins by the multiplication of the values of the geometric constant (K) and the resistivity values recorded from the ABEM-Terrameter in order to get the apparent resistivity (Table 3). The data analysis begins with a master curve plotting, which depicts the relative thickness of the different layers when interpreted and their relative resistivity which varies systematically over the ranges of thickness and resistivity for each layer that are expected lobe of practical interest, where (A13) is the current electrode separation).

The graph paper is then superimposed on the sheet containing the set of curves chosen for comparison, and its position shifted horizontally and vertically to obtain the best possible fit.

Another form of data processing is the computer iteration method, which is consists of both forward modeling and inverse modeling. The process begins when data acquired is keyed in to the Schlumberger Automatic Analysis Version 0.92 Computer Software which processes the data and finally produces results which are further used for interpretations. However, after the interpretation, it is expected that the Root Mean Square (RMS) error should not be greater than 10%, if this occurs then the field curve representing the data should be re- iterated to reduce error.

2.3. Results Presentation

Table 1 Quantitative parameters of Resistivity measurement of Egwi community

Layers	Resistivity(Ωm)	Thickness(m)	Depth(m)
1	295.88	0.54518	0.54518
2	798.60	3.5924	4.1376
3	864.62	2.1559	6.2935
4	1810.2	37.957	37.25
5	5634.2	∞	∞

Table 2 Quantitative parameters of Resistivity measurement of Ulakwo community

Layers	Resistivity(Ωm)	Thickness(m)	Depth(m)
1	14.369	0.124	0.12415
2	15.965	8.250	9.665
3	4591.4	27.074	47.738
4	5101.5	∞	∞

Table 3 Quantitative parameters of Resistivity measurement of Okehi community

Layers	Resistivity(Ωm)	Thickness(m)	Depth(m)
1	697.56	0.29506	0.29506
2	10642	0.51943	0.81449
3	5533.0	35.32	39.13
4	5776.1	∞	∞

Table 4 Quantitative parameters of Resistivity measurement of Opiro community.

Layers	Resistivity(Ωm)	Thickness(m)	Depth(m)
1	54.639	0.21470	0.21470
2	9147.8	0.30305	0.51774
3	1119.9	21.107	21.625
4	2566.8	∞	∞

Table 5 Quantitative parameters of Resistivity measurement of Odufor community

Layers	Resistivity(Ωm)	Thickness(m)	Depth(m)
1	20.320	0.13606	0.13606
2	851.16	1.1039	1.2399
3	2511.9	15.803	17.043
4	1345.0	∞	∞

Table 6 Quantitative parameters of Resistivity measurement of Akpoku community

Layers	Resistivity(Ωm)	Thickness(m)	Depth(m)
1	790.38	0.36897	0.36897
2	1854.8	0.8832	0.45729
3	2133.7	3.7316	4.1889
4	747.1	28.838	33.027
5	1230.6	48.108	81.135
6	2200.9	∞	∞

Table 7 Quantitative parameters of Resistivity measurement of Ndashi community

Layers	Resistivity(Ωm)	Thickness(m)	Depth(m)
1	13.515	0.49701	0.49701
2	1257.2	1.5896	2.0866
3	2041.3	4.5367	6.6232
4	1765.4	17.594	24.217
5	77.636	16.330	30.850
6	2384.1	∞	∞

Table 8 Quantitative parameters of Resistivity measurement of Umuokom community

Layers	Resistivity(Ωm)	Thickness(m)	Depth(m)
1	156.2	0.60549	0.60549
2	421.4	0.33169	0.93718
3	2559.4	4.3105	5.2477
4	1032.0	30.476	35.724
5	75.659	10.418	36.766
6	1081.5	∞	∞

Table 9 Summary of Quantitative parameters of Resistivity measurement of the study area

S/N	Location	No. of Layers	Curve Type	Aquifer Formation	Resistivity (Ωm)						Depth (m)				
					ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	D1	D2	D3	D4	D5
1	Egwi Community	5	A	Gravel	295.88	798.60	864.62	1810.2	5634.2	---	0.5	4.1	6.2	37	-
2	Ulakwo Community	4	A	Gravel	14.369	15.965	4591.4	5101.5	---	---	0.1	9.6	47.7	-	-
3	Okehi Community	4	KH	Gravel	697.5	10642	5533	5776	---	---	0.2	0.8	39	-	-
4	Opiro Community	4	A	Coarse Sand	54.639	9147.8	1119.9	2566.8	---	---	0.2	0.5	21.6	-	-
5	Odufor Community	4	A	Medium Sand	20.320	851.16	2511.9	1345	---	---	0.1	1.2	17	-	-
6	Akpoku Community	6	KH	Medium Sand	790.38	1854.8	2133.7	747.1	1230.6	2200.9	0.36897	0.4	4.1	33	81
7	Ndashi Community	6	KH	Coarse Sand	13.515	1257.2	2041.3	1765	77.6	2384	0.4	2	6.6	24	30
8	Umuokom Community	6	KH	Medium Sand	156.2	421.4	2559.4	1032	75.6	1081.5	0.6	0.9	5.2	35	36

3. Results

3.1. Qualitative Interpretation

The resistivity curve interpretations were done with the use of ID Interpex software in order to know the subsurface variations in resistivity with respect to depth of investigation. The resistivity curve on the left hand side of figure 2 shows an A type curve and this curve portrays an overall increase in resistivity trend ranging from 228.7Ωm - 5872Ωm. The resistivity trend in the form of $\rho_1 < \rho_2 < \rho_3 < \rho_4 < \rho_5$, an indication of the presence of conductive materials may be present at a shallow depth of the point of survey.

The depth against resistivity plot on the right hand side of figure 2 describes changes in resistivity behaviour with respect to depth of investigation. Five stratigraphic layers were delineated with thickness of 0.54m, 3.59m, 2.15m and 37.95m; depth of 0.55m, 4.14m, 6.29m and 37.25m and resistivity of 295.88Ωm, 798.6Ωm, 864.62Ωm, 1810.2Ωm and 5634.2Ωm respectively. The highest resistivity value is observed in layer five i.e., at a depth greater than 37.25m and it is believed to have gravely sized particles. A stratigraphic layer with gravely sized particles in this area is expected to have good aquifer quality such as porosity, permeability and saturation with reasonable quantity of aquifer fluid contained within the interconnected pore spaces.

This zone of the study area contains rock units from the geoelectric section such as silt, medium sand, coarse sand and gravel. The fifth layer is termed the prospect zone for aquifer delineation.

The resistivity profile obtained from Ulakwo community as part of the resistivity data obtained in the study area shows a steep slopping plot with an A type curve and trends in the form of $\rho_1 < \rho_2 < \rho_3 < \rho_4$. The profile can be seen on the left hand side of figure 3 and it shows an increasing resistivity trend or values with respect to depth. The depth versus resistivity observed at the left hand side of figure 3 was used to delineate the number of strata and the respective thickness and depth to zones of interest. Four stratigraphic layers were obtained from the in-homogenuity of the subsurface characteristics and it was observed that there are variations in litho-stratigraphic units, depth, thickness of the strata as well as the resistivity trend from one layer to another. The stratigraphic units are clay, coarse sand and gravel with depth values 0.12m, 9.6m and 47.7m ; thickness of 0.12m, 8.2m and 27m and resistivity of 14.3Ωm, 15.96Ωm, 4591.4Ωm and 5101.5Ωm respectively.

The prospect zone is the fifth layer and it has a gravely sized particles suspected to have good porosity, permeability and fluid saturation as the basic properties for any potential aquifer.

The resistivity profile of Okehi community has a KH type curve. The curve shows resistivity behaviour trending in the form of $\rho_1 < \rho_2 > \rho_3 < \rho_4$ and overlaps each other (figure 4). The depth to resistivity plot in figure 4 was used to determine depth and thickness of the lithostratigraphic units as well as resistivity value. The highest resistivity values according to table 4 is 5776.1Ωm and the least is 697.56Ωm respectively. The highest resistivity value denotes a freshwater aquiferous unit with little amount of conductive materials. While the layer with the least resistivity value denotes a shallow depth and the zones with high conductive materials with low resistive fluid. The high conductivity could be as a result of the presence of heavy metal concentrations, leachate plumes migrating from a nearby dump site, abandon channel or drainage path, etc.

Four lithostratigraphic units were delineated from this area of the study and they are silt (first layer), medium sand (second layer) and gravel (third and fourth layers). The depth values are 0.29m, 0.81m and 39.1m and thickness of the layers are 0.29m, 0.51m and 35.3m respectively.

The first and second layers are thin sediments of silt and medium sand compared to the lithostratigraphic units observed in figure 2 and 3. The prospect zone contained in layer three and four have reasonable thicknesses. The gravely sized grains in the third and fourth layers are indications to show that these layers can house potential aquiferous formation with appreciable properties as found in other locations (i.e., Egwi and Ulakwo community).The resistivity profile of Opiro community has an A type curve (figure 2). The curve trends in the form of $\rho_1 < \rho_2 < \rho_3 < \rho_4$ and indicates an overall increase in resistivity behaviour as depth to freshwater increases. The highest resistivity value (2566.8Ωm) is observed at a depth greater than 21.62m. A depth believed to be a freshwater formation and if a borehole is to be cited for domestic, industrial and agricultural use, it would be suitable.

From figure 5, a depth versus resistivity plot was obtained using the ID Interpex software. The plot shows a depth of 0.214m, 0.517m and 21.62m and resistivity values of 54.63Ωm, 9147.8Ωm, 1119.9Ωm and 2566.8Ωm respectively for the four stratigraphic layers interpreted. The increase in resistivity with depth from the profile, denotes an increase in grain size, pore space, permeability and water saturation. A geoelectric section that shows the subdivision of the lithostratigraphic units based on their electrical and geological properties was produced to explain certain geological and petrophysical properties of any given aquiferous unit in this area. The lithologic units obtained from the geoelectric section are clay, fine sand, medium sand and coarse sand (prospect zone).

Figure 6 contains a resistivity profile on the left hand side and a depth versus resistivity on the right hand side. The resistivity profile shows an A type curve with increasing resistivity property with depth of investigation. The curve is a steep one and could be as a result of very low concentration of conductive materials that may have caused the curve to undulate upward before getting to that threshold. The depth versus resistivity curve was used to obtain depth values for the various lithostratigraphic layers (i.e., 0.13m, 1.23m and 17.04m) and resistivity values of 20.32Ωm, 851.1Ωm, 2511.9Ωm and 1345Ωm respectively. For the first time the third layer has a resistivity value greater than the fourth layer. This is an indication of high amount of freshwater constituents than that of the fourth layer. The thickness of the third layer is 17.07m, a value greater than the above sedimentary units found in this data. This implies that good properties can be inferred from the aquifer formations existing the area.

The lithologic units from the geoelectric section produced from the acquired resistivity data, shows that the first layer is clay, the second layer is fine sand, the third layer is coarse sand suspected to be the prospect zone for aquifer delineation and the fourth layer is medium sand. A resistivity profiling method was carry out in Akpoku community as one of the communities for this research. The profile in figure 7 shows a resistivity curve with an undulating curve nature of a KH type curve. This sort of resistivity curve type trends in the form of $\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5 < \rho_6$, an indication of the inhomogenuity of the anisotropic nature of the subsurface layers existing in the area. The intercalations of clay beds within sandstone bed units and vise-versa may have resulted to this sort of undulation of the resistivity curve as the variations in resistivity values. The profile is almost similar to that seen in figure 4 (Okehi community) but more rugged due to the subsurface geologic changes.

Six lithostratigraphic units where delineated having resistivity values of 790.38Ωm, 1854.8Ωm, 2133.7Ωm, 747.1Ωm, 1230.6Ωm and 2200.9Ωm ; thickness of 0.36m, 0.88m, 3.73m, 28.8m and 48.1m and depth of 0.37m, 0.45m, 4.18m, 33m and 81.13m, respectively. The highest resistivity value (2200.9Ωm) is observed at a depth greater than 81.13m in layer six. It is worth noting that, layer four in this data (figure 7) has a low resistivity value compared to other data (of figures 2, 3, 4, 5 and 6) and it is also not the layer with the highest resistivity value. The reason for this may not be far fetch, as it could be due to potential leakage from industrial sites nearby, due to subsurface fracture tracing by injection of conductive solutions such as salt solution, presence of leachate materials, remediation process at environmental sites, groundwater recharge, infiltration processes, etc.

A geoelectric section drawn from the resistivity data shows that the first layer is silt, the second layer is fine sand, the third layer is medium sand, the fourth layer is silty sand, the fifth layer is fine sand and the sixth layer is medium sand. The sixth layer is believed to be the prospect zone for aquifer characterization. The resistivity profile of figure 8 is the resistivity data from Ndashi community. The profile is similar to that in figure 7 although, distinction can be made from the depth versus resistivity plot between figure 7 and 8. The curve type of this resistivity curve is KH type curve with resistivity trend of $\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5 < \rho_6$ as depth to aquifer formation increases.

The depth versus resistivity plot was used to obtain depth values for the subsurface layers and they are 0.49m, 2m, 6.6m, 24.2m and 30.8m; thickness of 0.49m, 1.58m, 4.53m, 17.5m and 16.3m and resistivity values of 13.5m, 1257.2Ωm, 2041.3Ωm, 17654Ωm, 77.6Ωm and 2384.1Ωm. The highest resistivity value is found at the sixth layer at a depth greater than 30.8m. The sixth layer believed to be the prospect zone due to its high resistivity value existing at that depth. Furthermore, the prospect zone is expected to have good porosity, permeability and high water saturation as its aquifer properties.

The fifth layer is clay bed with resistivity value of 77.6Ωm existing at a depth of 30.8m and thickness of 16.33m. Due to its low resistivity value it could not be regarded as an aquiferous unit, rather, it is acting as a cap seal to the underlying aquifer formation. Six lithostratigraphic units were observed from the geoelectric section produced from the resistivity data. And the section shows that the first layer is clay, the second layer is fine sand, the third layer is medium sand, the fourth layer is fine sand, the fifth layer is clay and the sixth layer is coarse sand (prospect zone).

The resistivity profile of Umuokom community shows a KH type curve. The curve portrays resistivity variations for the different subsurface layers as $\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5 < \rho_6$ (figure 4). The depth versus resistivity plot on the right hand side of figure 4 was used to obtain depth values such as 0.6m, 0.9m, 5.2m, 35.7m and36.7m; thickness of 0.6m, 0.3m, 4.3m, 30.4m and 10.4m and resistivity of 156.2Ωm, 421.4Ωm, 2559.4Ωm, 1032Ωm, 75.6Ωm and 1081.5Ωm. The sixth layer is believed to be the prospect zone for water exploration because of its high resistivity value and the depth at which it occurs. Although, the sixth layer does not have the highest resistivity value but for the fact that the subsurface earth acts as a filter. Therefore, fluids percolating through the earth's subsurface layers tend to filter the fluids and leave behind impurities of leachate materials, heavy metal concentration and other substances. The fifth layer has a low resistivity value of 75.6Ωm at a depth of 36.7m and thickness of 10.4m. The low resistivity value of the fifth layer made it to be called a clay bed. This clay bed is acting as a cap seal to the underlying aquifer bed unit and has the ability to prevent fluid migration from the aquifer.

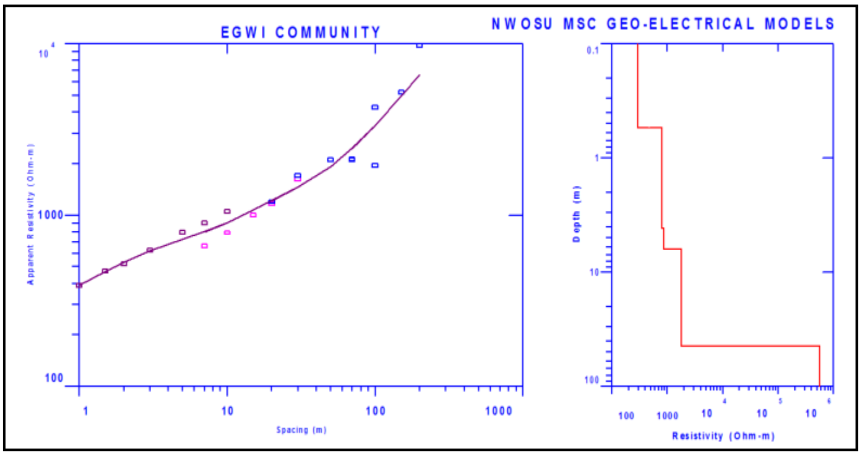

Figure 2 Resistivity profile with respect to subsurface depth of Egwi community

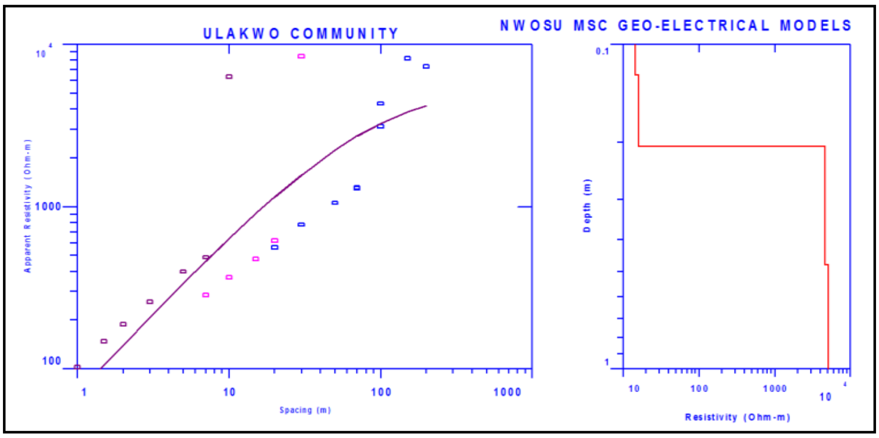

Figure 3 Resistivity profile with respect to subsurface depth of Ulakwo community

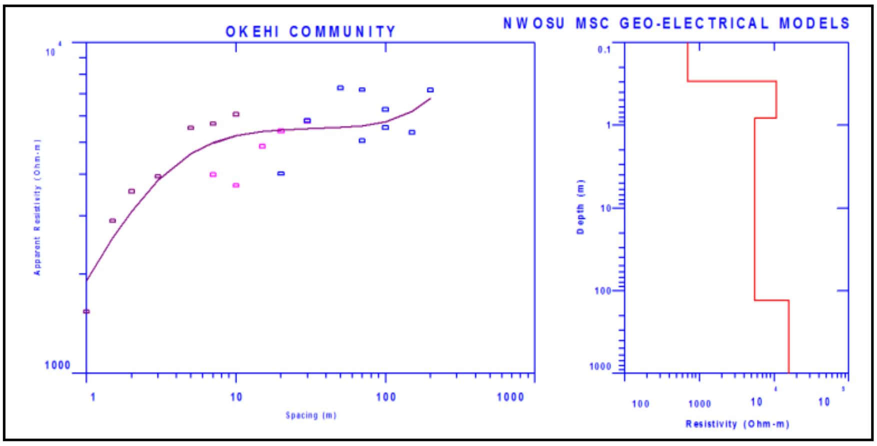

Figure 4 Resistivity profile with respect to subsurface depth of Okehi community

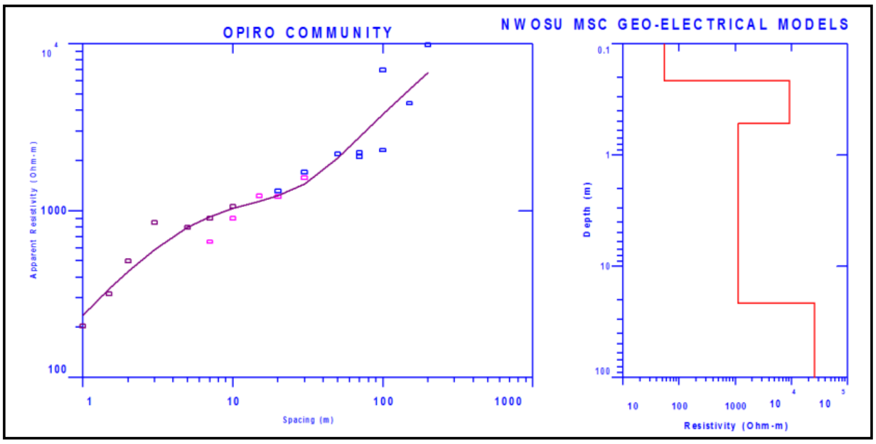

Figure 5 Resistivity profile with respect to subsurface depth of Opiro community

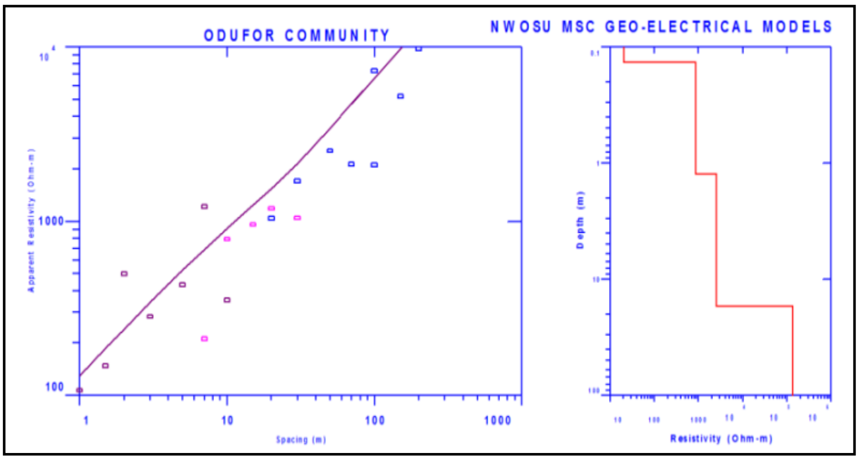

Figure 6 Resistivity profile with respect to subsurface depth of Odufor community

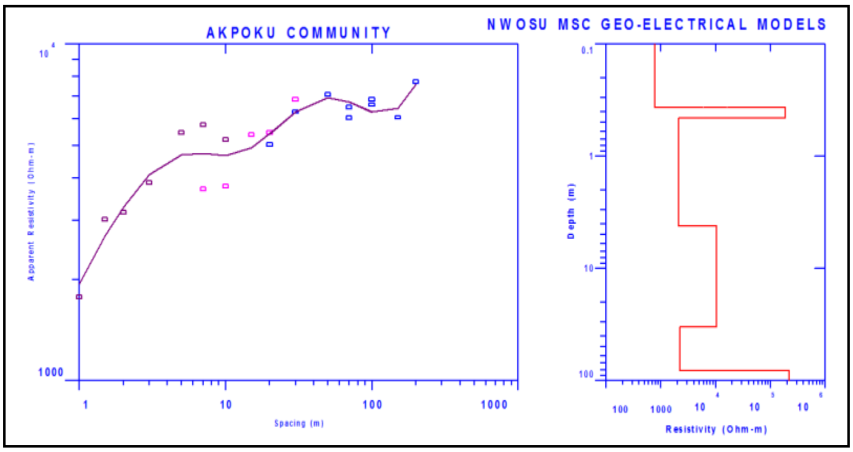

Figure 7 Resistivity profile with respect to subsurface depth of Akpoku community

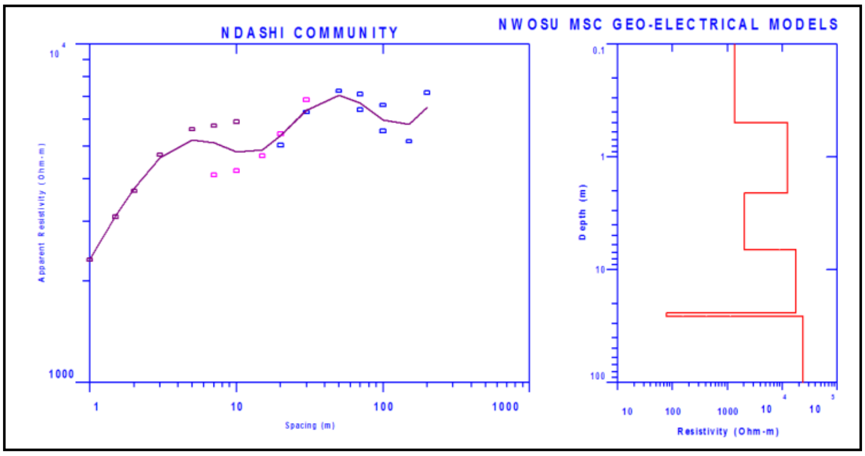

Figure 8 Resistivity profile with respect to subsurface depth of Ndashi community

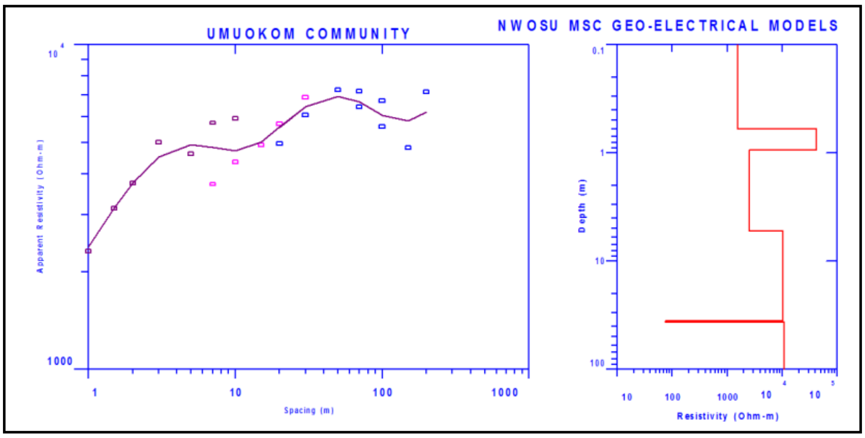

Figure 9 Resistivity profile with respect to subsurface depth of Umuokom community

3.2. Discussions of Geo-electric Sections

Geophysical data (vertical electrical sounding) was acquired from eight different communities of the study area. The data were processed with an ID Interpex software and interpreted in order to review certain geophysical characteristics of the subsurface rocks. Quantitative evaluation done on the resistivity data reviews that figure 2, 3, 5 and 6 have an A type curve while figure 4, 7, 8 and 9 have a KH type curve. A summary of the resistivity characteristics, the formation type prevailing the aquifer zone, the curve type, depth and the different communities in which the survey was carried out can be found in Table 9.The half current electrode spacing is 200m and was able to investigate stratigraphic units include clay, silt, silty sand, fine sand, medium sand, coarse sand and gravel.

Potential aquiferous beds were observed at a depth greater than 30.8m, 81.1m, 17.0m, 21.6m, 39.1m, 47.7m and 37.2m with respective resistivity values of 1081.5Ωm,2384.1Ωm, 2200.9Ωm, 1345Ωm, 2566.8Ωm, 5776.1Ωm, 5101.5Ωm and 5634.2Ωm (figure 2,3,4,5,6,7,8 and 9). The aquiferous zones have lithologic units such as medium sand, coarse sand and gravel. These sorts of lithologies with high resistivity values denote good porosity, permeability and high water saturation (freshwater). Some of the aquifer formations are capped by a clay seal, preventing fluid migration to other bed units within the formation and thereby, making the subsurface layer a potential aquifer formation able to accumulate and accommodate large quantity of pore fluids that has the ability to release these fluids when a well is drilled through it for groundwater exploration activities.

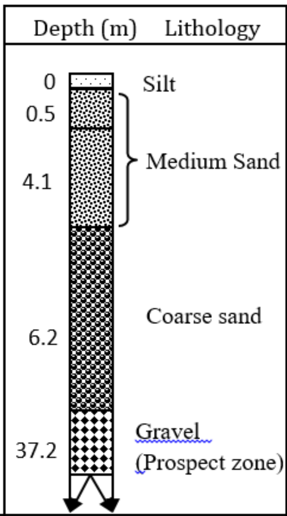

Figure10: A geoelectric section of Egwi community

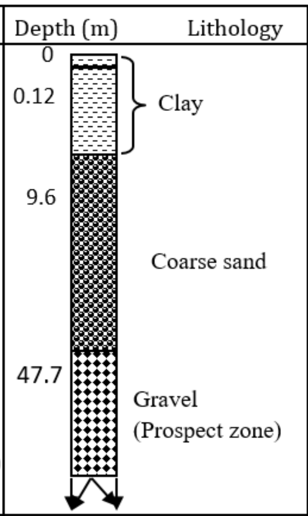

Figure11: A geoelectric section of Ulakwo community

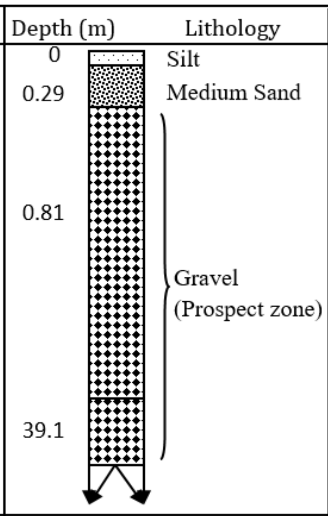

Figure12: A geoelectric section of Okehi community

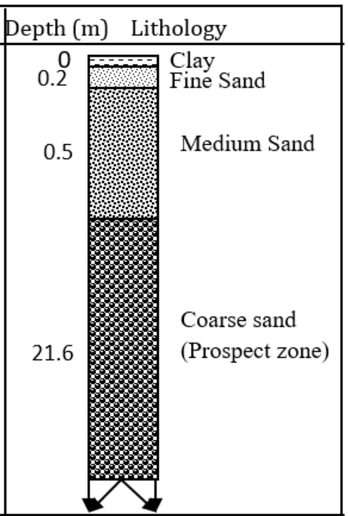

Figure 13: A geoelectric section of Opiro community

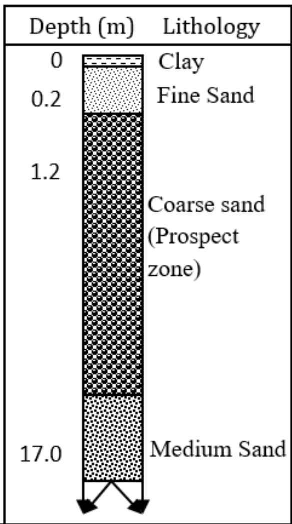

Figure14: A geoelectric section of Odufor community

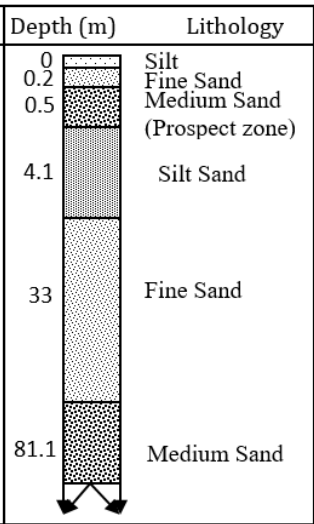

Figure 15: A geoelectric section of Akpoku community

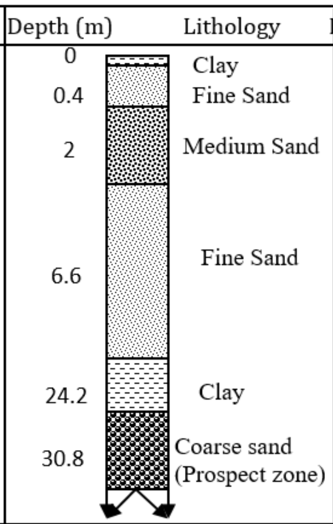

Figure 16: A geoelectric section of Ndashi community

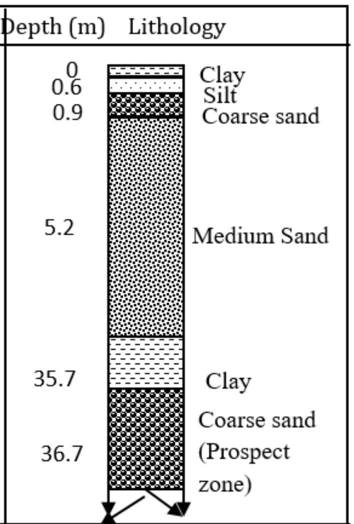

Figure 17: A geoelectric section of Umuokom community

4. Conclusion

The application of geophysical method i.e vertical electrical sounding in the exploration and exploitation of subsurface groundwater contain within potential aquifer formations in the study area has been efficient and effective.

The method was used to investigate subsurface parameters like depth to aquifer formation, resistivity trends as depth increases, thickness of medium, curve type, etc. All these subsurface parameters were used to do a quantitative and qualitative interpretation of the aquiferous units existing in the area in order to understand their geologic properties. These in effect would be used as a guide for citing a borehole in the area and to know at what depth at the subsurface screening can be done during casing of the well so as to all the influx of freshwater into the well bore.

The application of Schlumberger array configuration in investigating subsurface aquiferous units in the study area is brilliant but not enough. Therefore, it is recommended that an ideal of a data from a drilled borehole be introduced to this study so as to have a profound knowledge and views about the grain size, sphericity, roundness, parking, etc. These characteristics could be used to know the dominant grain size existing in these aquifers and characterize them appropriately.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The Authors declares that there is no conflict of interest.

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