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Research Article

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Aquifer Zones in Parts of Bayelsa State of Nigeria from VES

Peter O. Eke*, Lebura Teegha

Ignatius Ajuru University of Education, Port Harcourt, Nigeria
*Corresponding Author: Email: peter.eke@iaue.edu.ng

Abstract Bayelsa State is one of the fastest growing states in Nigeria in terms of population and industrialization. The presence of oil and gas has made this possible and has resulted in urbanization problems such as shortage of portable water. Ten VES using the Schlumberger array method were carried out in Alieberi, Ewegbene, Kanan, Sagbama, Tombia-Ama, toru, Toru Nduru and Berger Road all in Yenagoa, Sagbama and Ekeremor local governments of Bayelsa State. A maximum potential electrode spacing of 1,000 m with corresponding current electrode spacing were used to obtain the apparent resistivity of the subsurface Formations. This was plotted against the current electrode and interpreted using IP12WIN software to obtain the Formations true resistivity, thickness, depths and then infer the aquifer zones in the region. The results show that for the surveyed area; the average depth of top soil is 0.45 m, the average depth to near surface aquifer is 4.5 m, and the aquifer thickness range from 23m to 127 m with an average thickness of 50 m. The true resistivity of the aquifer formations range from 7 to 148 Ωm with an average of 115 Ωm and are mostly sandstones. Thus, good aquifers with high resistivity in the region can be found at depths of25 m and deeper.

Keywords Resistivity, Formations, ground water, geoelectric section, sandstones, Schlumberger array

1. Introduction

Several cities in Nigeria experience shortages of domestic water supply due to inadequacy of potable water. Bayelsa State is facing this problem due to rapid urbanization, increasing population, agricultural and industrial activities [1]. The availability of portable water has decreased from 10 liters person per day in 1994 to 5.5 liters per person per day in 2000 in this region according to [1]. This is a major challenge as water is essential to life.

Bayelsa State is in the Niger delta region of Nigeria. It is a wetland with all the surface water bodies in the state polluted because of hydrocarbon exploration activities [2]. However, it is blessed with large quantity of groundwater from shallow aquifers, and yet is still burdened by the inadequacy of potable water to the people. Groundwater is the main source of potable water in this region, as it is less prone to contamination as a result of its natural filtration and is tapped mostly by blind borehole drilling. According to [3], the state has no functional central potable water supply systems. The main source of domestic water is untreated water from indiscriminately cited private and commercial boreholes. The dangers posed by this blind drilling of boreholes according to [4] include over abstraction which exposes the upper aquifer and allows intrusion/suction of un-managed surface wastewater into the deep ground water aquifer, causing ground water contamination. Also the underground strata/geological formation get loosen as a result of the constant water abstraction/mining and after the exclusion of water from soil, the underground stratification is exposed to earth quakes/jolts. With time, the constant/over abstraction depletes the water table which adversely impacts on the local biodiversity and ecology of the area.

For proper management of water resources, borehole sites must be such to reduce the above risks and this require knowledge of aquifer characteristics as aquifer zones/depths, porosity, permeability and transmissivity.

A good aquifer must have high porosity, high permeability, transmissivity and at good depths to avoid contamination. These values can be determined from geophysical surveys from which a plot of resistivity values will indicate zones of high and low resistivity or zones of different groundwater potential at given depths underground.

In this work VES has been carried out in satellite cities of Aleibiri, Ewegbene, Kanan, Sagbama Tombia and Turuof Bayelsa State to determine some aquifer characteristics and zones of the region for better water management of the area.

2. The Study Area

The study area (Fig.1) is situated between latitudes 4°48′ and 5°8′ North and Longitudes 6°6′, and 6°30′ East, in south-south of Nigeria. The area is within three local governments of Yenagoa, Sagbama and Ekeremor of Bayelsa State. There are network of roads that links the different parts of the area and its environs.

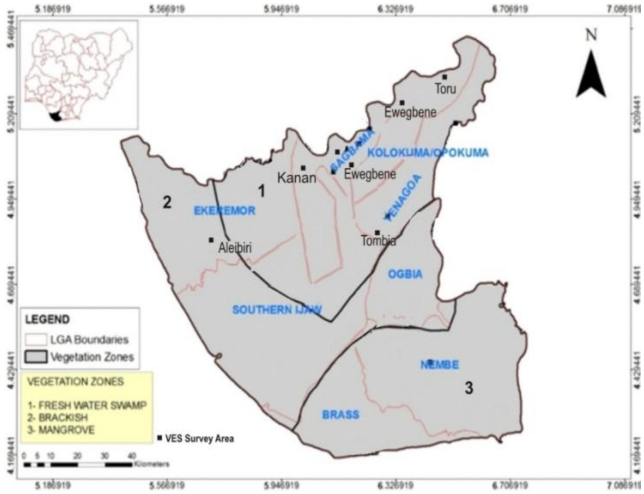


Figure 1: Map of Bayelsa State showing the study areas, modified from [5]

The topography of Bayelsa State shows that the land surfaces lie between I2 m and I5.5 m above sea level [6]. The plains are deltaic and lie below 2.5 m and form the main drainage system of the state. At high tide a considerable land area of the state is under water. The area is mainly drained by the Ogbia and the Ekoli creeks with three vegetation zones of Water Swamps, Brackish and Mangrove Swamps.

The State is south of the Niger Delta whose structure and stratigraphy has been discussed by several authors [7]. According to [8], the entire Niger Delta topography is characterized by creeks and swamps, crisscrossing low lying plains in varying dimensions that empty into the Brass River. Three major Formations; Benin, Agbada, and Akata formations have been identified by several authors.

The Benin Formation is the aquifer zone usually composed of thick and extensive sand and gravels. The sand and sandstones of this Formation are coarse to fine, commonly granular in texture and can be partly unconsolidated. The sands may represent upper deltaic plain deposit and/or braided stream point bars and channel fills [9]. Two types of aquifer have been identified by [10]; the first of Holocene age, is more prolific and extends to about 60 to 90 m (unconfined) while the second of Oligocene age is less prolific and underlies the first.

The Shales are few and thin and may represent back swamp deposits [11]. It is overlain by quaternary deposits, 40 to I50 m thick, and generally consists of rapidly alternating sequence of sands and silty clays with the latter become increasingly more prominent seawards [11]. The clayey intercalations within the Benin Formation have given rise to multi- aquifer system in the area [10] and [11]. Multi-aquifer systems have also been identified from lithology logs of boreholes from other parts of the Niger Delta by [12].

3. Methodology

Ten VES data were collected from the locations marked in Fig. 1 using the Schlumberger array method of electrode spacing. A maximum of 1,000 m potential electrode spacing was used and the current electrode adjusted accordingly. An ABEM Tetrameter was used to record the resultant resistance, R in ohms, and the apparent resistance, ρ_a , obtained from [13] as

$$\rho_a = \pi R[\frac{s^2}{a^2} - \frac{a}{4}] \tag{1}$$

s (m) is half the current electrode spacing and a (m) is the potential electrode spacing. The apparent resistivity values were inverted using IP12WIN resistivity sounding interpretation software to obtain the true resistivity, thickness and depths of the subsurface formations.

4. Result and Discussions

In Aleibiri location, four geo-electric layers were determined with characteristic curve layer type of $P_1>P_2>P_3<P_4$ (Fig. 2). The resistivity values varied from 0.737- 317Ωm with thickness range of from 0.737-12.3m. The uppermost layer is interpreted as clay sandstone and the top soil with a thickness of 0.737m and high resistivity value of 317Ωm. The second layer is 1.36m thick and consists of sandstones and is considered as a poor aquifer unit with resistivity value of 20.2Ωm. The third layer is 12.3m thick with low resistivity value of 6.4Ωm and consists of clayey soil.

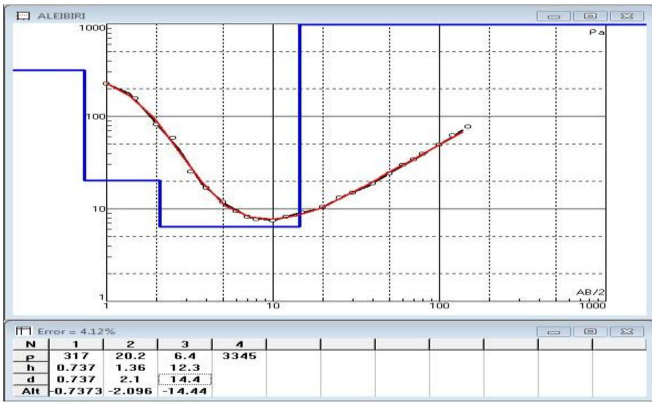


Figure 2: Apparent Resistivity versus Half-Current Electrode Spacing Curve for Aliebri

In Aleibiri 1 location, five geo-electric layer were determined with characteristic curve type of $P_1>P_2>P_3>P_4<P_5$ (Fig 3). The resistivity values range from 6.744 - 339.1 Ωm with thickness of 0.583-23.51m. The uppermost layer with thickness of 0.583m is interpreted as sandstone. The second layer with thickness of 0.7321m and resistivity of 67.81Ωm is interpreted as clay-sandstone. The third layer with sandstones and high resistivity of9.142Ωm and thickness of 3.134m and the fourth layer with resistivity value of 6.744 Ωm and thickness 23.51 m are interpreted as water saturated zones, as well as the aquifer units.

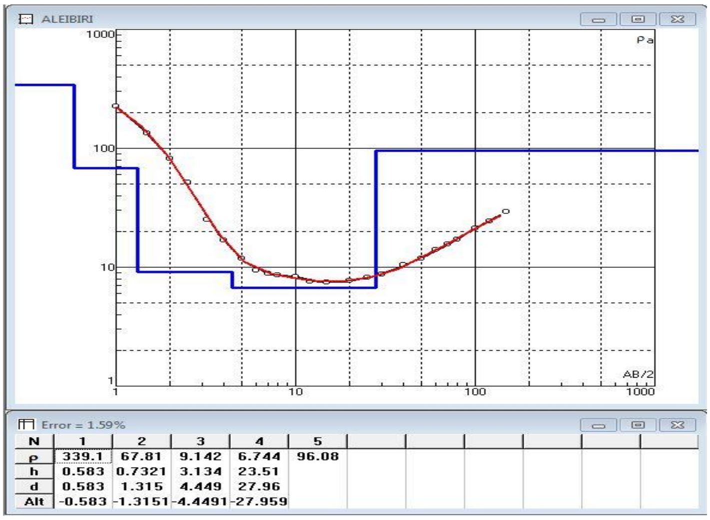
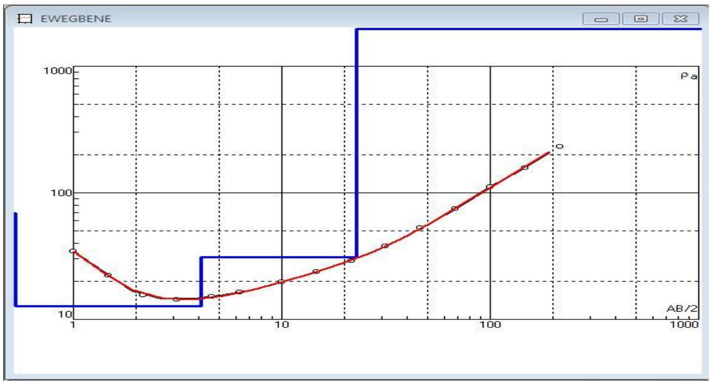


Figure 3: Apparent Resistivity versus Half-Current Electrode Spacing Curve for Aliebri 1

In Ewegbene location, four geo-electric layer were determined with characteristic curve type of $P_1>P_2<P_3<P_4$ (Fig 4). The resistivity in this location varies from31.14 - 69.22 Ωm and the thickness between 0.4313 - 18.77m. The upper layer with thickness of 0.4313m is interpreted as sandstones. The second layer which is 3.654m thick consists of clay with resistivity of 12.79Ωm. The third layer is composed of sandstones of 18.77m thickness and high resistivity value of 31.14Ωm. The high resistivity y and low conductivity of the formation is interpreted as water saturated zone and a good aquifer.



Error = 0.979%

N	1	2	3	4
ρ	69.22	12.79	31.14	7301
h	0.4313	3.654	18.77	
d	0.4313	4.085	22.86	
Alt	0.4312	-4.0848	-22.858	

Figure 4: Apparent Resistivity versus Half-Current Electrode Spacing Curve for Ewegene

In Kanan location, four geo-electric layers where delineated with characteristic curve $P_1< P_2>P_3>P_4$ (Fig 5). The resistivity of this location varied between 55.8Ωm to 148Ωm and thickness within 0.44 - 41.9m. The upper layer with resistivity 55.8Ωm and thickness 0.44m is interpreted as sandstones. The second layer has a resistivity of 648Ωm and thickness 7.65m. The third layer consists of high resistivity of 148Ωm and thickness of 41.9m. The high resistivity indicates low conductivity and is interpreted as a good aquifer unit.

Error = 3.42%

N	1	2	3	4
ρ	55.8	648	148	0.268
h	0.44	7.85	41.9	
d	0.44	8.29	50.2	
Alt	-0.4401	-8.293	-50.18	

Figure 5: Apparent Resistivity versus Half-Current Electrode Spacing Curve for Kanan

In Sagbama 1 location, six geo-electric layers were delineated with characteristic curve type $P_1< P_2>P_3<P_4>P_5<P_6$ (Fig 6). The resistivity of this location varies from 20.6 - 35.6Ωm and the thickness range of 0.402 - 56.3m. The resistivity value of 20.6Ωm and thickness 0.402 m is interpreted as sandstone, which is the upper topsoil. The second layer has a high resistivity of 3631Ωm and thickness 0.426m. The third layer, has resistivity of 1.56Ωm and thickness 3.31m and the fifth layer, has high resistivity of 35.6Ωm with thickness of 56.3 m. The high resistivity indicates low conductivity is interpreted as water saturated zone. The layer beneath consists of dry clay with resistivity of 0.189 Ωm whose bottom were not reached.

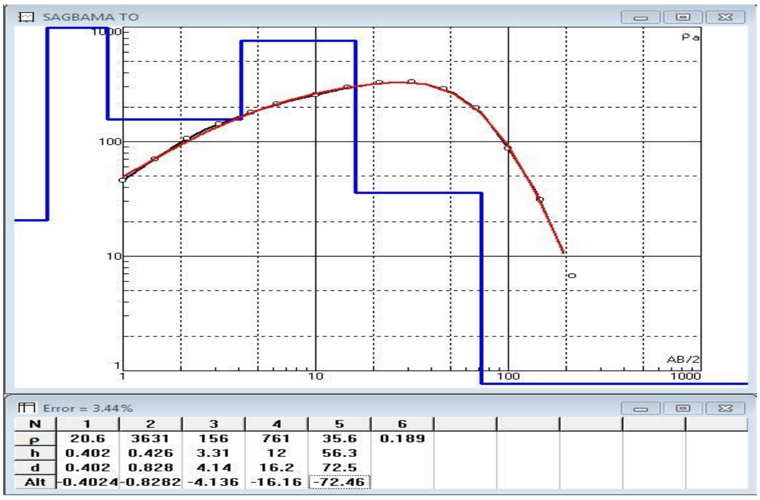


Figure 6: Apparent Resistivity versus Half-Current Electrode Spacing Curve for Sagbama 1

In Sagbama 2, four geo-electric layers were delineated with characteristic curve of $P_1<P_2>P_3>P_4$ (Fig 7). The resistivity of this location varies between 2.37Ωm and 84.5Ωm and thickness ranges of 0.344 - 127m. The resistivity value of 2.37Ωm and thickness 0.344 m represent the topsoil which consist of sandstone and clay soil. The second layer has resistivity of 20.64Ωm and thickness of 0.392m. The third layer, with high resistivity of 84.5Ωm and thickness value of 127m, indicates low conductivity and is interpreted as the good aquifer unit.

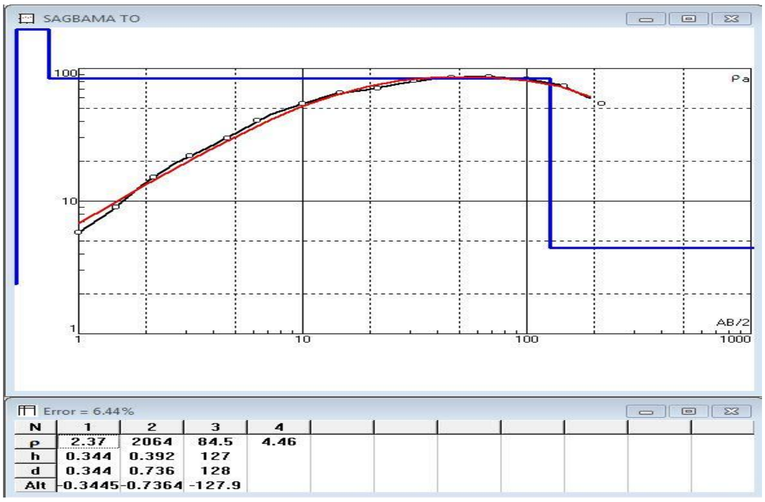


Figure 7: Apparent Resistivity versus Half-Current Electrode Spacing Curve for Sagbama 2

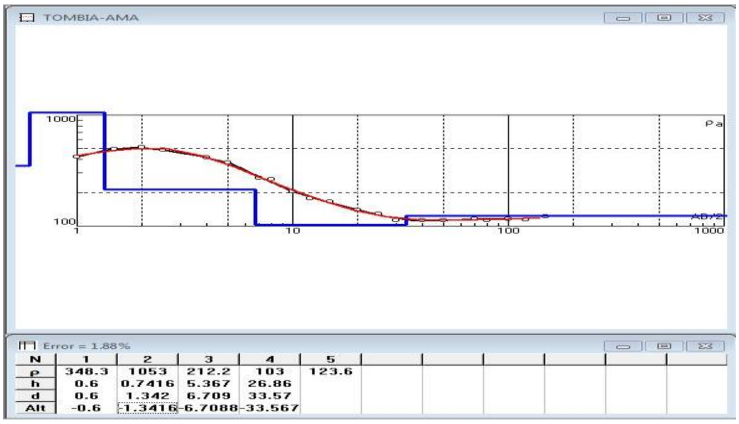


Figure 8: Apparent Resistivity versus Half-Current Electrode Spacing Curve for Tombia-Ama

In Tombia-Ama, five geo-electric layers were delineated with characteristic curve of $P_1< P_2>P_3>P_4<P_5$ (Fig 8). The resistivity of this location falls within 10. 3 - 348.3Ωm and thickness range of 0.6 - 26.86m. The resistivity

of 348.3Ωm with thickness 0.6m and resistivity value 105.3Ωm with thickness 0.7416, represent the topsoil which are clay sandstone. The third layer with resistivity of 212.2Ωm and thickness 5.367m consist of clay with saltwater. The fourth layer with resistivity value of 103Ωm and thickness 26.85 m is interpreted as freshwater saturated aquifer unit.

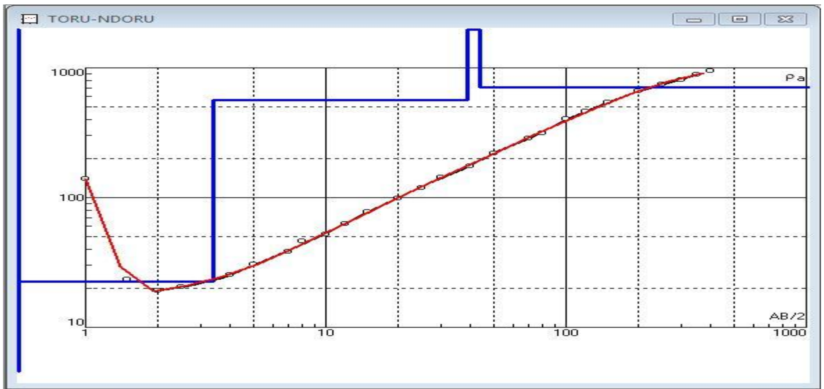
In Toru 2, four geo-electric layers were traced with characteristic curve $P_1>P_2<P_3<P_4$ (Fig. 9). The resistivity values of this location are between 1043Ωm and 226Ωm and thickness ranges of 0.564 - 32.6m. The topsoil which is the first sandstone layer has a resistivity of 1043 Ωm with thickness value of 0.564 m. The second layer has low resistivity of 24.3Ωm with thickness 4.67 m. The low resistivity is an indication of high conductivity which is interpreted as clay soil. The third layer, with high resistivity value of 226Ωm and thickness 32.8m is the good aquifer unit; this is because the high resistivity is an indication of low conductivity.

Error = 6.23%

N	1	2	3	4
ρ	1043	24.3	226	2.2E+5
h	0.564	4.67	32.8	
d	0.564	5.23	38	
Alt	-0.5636	-5.229	-38.01	

Figure 9: Apparent Resistivity versus Half-Current Electrode Spacing Curve for Toru 2

In Toru Ndru, five geo-electric when traced with characteristic curve of $P_1<P_2>P_3<P_4<P_5>P_6$ (Fig 10). The high resistivity values of this location falls between 4.281 and 60970Ωm with thickness range 0.2258 to 4.716m. The resistivity of layer one and two with values 4.281Ωm and 4.577m; thickness 0.2258m and 0.1835m represent the topsoil which consists of clay sandstone. The resistivity values of 22.56Ωm and 60970Ωm with thick 2.993m and 4.716m for the third and fifth layers consist of clay. The fourth layer with thickness 35.55m has a high resistivity value 565Ωm. The high resistivity indicates, low conductivity which is interpreted as good aquifer zone.



Error = 1.34%

N	1	2	3	4	5	6
ρ	4281	4.577	22.56	565	60970	703.1
h	0.2258	0.1835	2.993	35.55	4.716	
d	0.2258	0.4093	3.402	38.95	43.67	
Alt	-0.2258	-0.4093	-3.4023	-38.952	-43.668	

Figure 10: Apparent Resistivity versus Half-Current Electrode Spacing Curve for Toru Ndoru

In Berger Road, four geo-electric layers were delineated with characteristic curve $P_1>P_2<P_3<P_4<P_5$ (Fig 11). The upper layer is interpreted as clayey sandstone and is the topsoil with a thickness of 0.153m and resistivity value of 9.15Ωm. The second layer of 0.85m thick consists of clay with low resistivity value of 168Ωm. The third layer is 10.6m thick has a resistivity value of 22.2Ωm. The high resistivity indicates low conductivity and was interpreted as sandstones. The fourth layer has a thickness of 35.3 m and resistivity value of 34.5 Ωm. The low resistivity value indicates high conductivity and was interpreted as clay.

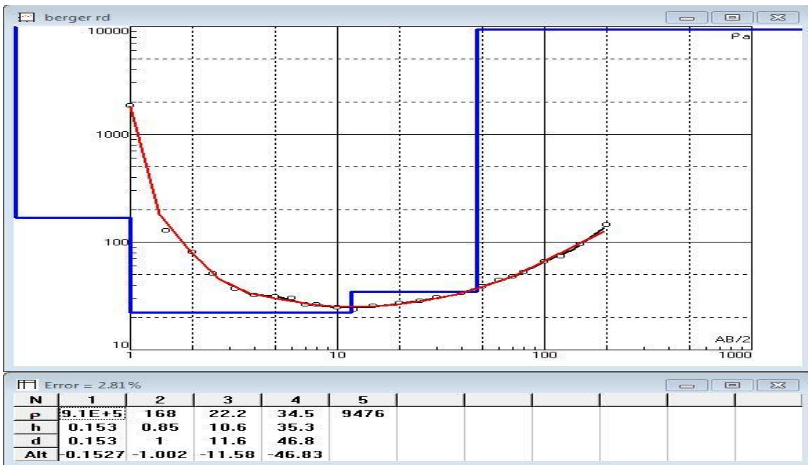


Figure 11: Apparent Resistivity versus Half-Current Electrode Spacing Curve for Berger Road

5. Conclusions

The results of the work show the following in this region; the average depth of top is 0.45 m, the average depth to near surface aquifer is 4.5 m, while the aquifer thickness ranges from 23 m to 127 m with an average of 50 m. The true resistivity of the aquifer formations range from 7 to 148 Ωm with an average of 115 Ωm. The region is also characterized with sand and shale formations as has been reported by several authors, with very near surface aquifers. Good aquifers with high resistance and thickness can be found in most parts of the study area at deeper depths of 30 m and more in the region. This can allow boreholes to be drilled at different depths within the same area.

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