Comparison of Vertical Electrical Sounding (VES) and Downhole Logs in Parts of Rivers State, Nigeria

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Abstract
This research was based on Vertical Electrical Sounding (VES) technique and Downhole log applied to study the subsurface geologic layers with a view of determining the depth and thickness for groundwater delineation of fresh water aquifer zones in shallow wells, parts of Niger Delta States, Nigeria. Vertical Electrical Sounding (VES) using Schlumberger configuration was carried out at Fifteen (15) stations. ABEM terrameter (SAS 300) was used for the data acquisition, with a maximum current electrode spread of 200m.IP2WIN and excel software were used for field data analysis and interpretation. The results of the interpreted VES data and down hole logs of the drilled borehole confirmed the following; The results indicated that the subsurface was drilled up to 77.6m depth and consisted of four major and a finite layers. The true resistivity of the top soil varies from 14.0-1048Ωm while the thickness varies from 0.331-276m.The result of the well log also showed electrical conductivity due to clay mineral. The second layer has resistivity ranging from 65.5-1613 Ωm and thickness ranging from 0.374-23.1m. The result of the down hole log indicated low to high resistivity in certain areas, that composed of clay to sand. The third layer, which constitutes an aquifer, has resistivity varying from 31.7 - 2484Ωm.While the thickness varies from 17.7-64.08m, the down hole log result indicated higher resistivity, and lithology was medium to fine-grained sand. The fourth geoelectric layer has resistivity a value ranging from 31.7 to 2484Ωm, the thickness varies from 25 to 64.08m. While the down hole log indicated high resistivity with lithology of fine to medium grained sand. The fifth layer has resistivity ranging from 19-2409Ωm. This layer is composed of fine, medium coarse grains; it constitutes an aquifer of very good quality groundwater aquifer. The average depth of this aquifer is between 30-40m.Geophysical VES reports and borehole logs confirm that the area is a homogeneous formation consisting of consistent lithology of sand with intercalation of silty clay layer. It is therefore recommended that boreholes for sustainable water supply should be drilled to a depth of between 35.00 m- 45.00 m and installation of sand screen location is 30-35m within these pats of Niger Delta.

Keywords: *Geoelectric, Aquifer, Resistivity, Vertical Electrical Sounding (VES) and Downhole logs, GPS*

Introduction

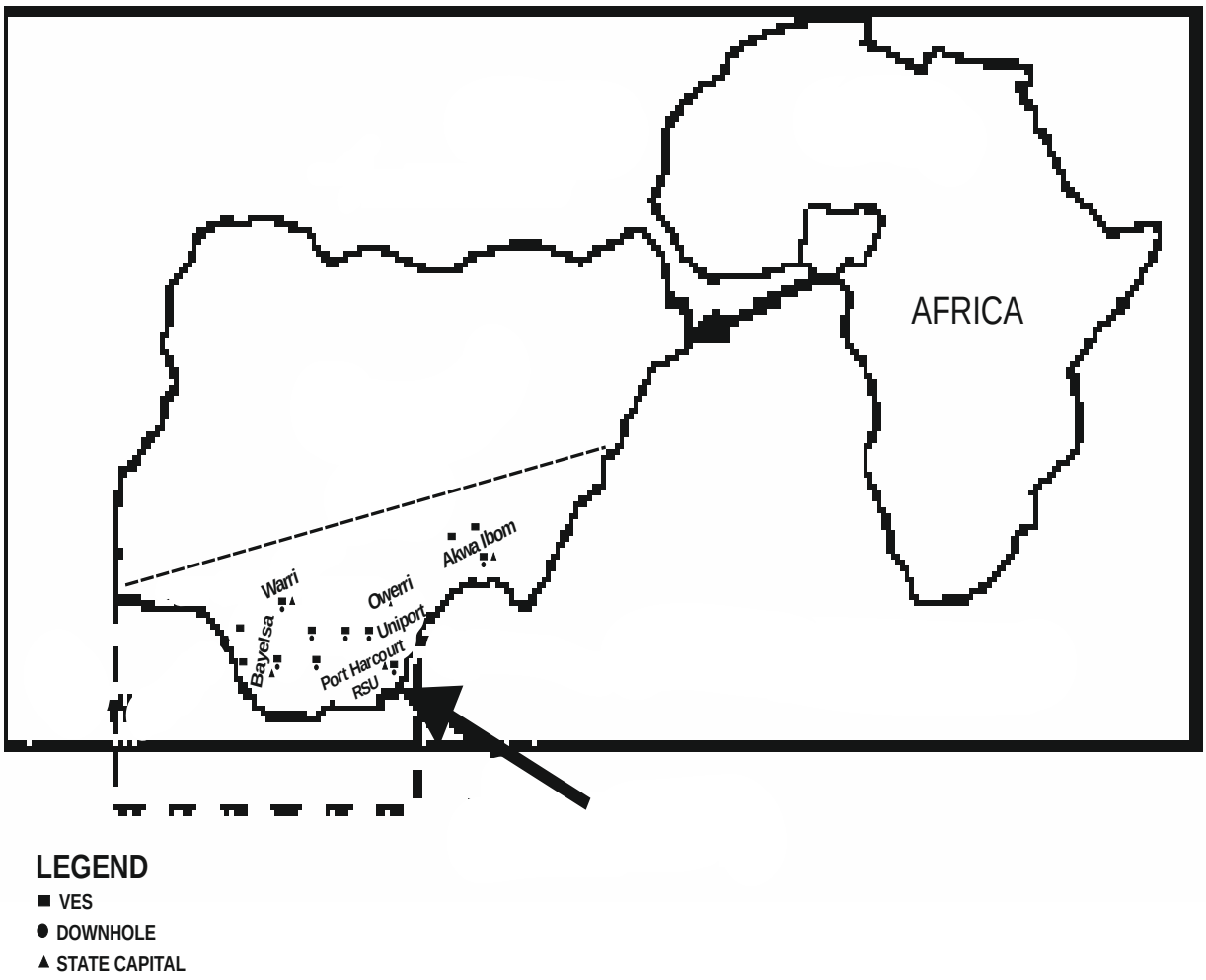
Background of the Study

Lack of appropriate hydrogeological base maps and poor knowledge of preliminary geology, no geophysical and hydrogeological investigations, due to absence of water policy and environmental laws, resulting in brine-salt water intrusions, borehole failure and insufficient

water delivery, causing problems in exploration, exploitation, operation, control and management of the abundant groundwater resources in Niger Delta.
The Vertical Electrical Sounding (VES) is a common geophysical technique in groundwater exploration (Ujuanbi and Asokhia, 2005; Alile *et al*., 2008; Sirhan *et al*., 2011). It has proved very popular with groundwater prospecting and engineering investigations due to simplicity of the techniques and rapid advances in computer software and associated numerical modeling solutions. This geophysical survey method used was Schlumberger array. this method will delineate water bearing formations (aquifers), because of its better depth interpretation and usefulness in mapping subsurface aquifers for groundwater exploration, it is more superior compared to other methods (Egai, 2013).

Geophysical logging technique utilizes the measurement of certain physical Parameters across different subsurface formations with the help of sensing probe inside the bore hole providing a continuous record of these parameters versus depth. It is used to determine the vertical variation of electrical resistivity below the earth surface and the potential field generated by the current (Otobo and Ifedili, 2005; Anomohanran, 2011a).

Location and Geology of the Study Area
The study areas comprises Rivers State, Bayelsa and State and Delta State .They are located within latitude N004^0 47’ 54.576’’and longitude E006^0 58’ 236’ at 264°W’ in Unitech, Port Harcourt, N005° 18’29.64Ɛ and E006 56’ 26.388Ɛ and Bayelsa State, Kiama N05° 65’88.8Ɛ E0^{0}208.2’89Ɛ and latitude 5.72˚N and 5.80˚N and longitude 5.94˚E and 6.08˚E Delta state. They recline within the coastal sedimentary lowlands hydro-geological province. They are within the lower section of the upper flood plain deposits of sub-aerial Niger Delta (Allen, 1965). The area lies within the depobelt, Prototype Quaternary sediments of Benin formation. These deposits are characterized by pebbles, sands intercalations of silt, mud and porous fresh water bearing sands with localized shale/clay inter-beds (Abam, K.S 1999). The area is within the tropical Equatorial climate dominated by abundant rainfall with an annual means of 3000mm (Amajor and Ofoegbu1988).



Maps showing the study area location and the (VES) profiles distribution **and downhole log**

Materials and Methods
Field Work Procedure /Data Acquisition
Vertical Electrical Sounding Field Procedure

The research project was carried out with schlumberger array in electrical resistivity. The basic field equipment for this study is the ABEM Terrameter SAS 3000 which displays apparent resistivity values digitally as computed from ohm's law. Applying two outer current electrodes (A and B) into the ground, and are adjusted to vary the distance. While the inner (potential) electrodes (M and N) remain fixed. The resultant potential difference (V) measured between the potentials M and N electrodes; the distance between the potential electrodes (MN) is small compared to the distance between current electrodes (AB) and AB, N 5MN. The spacing is adjusted when it is needed because of decreasing sensitivity of measurement. The centre point of the electrode array remains fixed but the spacing of the electrodes was increased so as to obtain the information about the stratification and deeper penetration of the ground.

When the ratio of the distance between the current electrodes to that between the potential electrodes become too large, the potential electrodes must also be displaced outwards otherwise the potential difference becomes too small to be measured with sufficient accuracy (15) VES points apparent resistivity (pa) field readings in this study were obtained, such that

AB/2 ≥ MN/2. Where AB/2 = Current electrode spacing which was usually increased in steps starting from 50 to 200 m and MN/2 = Potential electrode spacing was gradually increased in steps starting from 1 m to a 50 m. The current gain (output current) of the resistivity meter increased gradually from 1 to 1000 mAmp. To yield a current penetration to the required depths, the Schlumberger array was used by keeping the potential electrodes at a closer distance. The apparent resistivity (pa) was determined using Equation below.). Where AB = distance between the current electrodes in meters, MN = distance between potential electrodes in meters, V= potential difference measured between the potential electrodes (volts), and I = the applied current strength.

The geo-hydrological data acquired after profiling, using a maximum electrode spacing (AB) of 50-200m a total of ten (10) Schlumberger (VES) stations were taken using an ABEM Terramater (SAS 300). The resistively values obtained are multiplied by the corresponding geometric factor to obtain the apparent resistivity's recorded on the field data sheets. The obtained apparent resistivity recorded on the field, plot of current electrode spacing ($AB/_2$) using computer program software of IP2WIN was employed for the data interpretation.
The measurement of the electrical potential and the current especially on the earth's surface will make it possible to obtain information about the resistively variation of the sub face in the area concerned (Telford *et al*, 1976.)

Computer assisted interpretations are capable of providing thickness and resistivity of various subsistence layers according to (Mamah and Ekine 1999, Sadek *et, al.*, 1990, Mbonu *et al.*, 1991).

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

Where AB = distance between the current electrodes in meters, MN = distance between potential electrodes in meters, _V= potential difference measured between the potential electrodes (volts), and I = the applied current strength

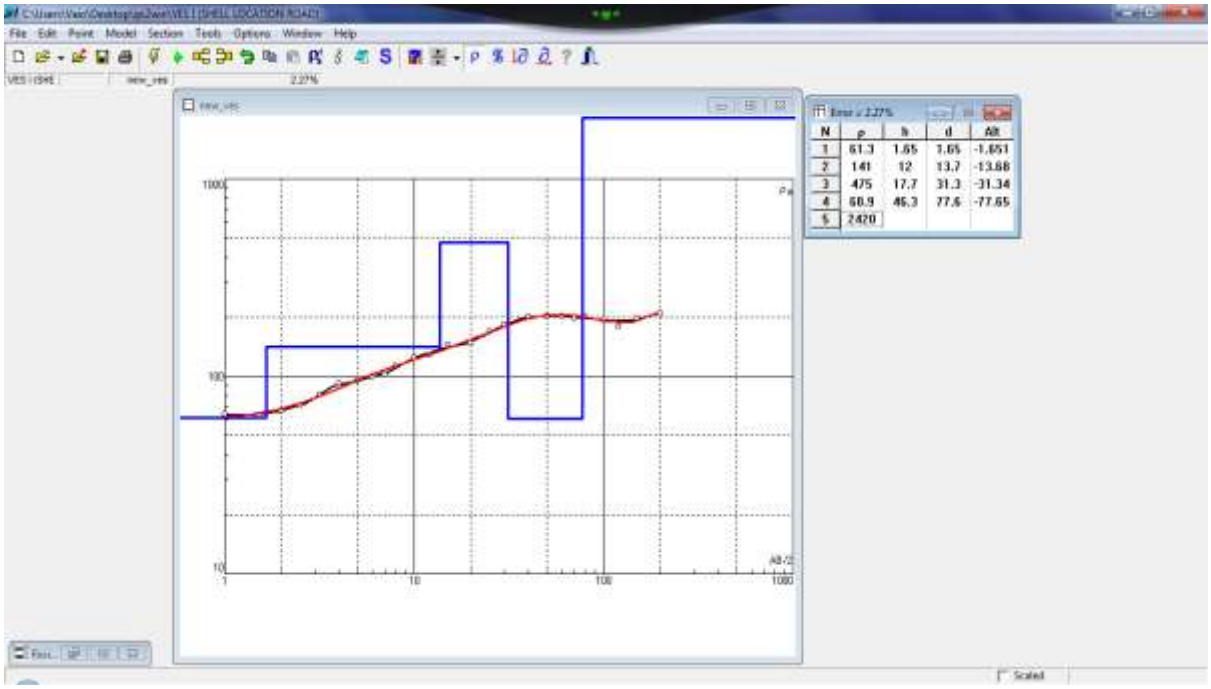
Downhole Geophysical Logging in Hydrogeological Investigation.
On conclusion of VES geophysical survey, an extensive suite of downhole geophysical log was conducted in 10 deep continuous drilled boreholes. Three types of logging tools are used (a) probe is lowered free in the hole, (b) the probe are centred in the hole by centralizer and (c) the sensors in the tool are pressed against the borehole wall. Spontaneous log records the long normal (LN64") and short normal (SN16"). The short normal records apparent resistivity of the mud-invaded zone (useful for locating boundaries of formations), while the long normal records apparent Resistivity beyond the invaded zone (useful for obtaining information on fluids in thick permeable formations) uninvaded zones. Lateral – actual formation resistivity beyond the mud-invaded zone Total depth of (150-200)ft was logged, the parameter recorded and analyzed using excel software.

Results and Discussion
The results of the field data used in running the computer iterative program of the corresponding vertical electrical sounding (VES) and Downhole log are presented; the

resistance in the electrode spacing and the drilled borehole logs confirms the following stratigraphy as presented. The computer generated curve with the geoelectric thickness and depth of each sounding station are presented. The normal resistivity logs (short normal, long normal and lateral variations) were recorded. Self-Potential (SP) logs recorded between the borehole electrode and the reference electrodes. The study area generally indicated a four to five layer case of lithological units at maximum in the sounding stations. The types of curve that were observed are AKH, HKH, HK, AK, KH curves.

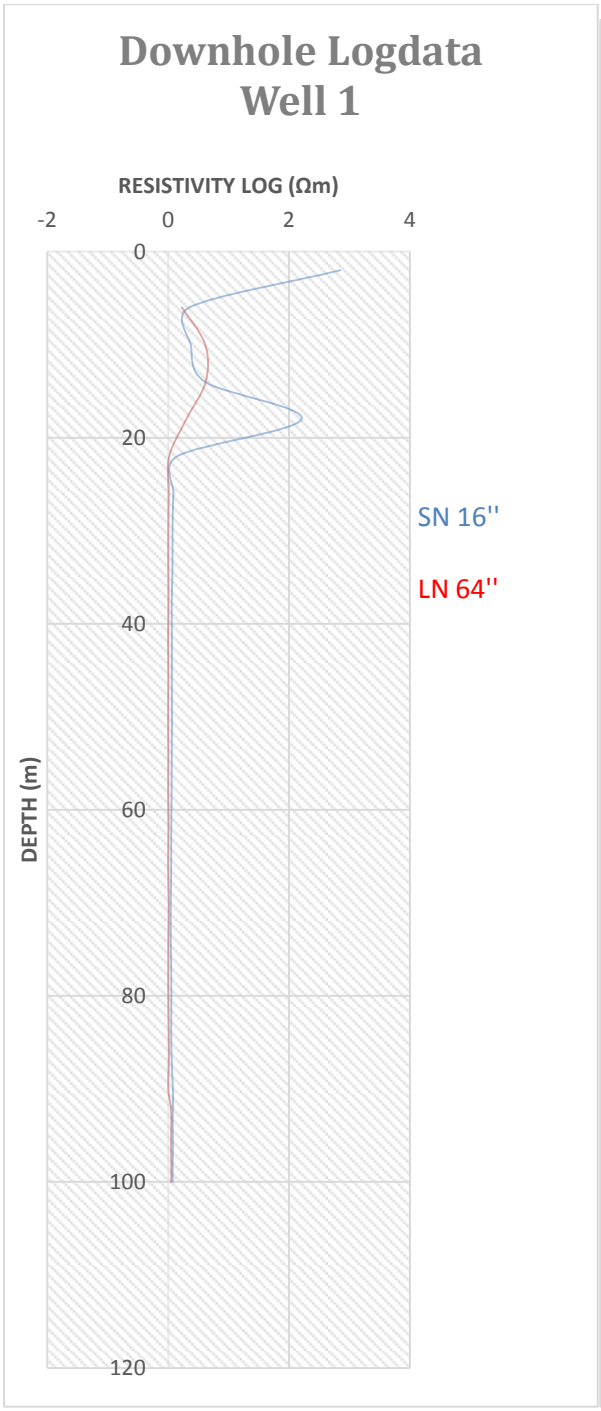
The types of curve was identified at VES 1 (Shell Location), five geoelectric layers and a total depth penetration probe of 77.63m, with absolute resistivity values ranges from 60.9Ωm to 2420Ωm. the topsoil has 61.3 Ωm underlay by a clayey sand formation to about 14m depth with the resistivity value of 141Ωm, The third layer is a coarse sandy formation having a thickness of about 18 m and the resistivity value of 475Ωm is a confined aquifer, the four layer is a thick clayey sand formation covering about 46 m of the formation, its resistivity values is 60.9Ωm and the fifth layer has a resistivity value of 2420Ωm, interpreted to be a medium coarse sand formation but the total depth cover is infinite.

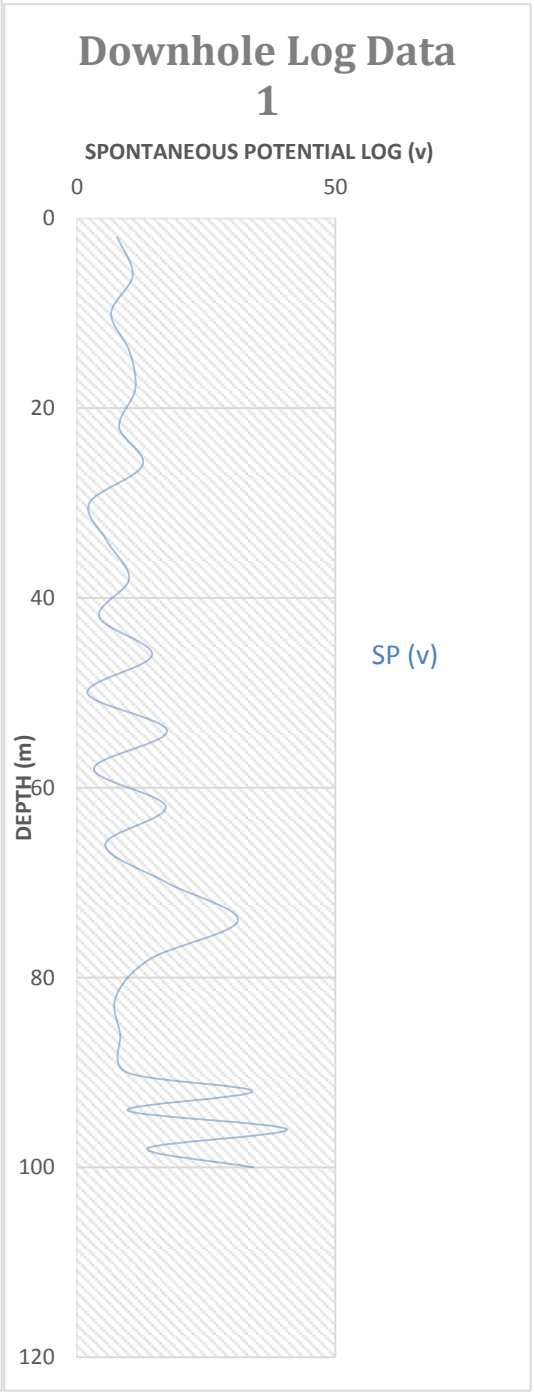
Therefore, comparing VES1 data with the down hole well log data of a borehole well data, located about 40m, it can be seen that from the first to fifth layer is clearly seen in the Spontaneous potential well information, and the richly coarse formation of the third layer is also signed on the resistivity log at same depth point on the VES interpretation .The cross signals of the SN 16'' and the LN 64'' of the resistivity log indicates that the formation is highly impermeable thick formation. From the borehole detail, it is recommended that boreholes are drilled up to 80 - 100m and installation of sand screen is between 50-554m to harness potable water.

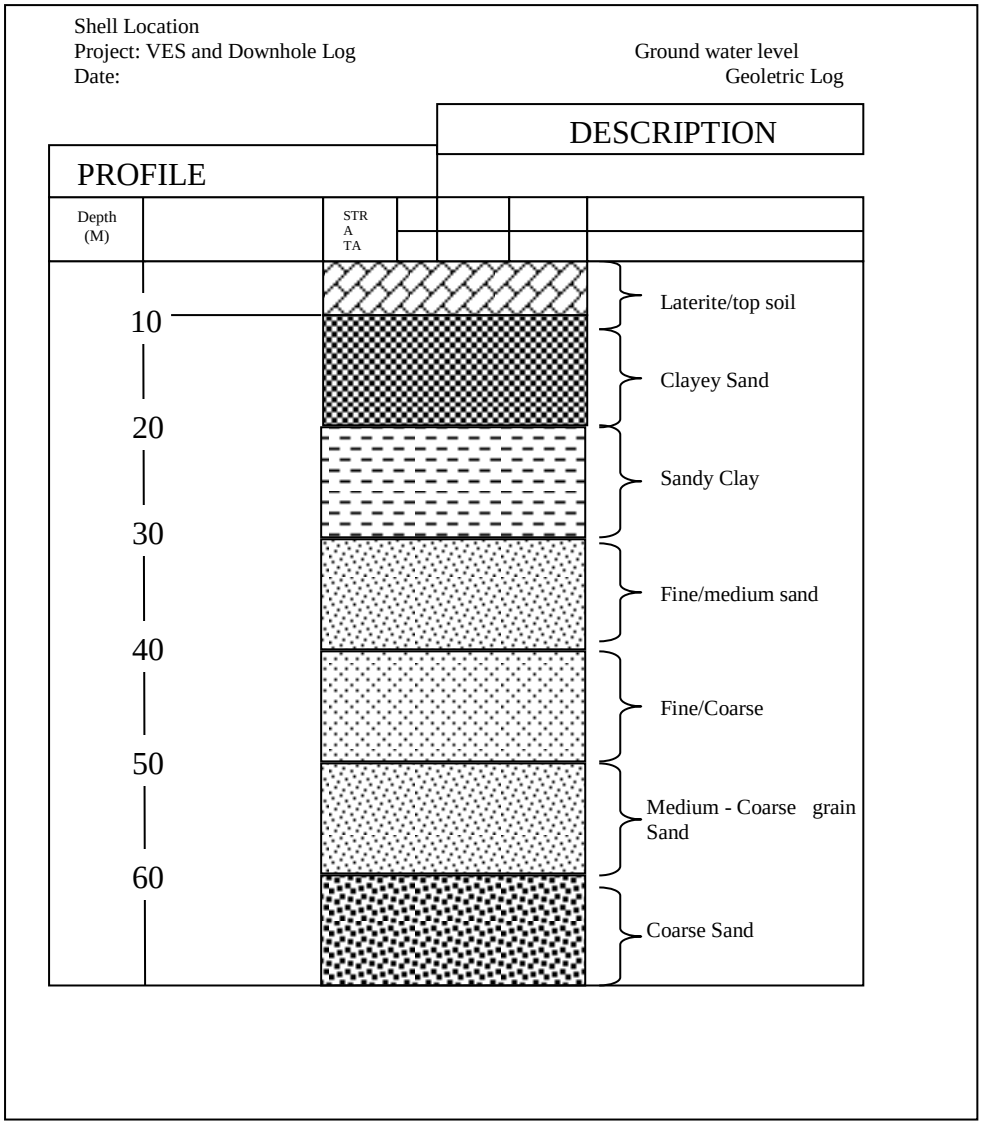


VES 1 (Shell location, Rivers State)

S/N	Resistivity	Thickness	Depth	Lithology/formation
1	61.3	1.65	1.65	Humid top soil
2	141	12	13.7	Medium coarse sand
3	475	17.7	31.3	Coarse sand
4	60.9	46.3	77.6	Clayey sand
5	2420	+++	+++	Fine to medium sand





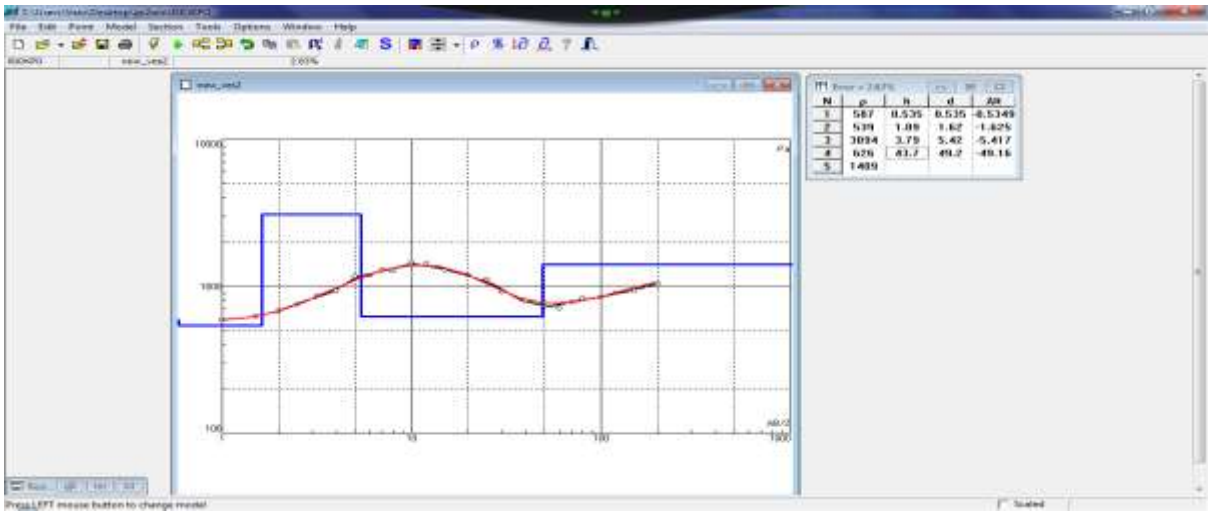


Hydrogeological Detail for Geophysical Downhole Log

Site/Location	Shell Location Rivers State
Date of Logging	April, 2017
Parameter Logged	Spontaneous Potential (SP), Normal Resistivity (SN 16", LN 64")
Total Depth Logged	50m
Total Depth Drilled	50-100m
Equipment Used	Terrameter

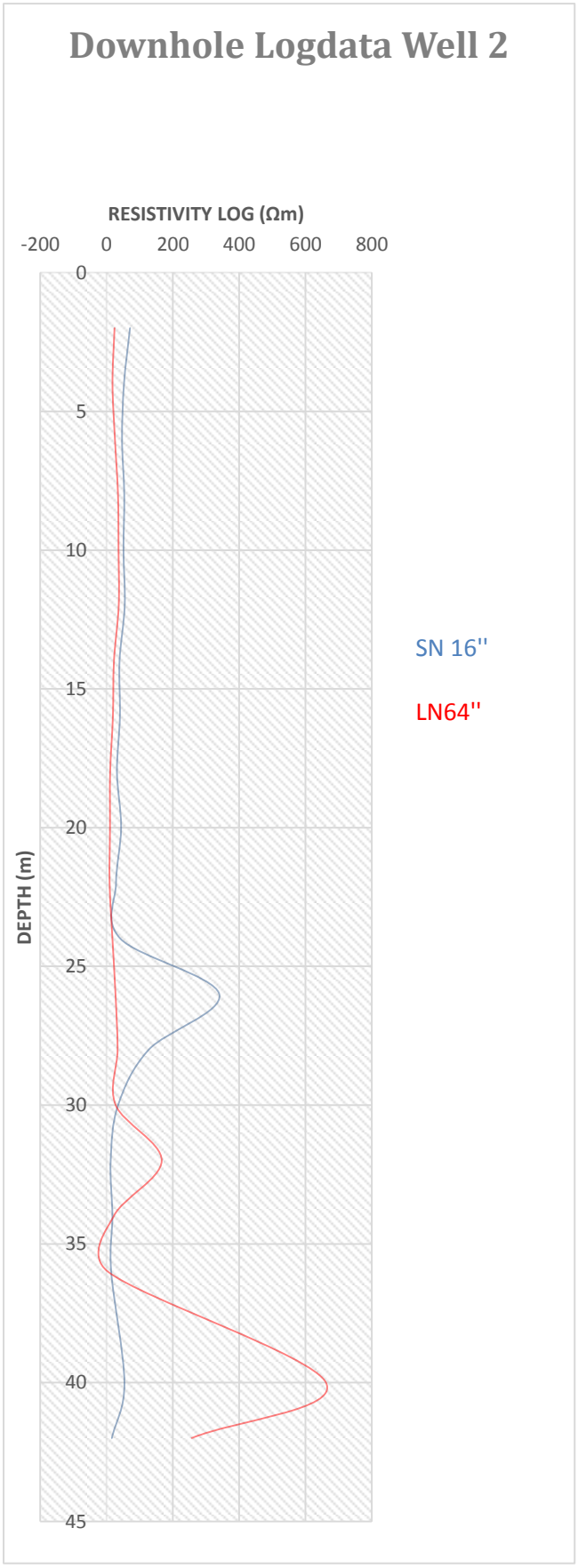
In VES2 (Physics Department) Rivers State also with five geoelectric layer units. Resistivity values' ranging that is purely a sandstone formation, from the fine to high coarse sand. The geoelectric layers with a resistivity of 587Ωm which is the top soil composed of sand intercalation with clay, second layer with a thickness of 1m and depth of 1.6m depth, the third layer is a coarse sand formation with high resistivity of 3094Ωm and a thickness of about 4m, the fourth layer has a resistivity value of 626Ωm with the largest thickness in the formation covering about 43.7m, this is underlain by an indefinite thick coarse sand formation of a resistivity value of 1409Ωm.

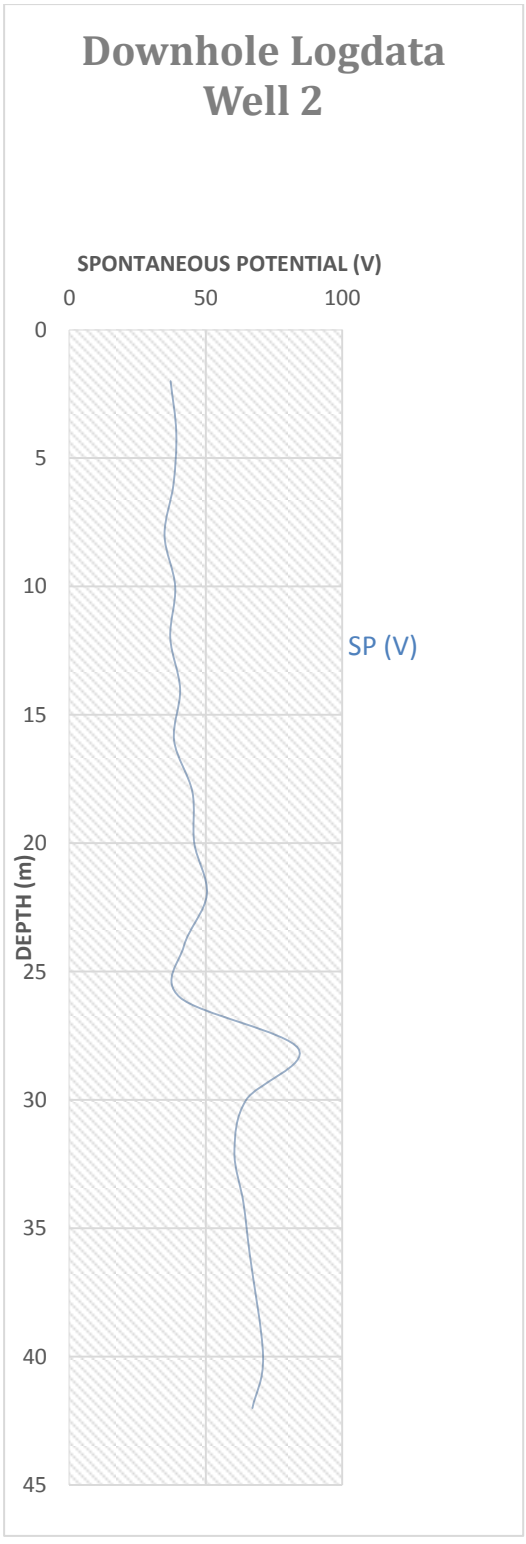
Therefore, comparing this information with the down hole well logging data of a borehole wells 1 located about 20m around this VES2 location it can be seen that the total depth of penetration of the VES investigation is about 49m and the borehole logged at the area was just about 40 to 45m deep. And the signed shows the corresponding signal (resistivity log, spontaneous potential and the geophysical data) that the lithology formation is a sandy formation, from a fine sand formation to a coarse sand formation layer, and the richly coarse formation of the fourth layer is also signed on the resistivity log/SP log at same depth point on the VES interpretation. The formation is unconsolidated down the depth of investigation but between 30 m and 35m there are indications of thin impermeable layers. It is recommended that boreholes are drilled to 50-60m sand screen is between 35 to 39m for fresh water aquifer.

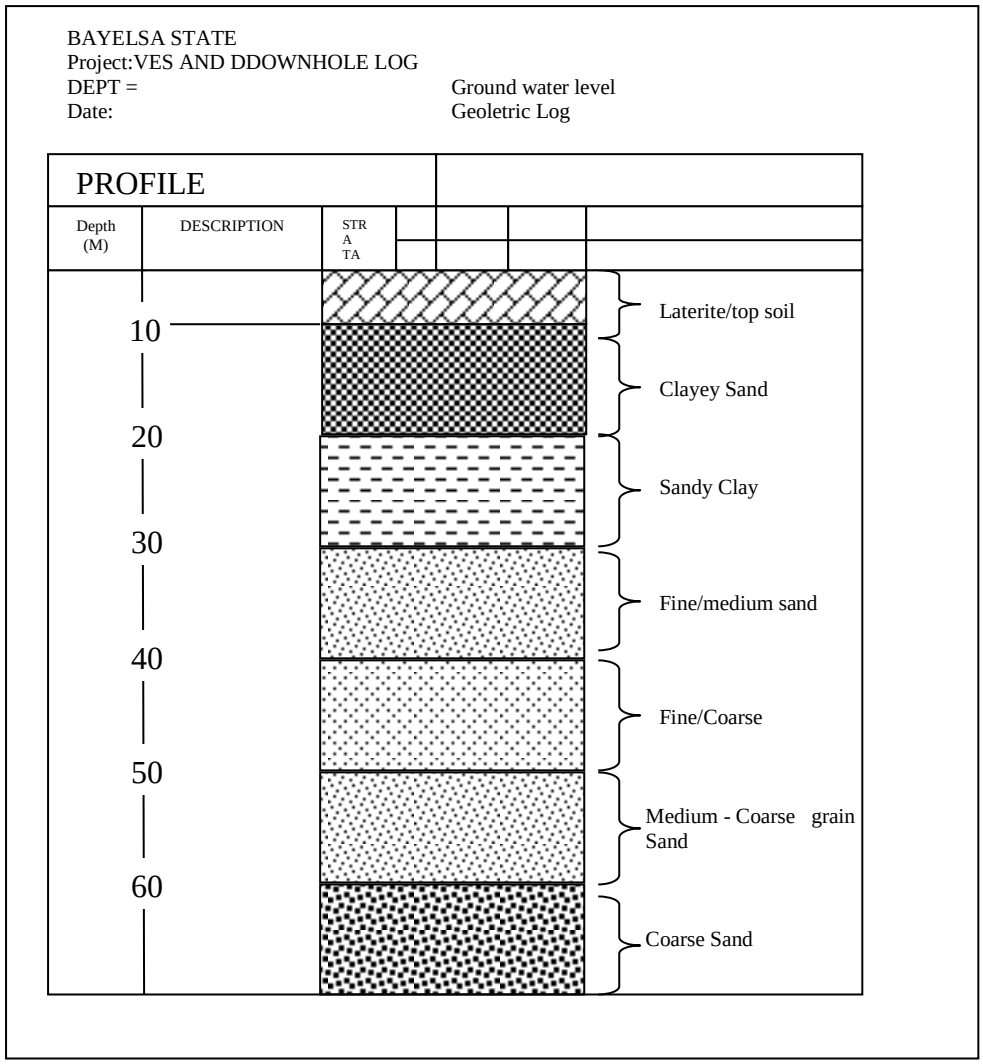


VES 2 (Physics Dept)

S/N	Resistivity	Thickness	Depth	Lithology/formation
1	587	0.535	0.535	Dry top soil
2	539	1.09	1.62	Medium coarse sand
3	3094	3.79	5.42	Coarse sand
4	626	43.7	49.2	Coarse sand
5	1409	+++	+++	Fine to medium sand


Downhole Logdata Well 2
RESISTIVITY LOG (Ωm)
-200
0
200
400
600
800
0
5
10
15
20
25
30
35
40
45
DEPTH (m)
SN 16''
LN64''

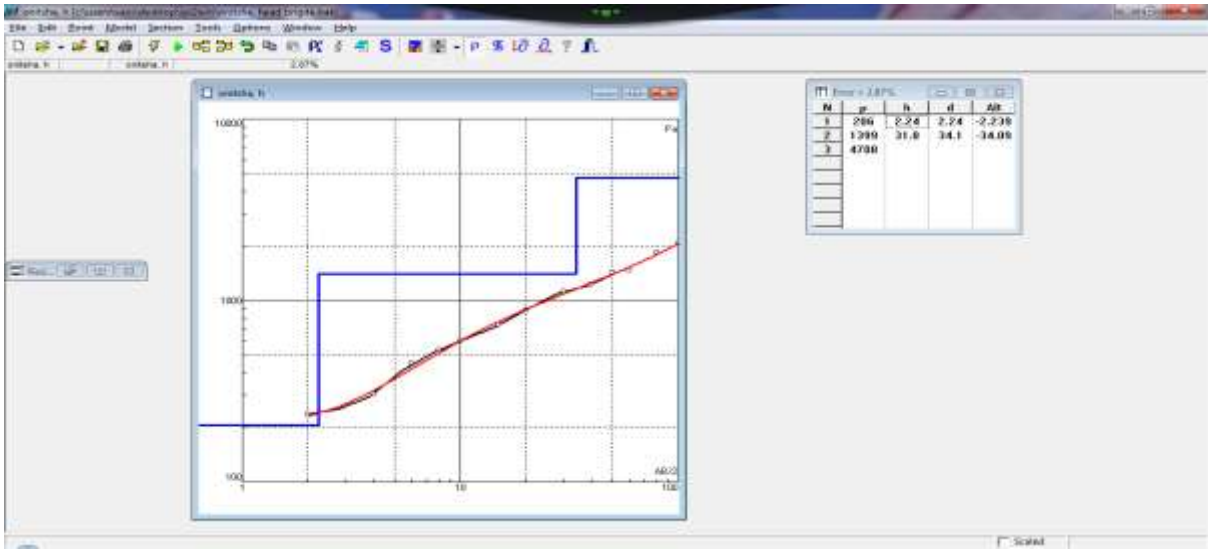

Downhole Logdata Well 2
SPONTANEOUS POTENTIAL (V)
0
50
100
0
5
10
15
20
25
30
35
40
45
DEPTH (m)
SP (V)



Technical Detail for Geophysical Downhole Log

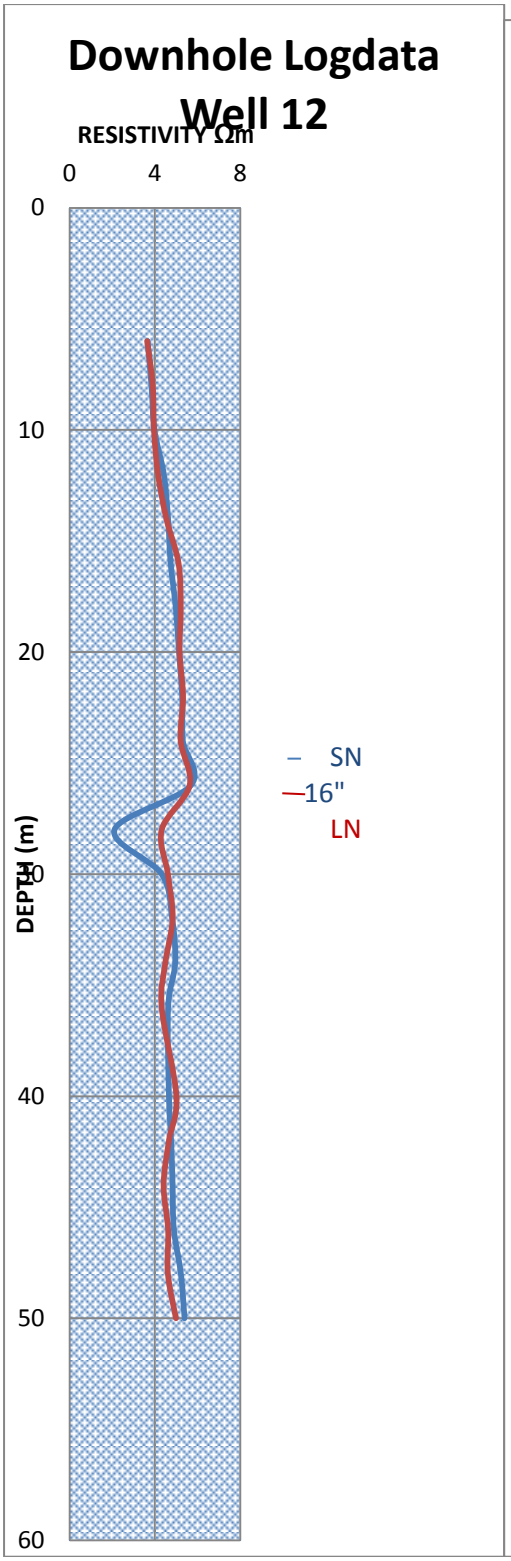
Site/location	Bayelsa State
Date of Logging	April 2017
Parameter logged	Spontaneous Potential (SP), Normal Resistivity (SN 16", LN 64")
Total Depth logged	60m
Total Depth Drilled	50-100m (not recovered due to heavy drilling mud)
Equipment used	Terrameter

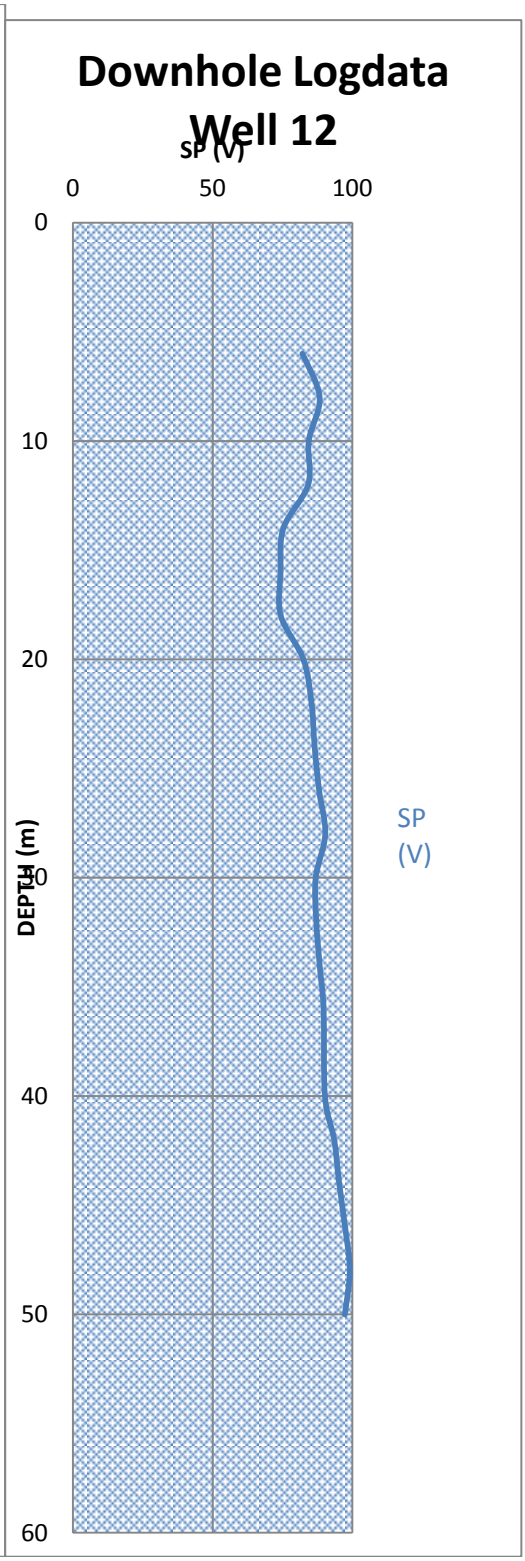
VES 12 (Akwa Ibom State) and the drilled log sections present predominantly sand with some undefined clay intercalations. The first layer has resistivity of 206Ωm, thickness of 2.24m and depth of 2.24m indicate top humus soil with clay. The second layer has resistivity of 1,399Ωm, 31.m thickness and the depth of 34.1m, it indicates intercalation of peaty clay sand formation, while the third has resistivity of 4,708Ωm. It is recommended that boreholes are drilled to 50-60m sand screen is between 45 to 50m for fresh water aquifer.

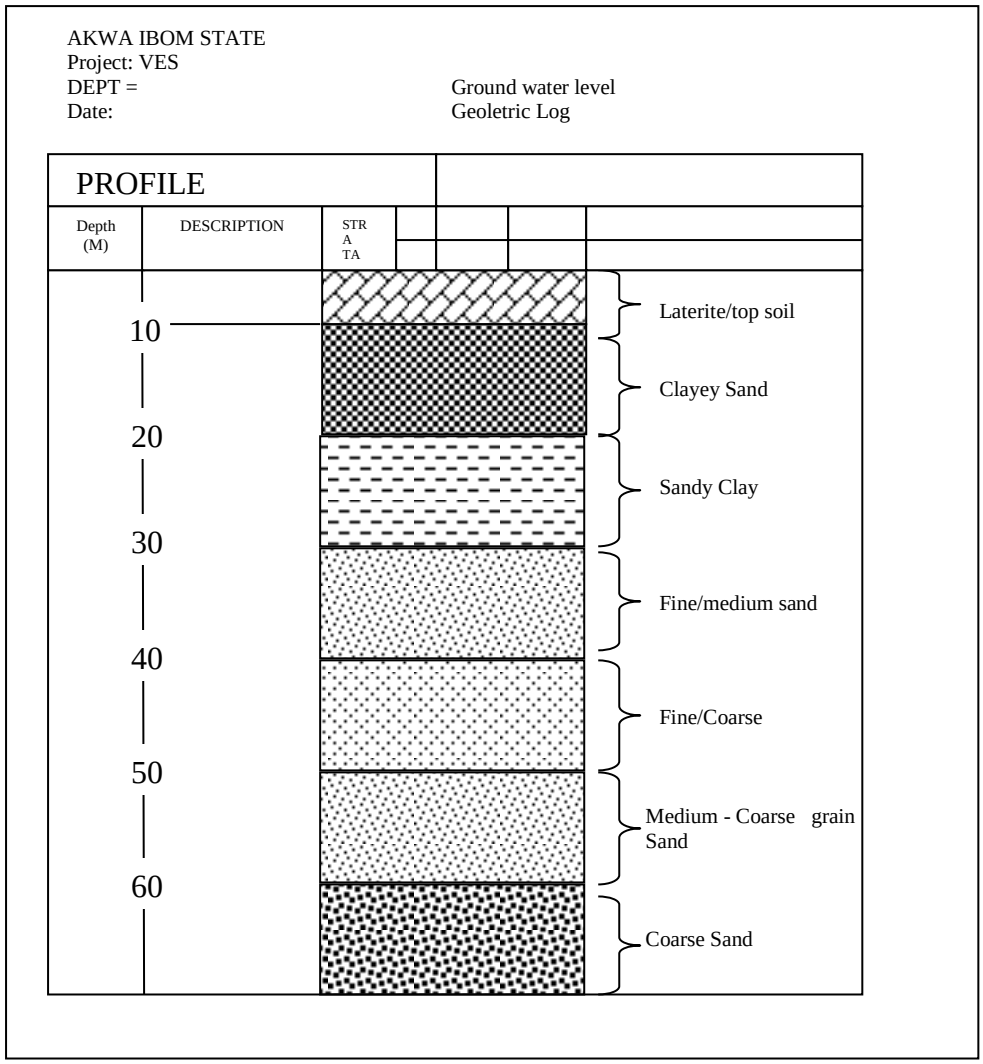


VES 12, AKWA IBOM STATE

S/N	Resistivity	Thickness	Depth	Lithology/information
1	206	2,24	2.24	Top lateritic soil
2	1399	31.8	34.1	Moderately fine sand
3	4708	+ +++	++++	Medium to coarse sand
4				


Downhole Logdata
Well 12
RESISTIVITY Ωm
0
4
8
0
10
20
30
40
50
60
DEPTH (m)
SN
16"
LN


Downhole Logdata
Well 12
SP (V)
0
50
100
0
10
20
30
40
50
60
DEPTH (m)
SP
(V)



Technical Detail for Geophysical Downhole Log

Site/location	Akwa Ibom
Date of Logging	April 2017
Parameter logged	Spontaneous Potential (SP), Normal Resistivity (SN 16”, LN 64”)
Total Depth logged	60m
Total Depth Drilled	50-100m (not recovered due to heavy drilling mud)
Equipment used	Terrameter

VES Name	Layers Resistivity Value	Thickness(m)	Depth(m)	Lithology	Curve Type
VES1(SHELL LOCATION,RIVERS STATE)	61.3ΩM	1.65	1.65	Humid Top Soil	
	141ΩM	12	13.7	Medium Coarse Sand	AKH
	475ΩM	17.7	31.3	Coarse Sand	
	60.9ΩM	46.3	77.6	Clayey Sand	
	2420ΩM	+++	+++	Fine To Medium Sand	
VES 2 (PHYSICS DEPT.) RIVERS STATE	587ΩM	0.535	0.535	Dry Top Soil	
	539ΩM	1.09	1.62	Medium Coarse Sand	HKH
	3094ΩM	3.79	5.42	Coarse Sand	
	626ΩM	43.7	49.2	Coarse Sand	
	1409ΩM	+++	+++	Fine To Medium Sand	
VES 3 (IGWRUTA)	1048ΩM	0.5369	0.5369	Top Soil	
	807ΩM	1.27	1.807	Medium Coarse Sand	HK
	2484ΩM	46.83	48.63	Coarse Sand	
	677.9ΩM	+++	+++	Fine To Medium Sand	
VES 4 DELTA STATE	871ΩM	1.386	1.386	Top Soil (Dry)	
	89.3ΩM	0.758	2.143	Clay Sand	HK
	615.9ΩM	46.49	48.63	Fine Grain Sand	
	341.7ΩM	+++	+++	Medium Grain Sand	
VES 5 (EAGLE CEMENT ROAD)R/S	18.2ΩM	2.59	2.59	Top Soil (Humid)	
	65.5ΩM	20.7	23.3	Clayey Sand	AK
	226ΩM	25	48.2	Silty Sand	
	19ΩM	+++	+++	Clay	
VES 6 (BAYELSA STATE)	162.6ΩM	0.66	0.66	Top Soil	
	351ΩM	11.33	12	Medium Coarse Sand	AK
	258.4ΩM	64.08	76.03	Medium Grain Sand	
	1.925ΩM	+++	+++	Fine Coarse Sand	
VES 7 (AGIP/RVU)	48ΩM	2.67	2.67	Top Soil (Humid)	
	104ΩM	23.1	25.8	Clayey Sand	KH
	33.9ΩM	29.7	55.5	Clay Sand	
	142ΩM	+++	+++	Coarse Silt Sand	
VES RUMUJI,RIVERS STATE	31.7ΩM	1.73	1.73	Top Soil	
	235ΩM	0.844	2.57	Silty Sand	KH

	37.9ΩM	40.7	43.3	Clayey Sand	
	2170ΩM	+++	+++	Coarse Sand	
VES 9 (OLOMAKA,BAYELSA)	14ΩM	0.331	0.331	Top Soil (Humid)	
					KH
	1488ΩM	0.374	0.705	Medium To Coarse Sand	
	132ΩM	43.4	44.1	Sandy Clay	
	1176ΩM	+++	+++	Fine To Medium Coarse Sand	
VES 10 (UBIMA,RIVERS STATE)	110ΩM	2.05	2.05	Top Soil (Dry)	
					KH
	1613ΩM	0.757	2.8	Coarse Sand	
	31.7ΩM	60	62.8	Clayey Sand	
	2409ΩM	+++	+++	Fine Sand	
VES 11 (LOCATION ROAD)	22.69ΩM	1.279	1.279	Humid Top Soil	
					KH
	217.4ΩM	0.498	1.777	Silty Sand	
	57.5ΩM	33.27	35.05	Clayey Sand	
	1502ΩM	+++	+++	Fine To Medium Sand	
AKWA-IBOM	206	2.24	2.24	Top Lateritic Soil	
	1399	31.8	34.1	Moderately Fine Sand	
	4708	+ +++	++++	Medium To Coarse Sand	

NLNG PORT HARCOURT

17.9	0.148	0.148	Top Humus Soil
56.4	4.18	4.33.	Clay Sand
67.4	63.8	68.1	Silt Sand
16745	++++	+++	Highly Coarse Sand

Conclusion and Recommendation

The Groundwater potential aquifers producing zones have been delineated through investigation conducted by the electrical resistivity survey and downhole in the study area parts of Niger Delta States, Nigeria. Good prospects therefore exist for groundwater development in the study area where the depth to the coarse and medium to fine layer is relatively thick and has favourable low resistivity, while those with thin depth layer and high resistivity value have a lower potential for an aquifer. Aquifers were found in surveyed station VES (1) with a depth above 77.6.m, VES (2) above 49.2.m. VES (3) with depth of 48.63m and VES (4) at a depth of 48.63m, VES (6) with infinite depth above 76.03m and VES (7) with resistivity of 140Ωm and infinite depth above 55.5m.VES (8) has resistivity of 2170Ωm and with depth of 43.3m, VES(9) resistivity of 1176Ωm and infinite depth above 44.4m and VES(10) has resistivity of 2409 and infinite depth above 62.8m shows the sounding station with the highest geoelectric five. The assumption of a heterogeneous formation was justified in view of the number of curve types obtained in the sounding stations of the study area.

Recommendation

Resistivity is recommended that vertical electrical sounding using schlumberger configuration should be applied with down hole logging to provide detailed geophysical properties that aids in lithological characterization and in determining the subsurface stratigraphy, water table and avoid in the study area.

An intensive hydro-chemical analysis should be carried out in the study area, especially at VES4 and 8 roundabout with a low resistivity value of 89.3 and 31.7Ωm at a thickness of about 0.758.m the depth of about 2.143m, before sitting a borehole due to the shallowness of the aquiferous zone which make it vulnerable to pollution of the water table. The exert location for the installation of sand screen similar, ranging from 35 to 45m these parts of Niger Delta.

Regional aquifer storage capacity should be determine through the use of GRACE data analysis to ascertain the rate of aquifer depletion and regional groundwater reserve and availability to prevent, drying up of well water, reduction of water in streams and lakes, Deterioration of water quality, Land subsidence.(Jay Famarietti)