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Correlation of Borehole Lithology Using Vertical Electrical Sounding (VES) Method for Groundwater Exploration in Part of Otuoke Bayelsa State Nigeria

P.P. Adejumo[1*], I.E. Ottih, A.N. Nwori[2]

[1,2]Department of Industrial Physics, Faculty of Physical Science, Chukwuemeka Odumegwu Ojukwu University Uli, Anambra State, Nigeria

[*]*Corresponding Author: patjumof@gmail.com, Tel: +234-7037269472*

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Abstract—In this work, the vertical electric sounding (VES) method was applied in parts of Otuoke Bayelsa State Nigeria and geoelectrical stratigraphy obtained correlates with the borehole lithology within the area for groundwater exploration and development. Five VES points with maximum and minimum electrode spacings of 350 m and l00 m respectively were used to determine the apparent electrical resistivity of the subsurface layers. The field resistivity sounding survey was carried out in these locations with an ABEM terameter (signal averaging system 1000). The field data obtained were interpreted using IP2 win computer software. The result of the interpreted VES data was used to correlate the drilled borehole logs which confirmed the following stratigraphy; sandy clay (19-584 Ωm), dry sand (77.2-737 Ωm), clay (2.44 Ωm) and saturated fine/coarse sand (3.65-566 Ωm) as an aquifer. Geophysical VES reports and borehole logs confirm that the area is a homogeneous formation consisting of the same lithological characteristics as sand and clay. The resistivity curve interpreted A, K and HK type curve layers. The available borehole lithology in the study area matches pretty well with the geoelectric stratigraphy. The results of our correlation revealed that almost all the five VES stations intercepted good aquifer zones for portable groundwater development in the area.

Keywords— Groundwater, Geoelectric layers, Schlumberger, Borehole lithology, Correlation

I. INTRODUCTION

Groundwater is abundant natural resources that serve as a source of drinking water because it can be referred to as fresh quality and less vulnerable to diseases and contamination [1]. The resistivity of a geological material can vary significantly depending on its porosity, water content and the concentration of salt in the groundwater.
This enables both quantifications of the water content material and estimation of the groundwater exceptional [2]. Understanding the high-quality of groundwater is as critical as its quantity because it's miles the principle factor determining its sustainability for home, agricultural and business purposes [3]. However, the resistivity of different materials is not unique. Resistivity of water may vary from 0.2 to over 100 Ωm depending on its ionic concentration and the amount of dissolve solids [4]. Resistivity of natural water and sediments without clay vary from 1 to 120 Ωm [5].

Over the last decade, Bayelsa state Nigeria, especially Yenagoa, the state capital city has witnessed a continuous influx of people and business activities due to its status as a state capital. Otuoke (the study area) has also fallen to this trend since it serves as a university community. Though surrounded by water, most parts of Otuoke lack the best water befitting for human consumption due to each natural and human activities [6]. The situation is further compounded by inadequate municipal water supply management, compelling most residents to depend solely on boreholes and hand dug wells for their domestic water supply. Otuoke is naturally placed within the transition area of the coastal sedimentary rocks. The effect is that the region has been taken for granted as a maintaining supply of abundant groundwater. To determine the aquifer characteristics of subsurface for groundwater exploration, the most commonly used method involve drilling borehole in the area then followed by soil and water sample analysis. These processes are quiet capital intensive and labour intensive as it requires drilling several boreholes and consequently time consuming. However, the alternative method to this early technique to estimating aquifer characteristics is the use of surface geoelectrical methods. These methods which involve mostly the Electrical resistivity and Electromagnetic method of investigation.Vertical Electrical Sounding method, a surface geoelectrical method of geophysical investigation that is interesting and less expensive technique used for locating depth of aquifer for groundwater exploitation. Vertical electrical sounding was adopted to correlate the geoelectric stratigraphy with borehole lithology in the study area. The VES is a non-invasive, cheap and quantitative evaluation technique, [7]. The aim of this work is to correlate the geoelectric stratigraphy with borehole lithology for groundwater exploration in the study area.

The study area lies between latitudes 4o 46' N and 5o 51' N and longitudes 6o 15 E and 6o 23' E [8] as displayed in figure 1. It is situated in the lower part of the upper flood plain deposits of sub-aerial Niger delta [9]. There are foremost climatic seasons inside the place, the moist season from April to October and the dry season from November to march. The average annual rainfall is set 3000 mm and this serves because the essential source of groundwater recharge. The Niger delta is a big and ecologically touchy region in Nigeria in which numerous water species together with surface and subsurface water bodies exist in a state of dynamic equilibrium [10]. Stratigraphically, the Niger delta is divided into Akata, agbada and Benin formations in order of decreasing age. The major aquiferous formation in this study area is Benin formation. It is the youngest and topmost unit. It extends from the west across the whole delta and southward beyond the coastline [11]. This unit is distinguished by its high sand percentage (70-100%) with minor shade intercalations and lack of microfauna characteristics [12]. It is about 2100m thick at the basin centre,[13]. The upper section of the Benin formation is the quaternary deposit which is about 40 to 120 m thick and comprise of sand and silt. The Benin formation is highly permeable, the sand are course grained, gravely and locally fine grained, poorly sorted, subangular to rounded and bears lignite streks and wood fragments. It is a continental deposit of probably upper deltaic environment the main source of recharge is through direct precipitation where annual rainfall is as high as 3000 mm [14]. The water infiltrates thru the pretty permeable sands of the Benin formation to recharge the aquifers. The groundwater in the study areas is known to occur basically beneath water table conditions [15].

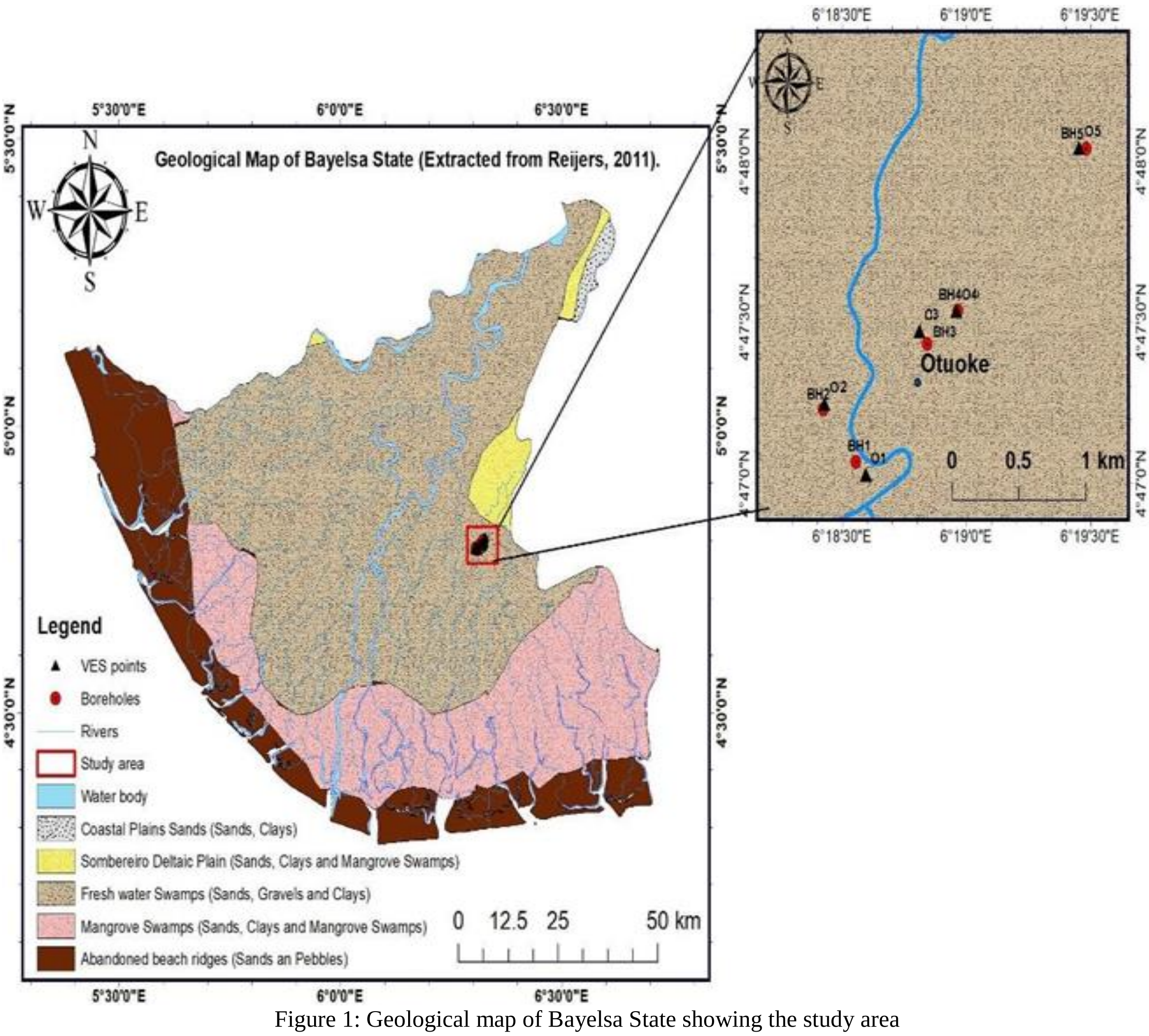


Figure 1: Geological map of Bayelsa State showing the study area

Figure 2: Photograph of drilled boreholes in the study area (a) BH_1 (b) BH_2 (c) BH_5 (d) photograph of people fetching water from the drilled borehole

II. RELATED WORK

The use of VES technique is one of the geophysical technique that have mostly used for groundwater exploration and many results have been achieved via the method. Vertical electrical resistivity soundings have been used by [16] to delineate groundwater potential aquifers in Akobo area of Ibadan, South western, Nigeria and correlated the obtained resistivity results with the existing lithology. Weathered and fractured horizons were identified in the study area underlying the VES stations, and all constitutee good aquifer zones for groundwater development in the area. Ref "[17]" reported the result of VES survey conducted in some parts of Kebbi State Nigeria using Schlumberger array and stated that weathered and fractured layers constituted aquiferous zone in all the stations surveyed in the area. They recommend that that boreholes can be sited in high conductivity zone as they contain probable aquifers at the depth between 15m to 30 m to advantage of basement fractures. Ref "[18]" used VES to delineate groundwater aquifer in parts of Anyigba in Kogi State Nigeria and recommended that the minimum depth for successful borehole citing in the surveyed areayields in the study area should be about 100 m. Integrated geoelectrical and hydrochemical surveys have been used to investigate and delineate different types of groundwater in the Kuala Selangor alluvial aquifer by [19]. The authors inferred that both the clean and brackish varieties of groundwater pumped from the boreholes appear to correlate with the interpreted clean and brackish resistivity zones of the VES survey. Vertical electrical soundings (VES) have also been achieved within and around Yenagoa city the capital of Bayelsa state by using Schlumberger array with a maximum current electrode separation ranging between 300 - 400 m to evaluate the vulnerability of the groundwater aquifer within the location according to [20]. The authors stated that high transmissivity values were recorded over most parts of the study area which agreed with the geology of the Benin Formation (Coastal Plain sands) consisting of fine-medium-coarse sands. They further concluded that the aquifer over burden protection capacity in the vicinity of most of the VES stattions are rated poor to weak aquifer and are vulnerable and hence susceptible to pollution through infiltration of leachate from decomposed refuse dumps and/or leakage from buried storage facilities.

III. METHODOLOGY

The basic equipment used for this study is the ABEM terameter. Signal averaging system (SAS 1000), four metal electrodes, cable for current and potential electrodes, three hammers, measuring tapes and cell phone for long distance communication. The ABEM terameter was used to display the apparent resistivity (ρ_α) of subsurface soil and is powered by a 12 volts DC power source (battery)

Vertical electrical sounding (VES) of electrical resistivity method was employed in this work to correlate geoelectric stratigraphy with borehole lithology for groundwater exploration in the study area. The VES survey was carried out at (5) stations in the study area using schlumberger electrode configuration. In resistivity sounding technique using schlumberger configuration, the current electrodes are paced much farther apart compare to potential electrodes. In this work, the total maximum current electrode spacing used is 350 m (Max. AB/2 = 175 m) while the total minimum current electrode distance is 100 m (Min. AB/2 = 50 m). On the other hand, the total maximum current electrode spacing used is 40 m (max. MN/2 = 20 m) while the total minimum potential electrode spacing is 7.0 m (Min. MN/ 2 = 3.5 m). The criteria for schlumberger electrode configuration is that current penetration is proportional to current electrode spacing. The field data obtain was interpreted using IP2 WIN computer softwareand and thereafter correlated with the drilled borehole lithology in the study area. The Schlumberger configuration schematic in VES is as shown in figure 3 [21].

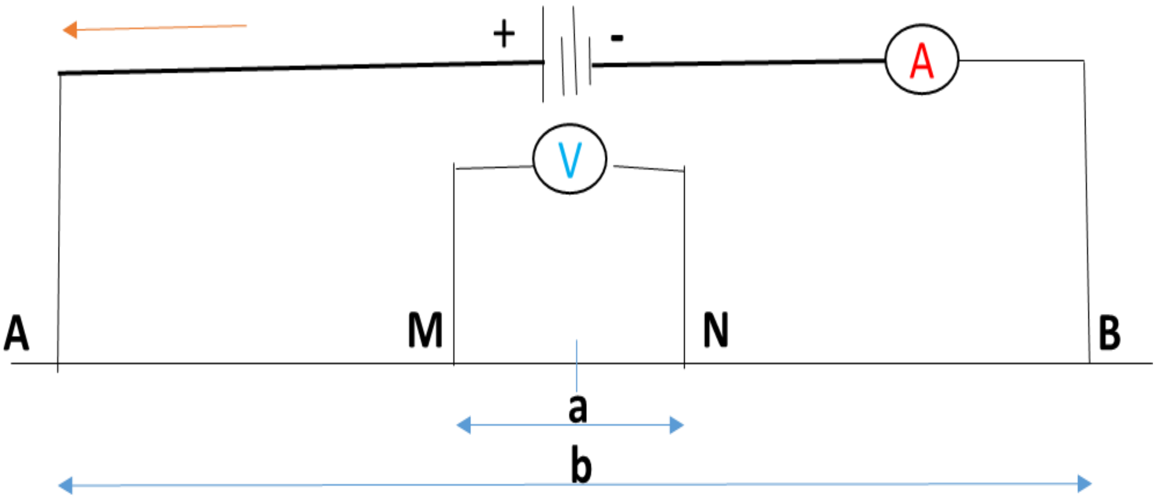


Figure 3: Schematics of Schlumberger array in VEE

The apparent resistivity (ρ_a) in the Schlumberger electrode configuration is given by the expression, [22, 23].

$$\rho_a = \frac{V}{I} \cdot \frac{(\frac{AB}{2})^2 - (\frac{MN}{2})^2}{MN} \qquad 1$$

or

$$\rho_a = \frac{V}{I} \cdot \frac{b^2 - a^2}{4a} \qquad 2$$

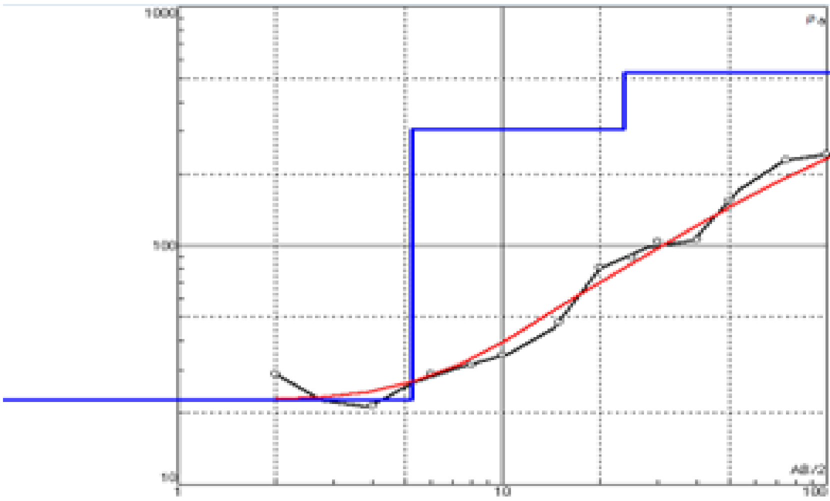
The geography of the locations showing the latitude, longtitude and elevations where the vertical electrical sounding (VES) were done, is showing in table 1. In the same vein, the geological map of Bayelsa state showing the location of the study area and the photograph of the nearby boreholes in the area are displayed in figure 1 and figure 2 respectively.

Table 1: Location of VES Stations

VES NO	VES Stations/locations	Latitude	Longitude	Elevation (m)
01	Engoye hotel road Nearby borehole	N 04^0 47^I 01.6^{II} N 04^0 47^I 04.0^{II}	E 006^0 18^I 35.6^{II} E 006^0 18^{I}33.2^{II}	2 10
02	Beside Beeh Hostel Nearby borehole	N 04^0 47^I 14.7^{II} N 04^0 47^I 13.7^{II}	E 006^0 18^I 25.7^{II} E 006^0 18^I 25.5^{II}	1 1
03	Beside Patience Square Nearby borehole	N 04^0 47^I 28.3^{II} N 04^0 47^{I}25.9^{II}	E 006^0 18^I 485.7^{II} E 006^{0}98^{I}50.0^{II}	6 1
04	Beside RCCG King Favour Nearby borehole	N 04^0 47^I 32.0^{II} N 04^0 47^I 32.2^{II}	E 006^0 18^I 57.5^{II} E 006^0 18^I 58.0^{II}	11 10
05	Kakata road Nearby borehole	N 04^0 48^{I}02.4^{II} N 04^0 48^{I}02.3^{II}	E 006^0 19^I 27.1^{II} E 006^0 19^I 26.9^{II}	7 6

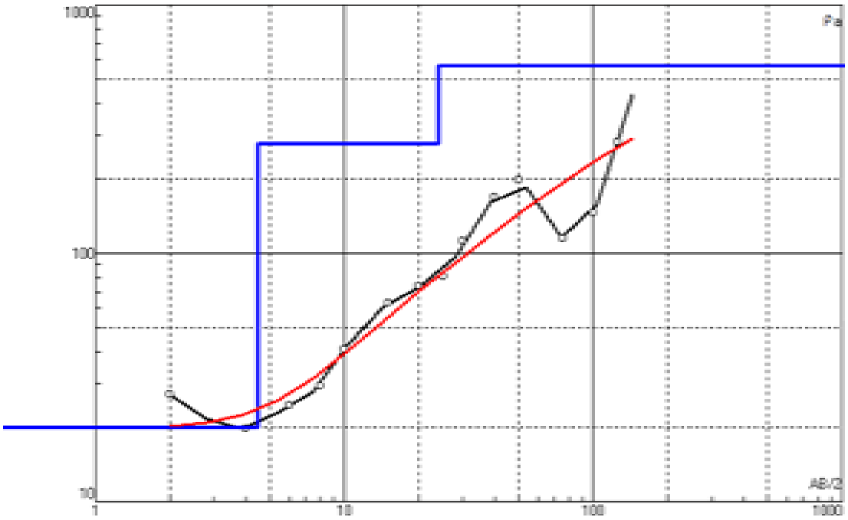
IV. RESULTS AND DISCUSSION

Results



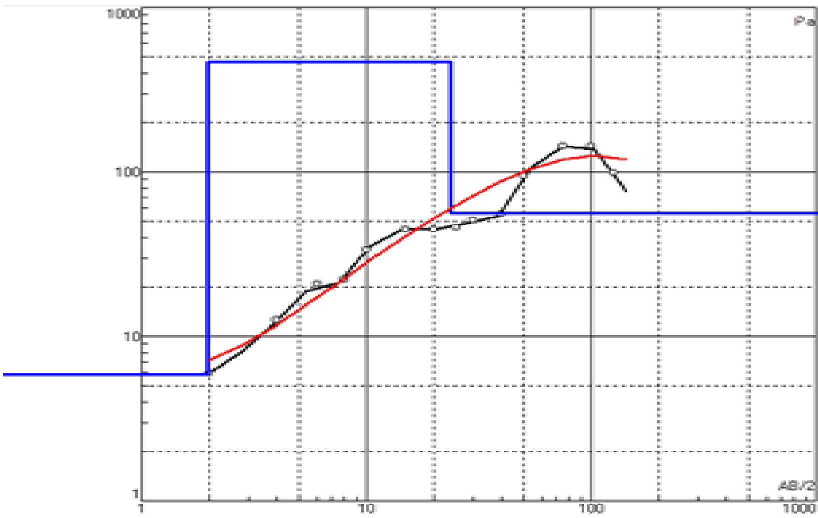
N	ρ	h	d	Alt
1	22.6	5.26	5.26	-5.258
2	307	10.5	23.7	-23.71
3	531			

Figure 4: Resistivity curve for VES station 1 (Engoye road) in the study area with typical sounding curve $p_1<p_2<p_3$



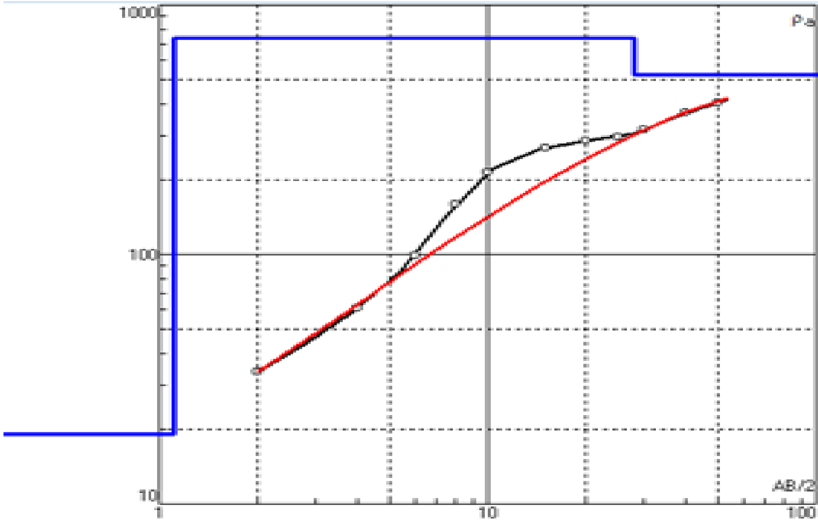
N	ρ	h	d	Alt
1	19.8	4.51	4.51	-4.507
2	275	19.4	23.9	-23.94
3	566			

Figure 5: Resistivity curve for VES station 2 (beach hostel) in the study area with typical sounding curve $p_1<p_2<p_3$



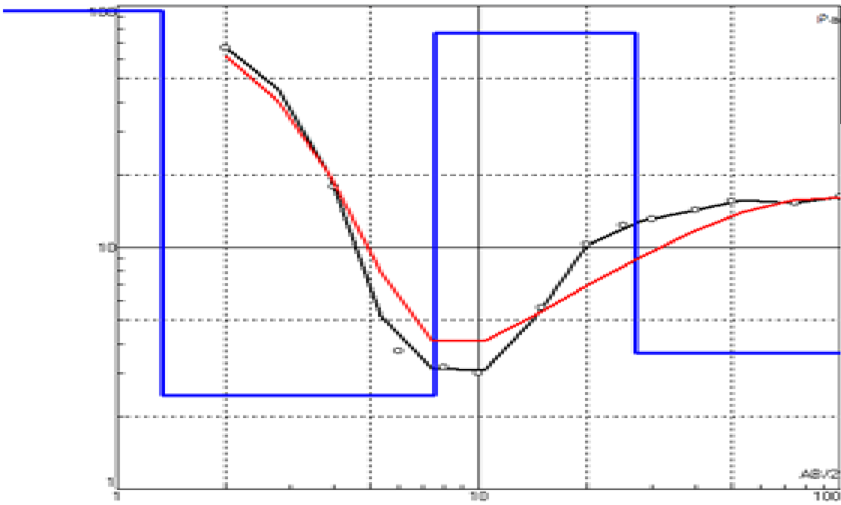
N	ρ	h	d	Alt
1	5.84	1.96	1.96	-1.957
2	464	21.8	23.7	-23.71
3	56.2			

Figure 6: Resistivity curve for VES station 3 (Patience square) in the study area with typical sounding curve $p_1<p_2<p_3$



N	ρ	h	d	Alt
1	19	1.11	1.11	-1.11
2	737	26.8	27.9	-27.93
3	526			

Figure 7: Resistivity curve for VES station 4 (RCCG king favour) in the study area with typical sounding curve of $\rho_1<\rho_2<\rho_3$



N	ρ	h	d	Alt
1	95.3	1.33	1.33	-1.334
2	2.44	6.24	7.57	-7.571
3	77.3	19.6	27.1	-27.12
4	3.65			

Figure 8: Resistivity curve for VES station 5 (Kakata road) in the study area with typical sounding curve of $\rho_1<\rho_2<\rho_3<\rho_4$

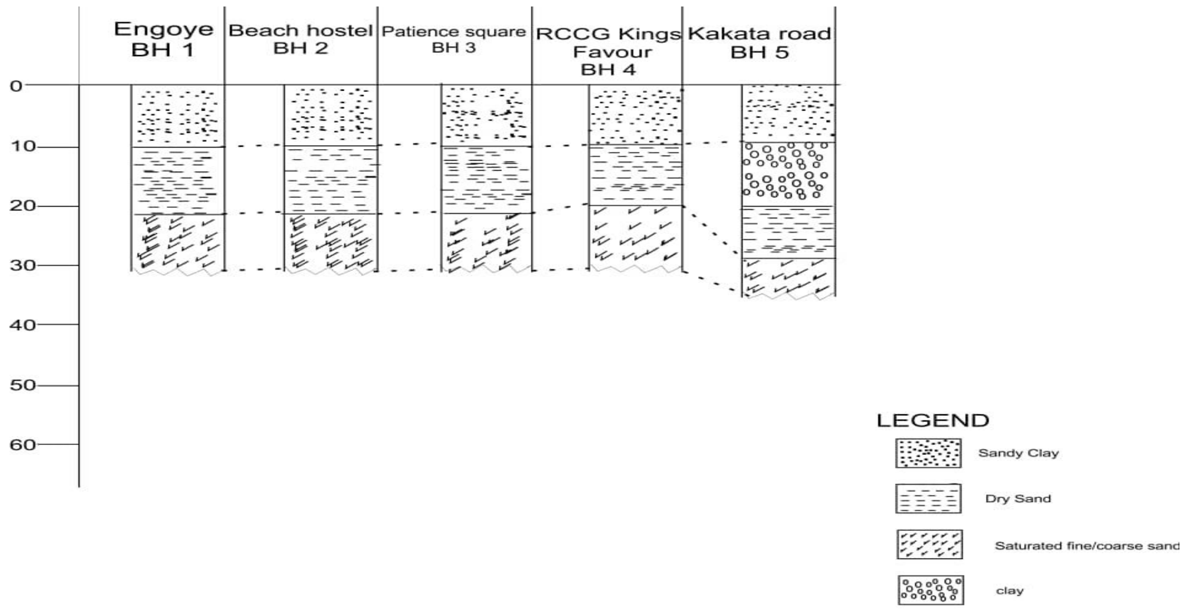


Figure 9: Borehole layers in the study area (BH_1, BH_2, BH_3, BH_4, BH_5)

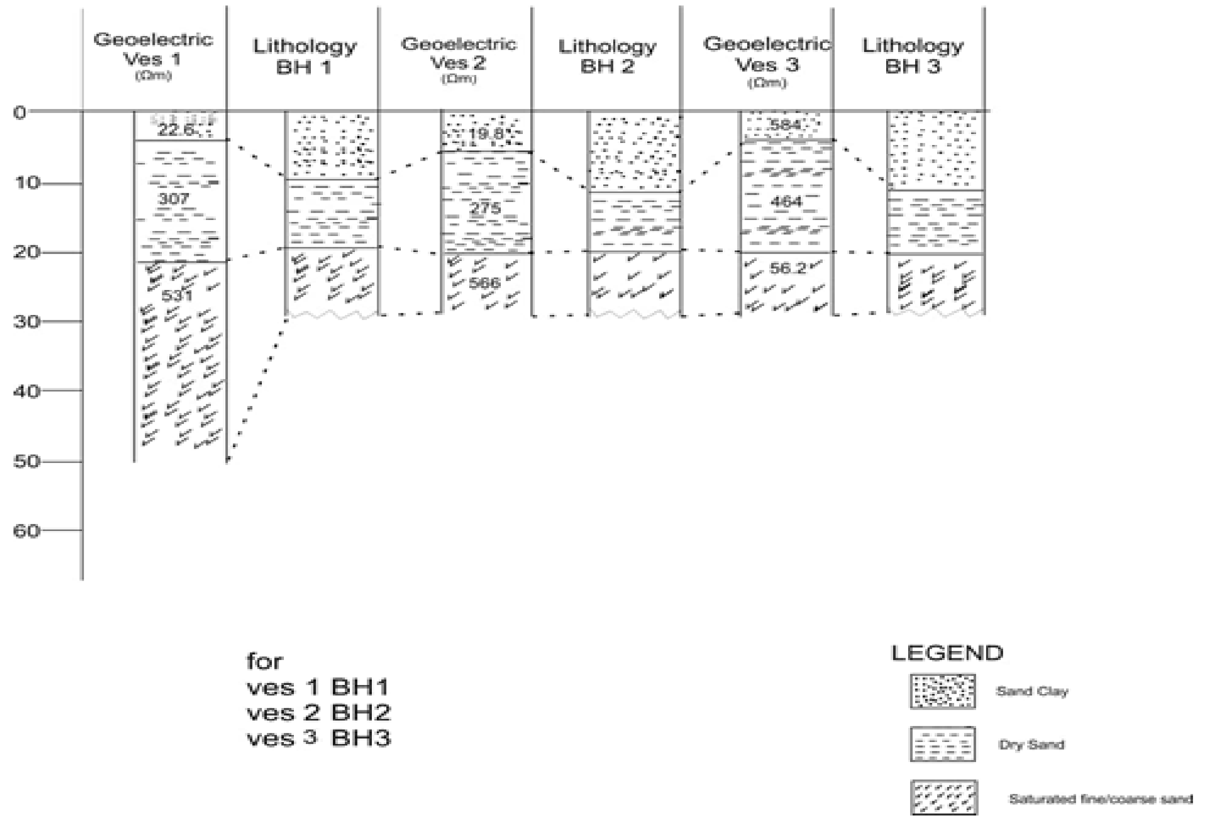


Figure 10: Correlation of the VES stations with borehole lithologies (VES 1 with BH1, VES 2 with BH2 and VES 3with BH 3

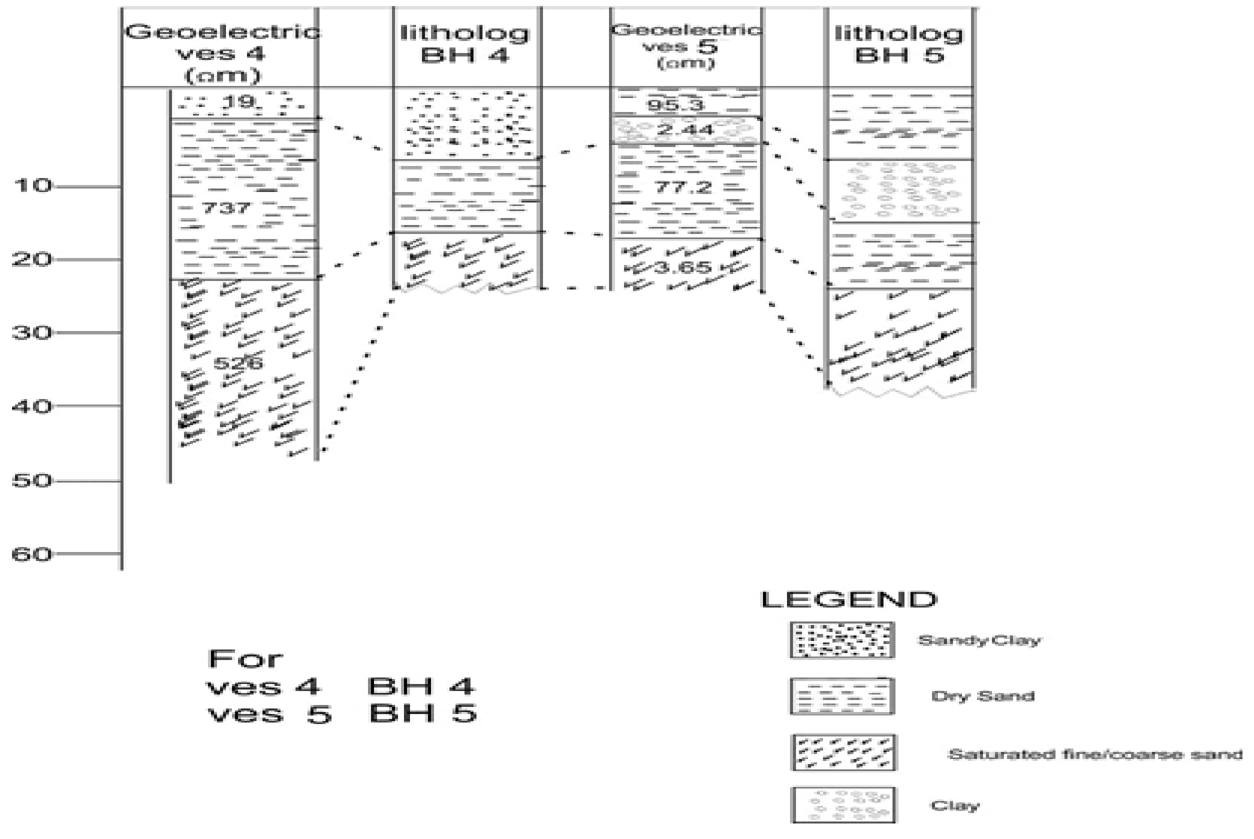


Figure 11: Correlation the VES stations with borehole lithologies (VES 4 wth BH4 and VES 5 with BH5

Discussions

Figure 4 is the resistivity curve for VES 1 (Engoye hotel road). The figure indicates that three sounding layer were delineated with resistivities ranging from 22.6 – 531 Ωm, and reveales sandy clay, dry sand and saturated fine/coarse sand. However from the geoelectric layer in VES 1, the highest resistivities value of 531 Ωm, with the thickness of 18.5m, was obtained. The aquiferous zone for groundwater prospecting lies within a depth of 20-30 m. Hence, borehole sinking is recommended within the spread of VES 1. Figure 5 is the apparent restivity curve for VES 2 (Beside Beeh Hostel) in the study area. Three geo-electric layers were delineated in the VES 2, with resistivities and thickness range of 19.8 – 566 Ωm and 4.51- 19.4 m respectively. The sub-surface geoelectric layers showcase a sandy clay (19.8 Ωm), dry sand (275 Ωm), saturated fine/coarse sand layer (566 Ωm), as the aquifer layers. However the targeted aquiferous zone reflected on the third layer. Therefore groundwater abstraction well can be suitably cited at a depth of 20-30 metres around Beside Beeh Hostel. Figure 6 is the resistivity curve for VES 3 (Beside Patience Square). The figure indicates typical K curve with resistivities and thickness range of 5.84 - 56.2 Ωm and 1.96 - 21.8 m respectively. The inferred lithology delineated a sandy clay 5.84 Ωm, 1.96 m, dry sand 464 Ωm, 21.8 m and saturated fine/coarse sand with resistivity of 56.2 Ωm. The target aquiferous zone is at the third layer, therefore sinking of borehole can be recommended at the depth of 20-30 m in this VES location. In figure 7, the geoelectric section for VES 4 (Beside RCCG King Favour) is displayed. Three geoelectric layers, ranging from sandy clay as the first layer with resistivities of 19 Ωm and thickness 1.11 m, the second layer is dry sand with resistivities of 737 Ωm and thickness of 26.8 m while the third layer is water saturated sandstone with resistivities of 526 Ωm, whereas the aquifer targeted zone which is at the resistivity of 526 Ωm, is delineated in this VES location. Hence, borehole can be recommended to be sink to a depth of 20-30 m in this VES location. Figure 8 is the geoelectric section for VES 5 (Kakata road). The VES revealed that up to four geoelectric layers ranging from dry sand with resistivities and thickness of 95.3 Ωm, 1.33 m, as the first layer, the second layer is clay with resistivities and thickness of 2.44 Ωm, 6.24 m and the third layer is dry sand with resistivities and thickness of 77.2 Ωm, 19.6 m. The fourth layer is saturated fine/coarse sand aquifer with resistivities and thickness of 3.65 Ωm, 19.60 m. The resistivity of aquifer layer is 3.65 Ωm which is the fourth layer. Therefore sinking of borehole can be recommended to be drill to a depth of about 30 - 40 m in the area.

Figure 9 is the lithologic layers of the five boreholes drilled in the study area (BH_1, BH_2, BH_3, BH_4, BH_5). Borehole BH_1, BH_2, BH_3 and BH_4 has the same lithologic layers which are sandy clay, dry sand and saturated fine/coarse sand which serve as aquifer layer in the third layer but BH_5 has four lithologic area which ranges from dry sand, clay, dry sand and saturated fine/coarse sand. The data from the five borehole drilled in the study area were collected and use to correlate with the VES stations (01, 02,03,04,05) locations as shown in figures 10 and 11. Each of these VES locations is directly close at about 2 m to each of the five boreholes in the study area. The borehole logs confirm the same lithology in boreholes 1,2,3,4, (figure 10) and different lithologies in the borehole 5 (figure 11) drilled in the study area. Aquifers were encountered at the same depth in the Borehole 1,2,3,4, but in BH_5 the aquifer was encountered at different depth. The borehole log further envisaged saturated fine/coarse sand with stained precipitate as aquifers in which casing was done. However, many private borehole owners in the study area prefer to exploit ground water from the third layer because generally the value of F^{2+} (Iron) content increases with depth beyond approximately 20-30 m in most locations in this area. Examination of most drill cuttings show an increase in the tiny silver tints that indicates the presence of Fe^{2+} in the sediments which are eventually oxidized to Fe^{3+} state [24]. Another obvious reason most clients of borehole projects tend to settle for the third geoelectric layer is the fact that deeper wells are cost intensive compared to shallower ones.

V. CONCLUSION AND FUTURE SCOPE

In this work the result of VES conducted in five stations in Otuoke using schlumberger configuration were analysed and interpreted and correlated with the borehole lithology drilled in the area. The interpreted results generally showed that saturated fine/coarse sand forms the major promising ground water aquifer in the study area. The borehole lithology in the study area also shows the same lithology with the geoelectric layers. The geoelectric survey/analysis also generally indicates that three to four resistivity/geoelectric layers are present down to the depth of investigation. The resistivity arrangement of these layers in the area is A-type Curve for two VES stations (VES 1 and VES 2), K-type curve for two VES stations (VES 3 and VES 4), one HK-type curve for one VES station (VES 5). The borehole lithology in the study area correlated pretty well with the geoelectric layers. The result of our investigation revealed that almost all the VES station delineated good potential aquiferous zones for portable groundwater development and exploitation in the area.

The major limiting factor to the exploration and subsequent development of groundwater in the study area is the lack of research grants by the government or the related agencies. It is therefore recommended that government of Nigeria should do well in funding the research of this nature for development of portable water in this part of the Nger-delta region of the country whose surface water have been adversely polluted mostly by crude oil exploration in the area.

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AUTHORS PROFILE

Mr. P.P. Adejumo, obtained Bachelor of Science (B. Sc.) Degree from Adekunle Ajasin University Akungba Akoko, Ondo State, Nigeria, in 2010. He is currently doing his Masters of Science (M. Sc.) Degree in geophysics in the department of Industrial Physics Chukwuemeka Odumegwu Ojukwu University Uli, Anambra State, Nigeria. He is currently as Laboratory Technologist in the Department of Physics, Federal University Otuoke Bayelsa State, Nigeria. He has published 2 research journals one each in international and local journals. His research interest is solid earth geophysics.

Prof. I.E. Ottih, obtained her B. Sc. in 1994, M. Sc. in 2003 and PhD. degree in 2012 from Nnamdi Azikiwe University Awka, Nigeria. She is a professor with the department of Industrial Physics Chukwuemeka Odumegwu Ojukwu University Anambra State, Nigeria. She is a member of Nigerian Institute of physics, member solar energy society of Nigeria and Fellow Strategic Institute for Natural Resources and Human Development. She has published 35 research papers both in international and local journals with 14 years of teaching and research experiences to her credit. Her main area of interest is solid state/material physics.

Mr. A.N. Nwori, obtained Bachelor of Science (B. Sc.) Degree from Ebonyi State University Abakaliki, Ebonyi State, Nigeria, in 2009 and Masters of Science (M. Sc.) Degree from Chukwuemeka Odumegwu Ojukwu University Uli, Anambra State, Nigeria in 2017. He is currently pursuing his PhD. in solid state/solar energy physics in the department of Industrial Physics Chukwuemeka Odumegwu Ojukwu University Uli, Anambra State, Nigeria. He has published about 12 research journals in both international and local journals. His research interest is fabrications of new thin film materials for solar energy applications and development.