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DC Resistivity Survey Of Groundwater Prospecting In Agbura, Bayelsa, Niger Delta, Using Schlumberger Electrode Configuration

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Abstract
Vertical electrical resistivity survey was carried out at Agbura in Bayelsa State to investigate the groundwater potential of the area. ABEM Terrameter SAS-1000 was used, employing Schlumberger Electrode Configuration. Maximum half-current electrode spread AB/2 of 1 m to 133 m was used while the potential electrodes separation MN/2 was maintained between 0.25 m to 5.00 m. The VES curve was quantitatively interpreted by computer iteration techniques using IP2Win computer software. The result of the interpreted geo-electric survey delineated a cross-section of six geo-electric units before the seventh infinite layer goes to infinity hence its geo-electric parameters are considered artefacts. The model and layer parameters showed a first layer with high resistivity of 480 Ωm which can be attributed to an artificial, relatively compacted topsoil. The second layer comprises mainly silty-clay with resistivity of 120 Ωm and 4.4 m thickness extending to a depth of 6.0 m. The third layer is comprised of clay with resistivity 72Ω m and 8.3 m thickness extending to 14.3 m depth. The fourth layer which is the first aquifer is composed of sandstones with resistivity 408 Ωm and thickness 9.6 m extending to 23.9 m depth. The fifth layer is comprised of silty-clay with resistivity 98 Ωm and thickness 7.2 m extending to 31.1 m depth and act as a seal between the fourth and sixth layers. The sixth layer is the second aquifer characterized with sandstone with resistivity 458 Ωm and thickness 11.8 m extending to 42.9 m depth. The water at these depths of the delineated aquifers can be harnessed by sinking of borehole to solve the water problem of the community.

Keywords: *Resistivity, Aquifer, Geo-electric, Groundwater, Schlumberger*

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I. Introduction

Electrical resistivity method is geophysical survey method widely used for groundwater prospecting[6,3,5,15]. The direct current electrical resistivity method is useful in providing information on depths of the subsurface ranging from a few meters to hundreds of meters beneath the surface. It can be used to solve hydro-geological problems, including determining the location and extent of groundwater aquifers[4], estimate the hydraulic parameters of aquifers[5] and monitoring of aquifer recharge ponds[13]. The objective of this electrical resistivity survey was to study the groundwater aquifer and understand the resistivity framework and distribution within the study area. In addition to above objective, the study also aimed at determining the depth and thickness of the aquifer and saturated zone for future possible drilling of boreholes for groundwater extraction. Groundwater is the water existing beneath the subsurface and can be harnessed by drilling boreholes and hand dug wells.

II. Literature Review

Groundwater can be found in pore spaces in all rocks types and its flows are usually influenced by interconnectivity of pore spaces and other sedimentary structures. The flow in igneous and sedimentary rocks is majorly controlled by induced tectonic structures which include faults, joints and fractures[10].

Apart from climate change, other factor that has dominant and significant effect on groundwater resource in the Niger Delta is geology[18]. The ease of groundwater withdrawal, quality and the other factors involved with distribution of groundwater within the Niger Delta region are linked to the geology[8]. When rain falls, water may be evaporated from the earth surface, flow along the earth surface or seeps down through the pore spaces of the earth's mantle. This water can be held below the earth's surface at depths where all the pore spaces in the soil or rock are filled with water known as saturated zone where groundwater is found. When water seeps into the ground, it enters into the unsaturated zone, which is held in voids between particles by capillary forces. Once the voids are filled, the water is free to descend under the effect of gravity. As long as there is enough water to maintain saturation, the water will descend until it is stopped by some impervious layer, such as rock or highly impervious clay. The water can then flow laterally through the void or rock crevices above the barrier. If there are significant differences in surface elevation, the water may flow along the impervious layer at some lower point known as a spring. If a hole is made vertically down into the saturated layer, water will flow into the hole. If the saturated layer has sufficient interconnected voids (opening) water will flow through it rapidly. When the saturated zone contains water in economic quantities, it is referred to as aquifer. The hole made into it could be developed into a well.

Aquifer

An aquifer is an underground formation of permeable rock or loose material which can produce useful quantities of water trapped by a well. It is typically saturated regions of the subsurface which produce an economically feasible quantity of water to a well or spring, (e.g., sand, gravel or fractural bedrock). In hydrologic terms, it is permeable layers of underground rock or sand that hold or transmit groundwater below the water table that will yield water. The permeability of an aquifer usually is in excess of 10 - 15 m/s. But a formation having a permeability of less than 10 - °m/s is termed impermeable and is called aquiclude. It is a solid, impermeable area beneath an aquifer. Examples are shales and clay.

Geology of the Study Area

The Niger Delta region is located in the southern part of Nigeria, between longitudes 3-9° E and latitudes 4°31′-5°20′N and lies in the humid tropics[14]. The Niger Delta basin began to form in the Cretaceous when the African plate separated from the South American plate.

The Cenozoic Niger Delta basin, a wave dominated arcuate – lobate tropical delta is an extensional rift basin located on the passive continental margin of the Gulf of Guinea, near the western coast of Nigeria, equatorial West Africa[12]. When viewed from the Gulf of Guinea to the Chad basin, the Niger Delta forms a SW – NE trending continuous strip of Mesozoic to Recent deposits resting on the Pan Africa mobile belt of West Africa. It is bounded on the North by the Benin flank and the Anambra basin; the Abakaliki high to the North-East, the Cameroon Volcanic line to the East, the Dahomey Embayment to the West and the Gulf of Guinea to the South and South West by the 4000m bathymetric contour[9]. Figure 1 shows the stratigraphic column for the three formations of the Niger Delta.

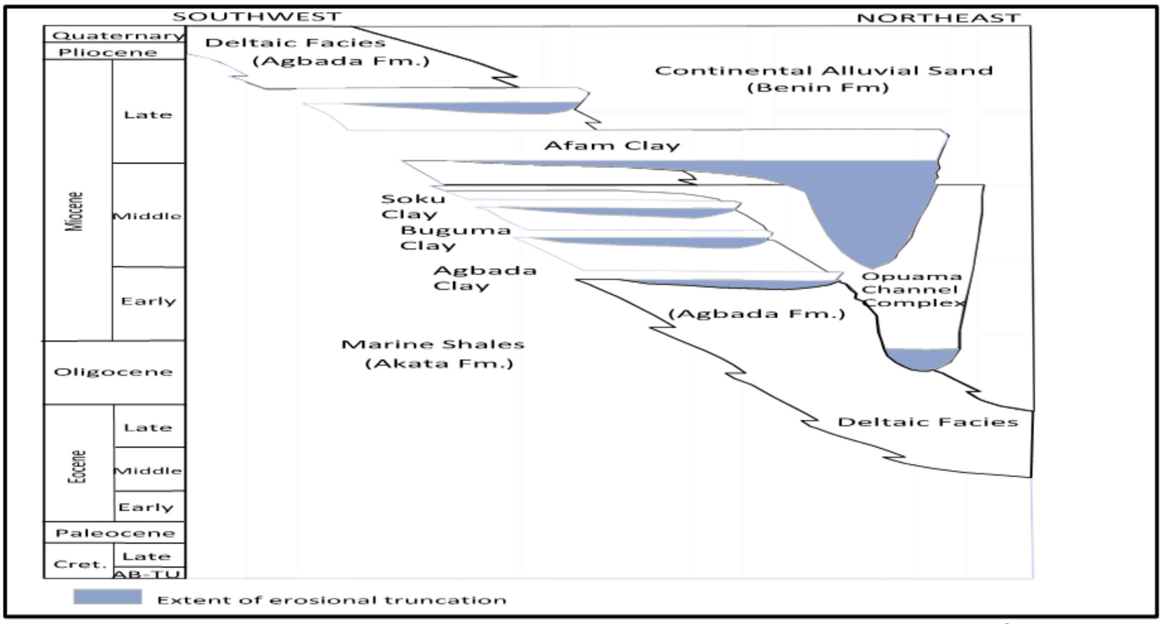

Figure 1: Stratigraphic column showing the three formations of the Niger Delta[2]

Climate and Vegetation

Vegetation is an assemblage of plant species and the ground cover they provide. Rainfall amount varies from low to high during the dry and the wet seasons, respectively. Rainfall amount is greater than 3000 mm per annum[11]. Temperature rarely exceeds 34 °C and is influenced by the prevailing climatic conditions[11]. Low and high temperatures are experienced during the rainy and dry season, which range from as low as 24 to 34 °C.

III. Materials And Methods

Electrical resistivity survey involves measurement of apparent resistivity of soils and rock as a function of porosity, ionic content of the pore fluids, permeability and clay mineral in the subsurface. Resistivity survey for search of groundwater is a pre-drilling geophysical technique and important information about the survey area such as estimates of drill depths, the type of geological formation and the viability of the project at that area helps in proper management of time and materials.

For data collection, the ABEM Terrameter SAS 1000 resistivity equipment was used which is a compact digital resistivity meter that comprises a transmitter and receiver function packed in one unit. The instrument has a light weight, it is highly sophisticated and it takes consecutive resistivity values in several cycles, averaging the values obtained at each cycle to give a final resistivity[7]. It comprises a battery, a deep penetration resistivity meter with an output sufficient for a current electrode separation of 200m under good survey conditions. Other instrumentations for survey are measuring tape, cello tape, cables, recording sheets, hammers and electrodes.

Principle of operation of the ABEM Terrameter SAS 1000

Vertical Electric Sounding (VES) explores the area of ground lying between the potential electrodes M and N (figure 2). It can therefore measure resistivity as a function of depth by progressively increasing the distance the current electrodes A and B (figure 2). Direct current resistivity measurements were carried out by transmitting controlled amounts of current (I) through two current electrodes transmitted into the ground while measuring the potential (U) between the two potential electrodes. Maximum half-current electrode spread of up to was used, while the half potential electrode separation was maintained. The systematic increase in the distance between current electrodes, provide information on subsurface resistivity from successively greater depth. The variation of resistivity with depth is modeled using forward and inverse modeling computer software.

The VES curves were quantitatively interpreted by computer iteration techniques, using IP2WIN software, a computer program based on linear filter theory. The potential difference to the ground ratio was displayed by the Terrameter as resistance. A geometric factor in meter was calculated as a function of the electrode spacing. The resistance readings obtained from the Terrameter was multiplied by this factor to give an apparent resistivity value.

The resistance, R is estimated using Ohm's Law:

$$R = \frac{V}{I}. \qquad (1)$$

Where R is the electrical resistance, V is the potential difference and I is the current

The material parameter resistivity (ρ), which is the inverse of electrical conductivity (б), is related to the resistance via a geometric factor. The resistance is also proportional to the cross sectional area and the distance between the electrodes. The relationship is given by:

$$R = \frac{\rho L}{A} = \frac{V}{I}. \qquad (2)$$

Data from resistivity surveys are represented by apparent resistivity which takes into account, the arrangement and spacing of electrodes. From the relationship above, the potential at any point is given by

$$V = \frac{\rho I}{2\pi r}. \qquad (3)$$

Where V is the potential difference in volts, ρ is the resistivity of the medium and r is the distance from the electrode.

Schlumberger Electrode Configuration

Schlumberger electrode configuration was used in this study to harness the groundwater potentials in the area. This configuration is most widely used in electrical prospecting and is used for vertical electrical sounding (VES). Four electrodes are placed along a straight line on the earth surface such that AB>MN[16]. In the Schlumberger configuration, the spacing between the potential electrodes 'a' is fixed (figure 2), while the current electrodes are progressively increased during survey causing the current lines to penetrate to increasing greater depth. The spacing of the potential electrodes "a' is adjusted, when necessary, because of decreasing sensitivity of measurement of potential. In this arrangement, the current and potential electrodes have a common mid-point but the distance between adjacent electrodes are different.

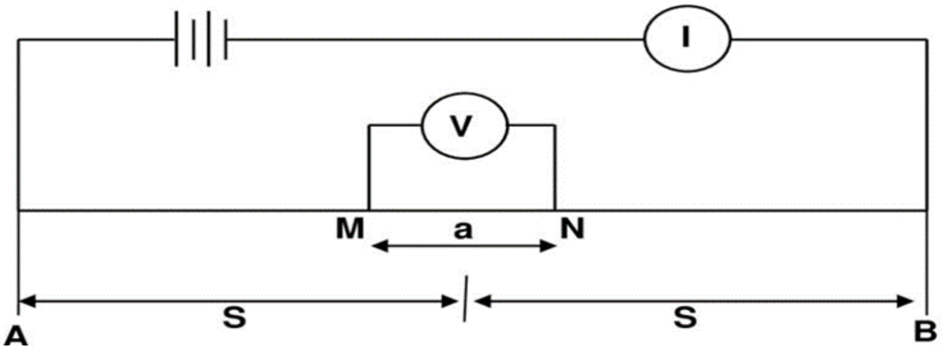

Fig 2 Schlumberger array.

From the figure 2

$r_1 = r_4 = AM = NB = \frac{L-a}{2}$ and $r_2 = r_3 = \frac{L+a}{2}$ = AN = MB

The apparent resistivity

$$\rho_a = \frac{2\pi\Delta V}{I}\left[\frac{1}{\left|\frac{2}{L-a}-\frac{2}{L+a}\right| - \left|\frac{2}{2-a}-\frac{2}{L+a}\right|}\right] \tag{4}$$

$$\rho_a = \frac{\pi\Delta V}{4\,I}\left[\frac{L^2-a^2}{a}\right] \tag{5}$$

For $L^2 \gg a^2$

$$\rho_a = \frac{\pi L^2 \Delta V}{4\,Ia} \tag{6}$$

IV. Results

Vertical Electrical Sounding (VES) was carried out to investigate groundwater potentials, determine the geo-electric and hydrogeological characteristics of aquifer in the study area. Maximum half-current electrode spread (AB/2) of 1.0 m to 133.0 m was actualized, while maintaining a half-potential electrode separation (MN/2) between 0.25 m and 5.00 m. Aquifer characterization involves investigating the subsurface geo-electric profile of a site, to achieve this, a single VES station was occupied closest to the intended drilling point and 1-D data acquired using the Schlumberger array (Table 1).

Table 1: Raw geo-electric field data

AB/2	MN/2	K	R (Ωm)	KR (Ωm)
1	0.25	6.28	25.73	161.5844
1.3	0.25	10.62	13.21	140.2902
1.8	0.25	20.36	5.53	112.5908
2.4	0.25	36.19	2.82	102.0558
3.2	0.25	64.34	0.46	29.5964
4.2	0.25	110.85	0.28	31.038
4.2	1	27.71	8.75	242.4625
5.5	1	47.52	3.78	179.6256
7.5	1	88.36	1.23	108.6828
10	1	157.08	0.24	37.6992
13	1	265.47	0.18	47.7846
13	2.5	106.19	0.87	92.3853
18	2.5	203.6	0.27	54.972
24	2.5	361.91	0.06	21.7146
32	2.5	643.4	0.05	32.17
42	2.5	1108.35	0.04	44.334
55	2.5	1900.66	0.03	57.0198
55	5	950.33	0.01	9.5033
75	5	1767.16	0.02	35.3432
100	5	3141.59	0.04	125.6636
133	5	5557.16	0.06	333.4296

Data obtained was used to generate a geo-electric model of the area using IP2Win software to obtain a geo-electric curve and model parameters of the profile. The resultant curve and parameters obtained are presented in Fig. 3 and Table 2.

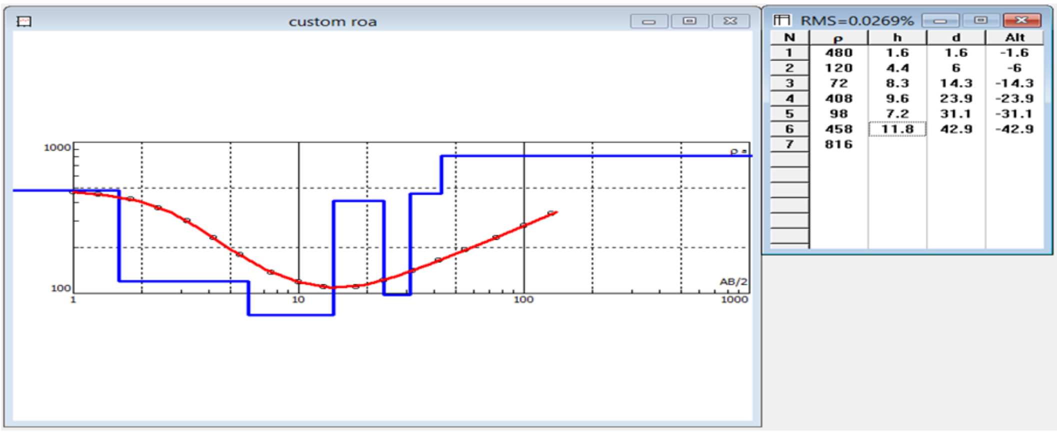

Fig. 3: Geo-electric model generated for VES data

Table 2: Geo-electric layer parameters

Layer	ρ_a (Ωm)	Thickness (m)	Depth (m)	Lithology
1	480	1.6	1.6	Topsoil
2	120	4.4	6	Silty clay
3	72	8.3	14.3	Clay
4	408	9.6	23.9	Sandstone
5	98	7.2	31.1	Silty clay
6	458	11.8	42.9	Sandstone
7	**816**	∞	∞	

Figure 4 shows a schematic of the geo-electric layers in the study area showing target aquifer

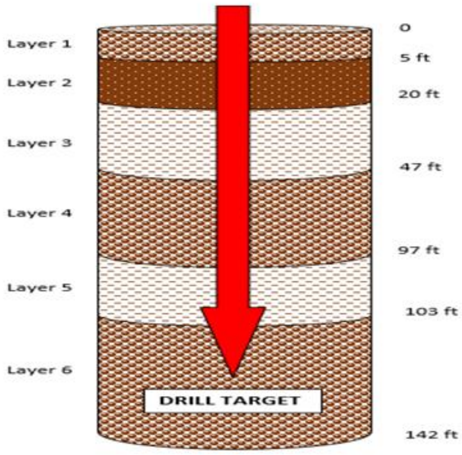

Fig. 4: Schematic of Geo-electric layers showing target aquifer

V. Discussion

The study area is located at Agbura, Yenagoa Local Government area of Bayelsa State, Niger Delta Nigeria. The result of the geo-electric survey delineated a cross-section of six (6) geo-electric units before the seventh (7th) infinite layer (the seventh layer goes to infinity hence it's geo-electric parameters are considered as artefacts), the section represents a QHKH curve type. Model and layer parameters showed a high resistivity of 480 Ωm which can be attributed to an artificial, relatively compacted soil material. The second layer is composed mainly of silty clay with a resistivity of 120 Ωm, it has a thickness of 4.4 m (15 ft) extending to a depth of 6.0 m (20 ft). The third layer is comprised of clays, it has a resistivity of 72 Ωm and thickness of 8.3 m (27 ft) extending to a depth of 14.3 m (47 ft). The fourth layer is the first aquifer. It is composed of sandstones, it has resistivity of 408 Ωm and thickness of 9.6 m (32 ft) extending to a depth of 23.9 m (97 ft), The fifth layer is composed of silty clay, it has a resistivity of 98 Ωm and a thickness of 7.2 m (24 ft) going to a depth of 31.1 m (103 ft), it acts as a seal between the fourth layer which is the first aquifer above and the sixth layer below. The sixth layer is the second aquifer in the area. This layer has a resistivity of 458 Ωm characteristic of sandstone with a thickness of 11.8 m (39 ft), extending to a depth of 42.9 m (142 ft).

The geo-electric sections reveal that the aquiferous units occurs at the fourth and sixth layers respectively which are mostly confined, with depth of about 23.9 m (97 ft) for the fourth layer and depth of 42.9 m (142 ft) for the sixth layer. Figure 3 shows the schematic of geo-electric layers showing target aquifer.

VI. Conclusion

In conclusion, the result from the investigation primarily delineated six stratigraphic layers: The geo-electric sections reveal that the aquiferous units occurs at the fourth and sixth layers respectively which are mostly confined, with depth of about 23.9 m (97 ft) for the fourth layer and depth of 42.9 m (142 ft) for the sixth layer. Figure 4 shows the schematic of geo-electric layers showing target aquifer. This implies that before sinking a borehole in this area, it should be drilled to such depth range. This column may be regarded as saturated zone. Based on lithologic and/or geohydrologic model, this column is made up of fractured, saturated sandstone and silty clay. The groundwater of this area under investigation is promising for borehole development. VES have proven to be very reliable for underground water studies and can be used for shallow and deep underground water geophysical investigations.

These results are important for future groundwater exploration in the study area and can help in localizing drilling water wells in the area. Understanding the lateral extent of the groundwater aquifer and the depth to the water-saturated zone (aquifer) will minimize the costs and time required for drilling. Such investigations are recommended for any hydrogeological characterization studies.

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