International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-8, Issue-6, June 2022
ISSN: 2395-3470
www.ijseas.com

Combined Geoelectric and Drill Hole Investigations For Detecting Fresh Water Aquifer at the NLNG Head office Development Project, Port Harcourt, Nigeria.

[1]Amechi, Bright U, [1]Tammy Morrison and [2]Baatee Vurasi
[1]Department of Geology, Rivers State University, Port Harcourt.
[2]Department of Physics, Rivers State University, Port Harcourt.

Abstract

Geoelectric and drill hole investigations were carried out at Nigeria Liquefied Natural Gas (NLNG) Head office Development project located along the shoreline of Amadi creek, off Eastern by-pass Port Harcourt, for the purpose of fresh water aquifer delineation. The study is also aimed at establishing the geophysical characteristics of subsurface lithologies, assessment of existing potential aquifer(s) as well as to determine the appropriate borehole depth for water supply to the complex. Abem terrameter was used for the investigations. A total of current electrode spread of 700m was achieved for the vertical electrical sounding of the two (2) profiles conducted using the Schlumberger configuration. The Spontaneous Potential (SP) and Resistivity (Short and Long Normal) downhole logs were adopted. The short normal of the Resistivity log is useful in locating strata interface while the long normal provides better information on the formation lithology (grain sizes) as well as fluids in permeable strata. The interpretation of Schlumberger sounding data (using IP12Win software) was first calibrated with the lithology of available drill borehole samples. The drill depth of 200m and VES result of 240m indicated fresh water artesian aquiferous zone. The study revealed that fresh water occurred at depth 150 – 230mm while 100 – 140 depicted saline water zone. The depth of 200m was recommended for the screen position.

Key words; Downhole log, Vertical Electrical sounding, Schlumberger, groundwater, lithology

Research overview

The NLNG Head office Development project is located along Amadi creek, off Eastern by-pass. naturally. This ultra-modern corporate office owned by Nigeria LNG Limited (NLNG), a liquefied natural gas (LNG)-producing company, was built by Bouygues Construction Nigeria, a subsidiary of Bouygues Construction, on a **100,000 m²** site located on the Niger delta in Port Harcourt. It is at the shoreline of saline water zone which requires proper conduct of studies to delineate fresh/saline water boundary. A surface geophysical investigations for the location of potable groundwater aquifer for the sitting of water borehole at NLNG Head office complex, Port Harcourt was conducted. The area falls within latitude 4.8397° N, and longitude 7.0446° E, elevation of 1.6m. The study was aimed at furnishing information on the nature and thickness of the different subsurface layers as well as formation resistivities in order to assess the portability of the aquifer water supply to the inhabitants in the area. Some other vital information obtained from the survey include; estimation of the drill depth, viability of the project at the chosen site, type and nature of the geologic formations to be encountered, etc

However, ground water occurs almost everywhere beneath the land surface and is an integral part of a complex hydrologic cycle that involves continuous movement of water on Earth. The widespread occurrence of potable ground water is a major reason for its use as a source of water supply worldwide. The upper surface of the saturated zone is called the water table. Contrary to popular belief, groundwater does not form underground rivers. It fills the pores and fractures in underground materials such as sand, gravel, and other rock, much the same way that water fills a sponge. The unconfined and confined saturated formations in the subsurface can only be extracted by well bore.

The Vertical electrical sounding (VES) was employed since it is an effective, quick, reliable and economic means of obtaining details about the electrical characteristics of the subsurface. Schlumberger array was employed because of its advantages over the Wenner. Schlumberger array used in the field survey is found to be more suitable for this study (Reynold, 1997). The elliptical resistivities (apparent resistivity) of rocks are mainly determined by this survey. The earth resistivity (ER) survey was conducted using Schlumberger configuration for data acquisition. The electrical resistance of rock samples determines the aquifer characteristics and the mineral present in the pores and interstices of the rock formation. (O. Anomahanran 2013). The different hydrogeologic units found in the subsurface display a wide range of capabilities to store and transmit ground water and contaminants. Borehole-geophysical logging provides a highly efficient means to determine the character and thickness of the different geologic materials penetrated by wells and test holes. This information is essential for proper placement of casing and screens in water-supply wells and for characterizing and remediating ground-water contamination. Amechi, et al 2015

Open down hole logging was also conducted at the drilled uncased well as a confirmatory test since the geoelectric method is an approximation. In order to guarantee good-quality, and sustainable groundwater, it is important to integrate aquifer parameters determined from downhole logging. (O. Anomahanran 2013) The logs involve lowering the sonde into freshly drilled uncased well. The Spontaneous potential (SP) log, normal resistivity logs (Long and short normal) were also carried out to compare the subsurface formation of the study area. The downhole logging is used to evaluate the character and thickness of the different geological materials penetrated by wells and test holes.

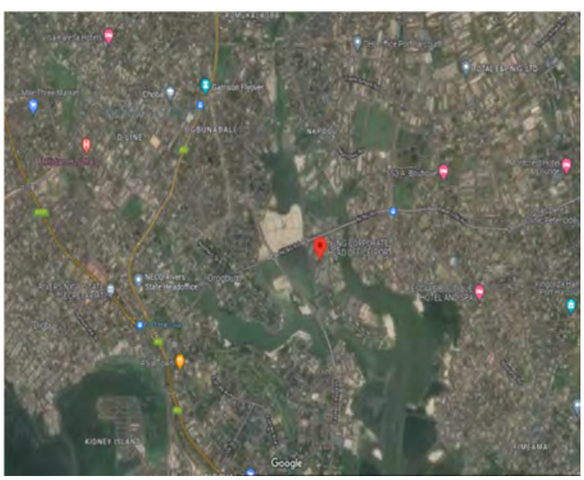


Fig 1. Satellite image map of the study area (Google map)

Site Geology and Groundwater Hydrology.

The geology of the Niger Delta has been studied by several geoscientists. There is agreement amongst these that the Niger Delta is underlain by three principal formations, namely: Akata, Agbada and Benin Formations. The Akata Formation, which is predominantly shale and clay and the Agbada Formation which is generally fluviatile and fluviomarine are primarily of interest to the hydrocarbon industry. (Etu-Efector, et al 1990) The depositional pattern which accompanied sedimentation during the formation of the delta, gave rise to structural traps (growth faults and roll-over anticlines) in the Agbada Formation, which facilitated the accumulation of petroleum in the reservoirs of the Niger Delta. The Agbada Formation while suitable for petroleum accumulation is considered too deep to be of interest for groundwater abstraction. Together, Akata and Agbada formations provide hydrocarbon source rock and reservoir and account for nearly all the hydrocarbon discoveries in the Nigeria. The Benin Formation on the other hand which occurs at shallower horizons consists of continental deposit of sand and gravel and is therefore of greater significance to the groundwater and civil construction sectors. It is now well known that the Benin Formation (Miocene to Recent) posses' excellent water yielding properties even at great depths. (Amajor, 1991). The high permeability of Benin formation, the overlying lateritic red sand and weathered top of the formation provide the hydrologic condition favoring aquifer formation in the area. (Short and Stauble 1967). Groundwater potentials are very high due to the high permeability, high recharge potential and considerable aquifer thickness. The water in most of the area has high iron content and water table varying between 1.0m to 15.0m inland. Basically, the area consists of medium to coarse unconsolidated sands with groundwater at the water table atmospheric pressure. The top sediments are aerated unconsolidated and highly variable thickness throughout the area. (Omaha and Mbazi 1988),

Well cuttings from the logs of oil wells spread across the Niger delta, reveal that the Benin Formation is laterally extensive and extends to depths of 2000 m in places. (Allen 1965). The granular composition of Benin Formation presents it as a veritable construction aggregate, besides serving as competent layer to support most piled foundations within depths of civil engineering significance.

However, due to the continuing evolution of the delta, the three major formations have now been overlain by various types of Quaternary and Cenozoic deposits (Fig.2). The Cenozoic succession of recent Niger Delta consists of a continental Upper Deltaic plains made up continental alluvial plains, braided streams and meander Beds. The sediments here are largely unconsolidated sands, feldspar, limonite coated sand grains silt and clay deposited in fresh water beach swamps. Deposition of the aquifer materials is thought to have occurred in alluvial fan, fluvial channel, tidal channel, intertidal flat, beach, and related microenvironments (Amajor, 1991). According to Nwankoala and Ngah the influence of geology on the groundwater resources of the Niger Delta constitutes the most important factor besides that of climate in the region (Nwankwoala, et al 2014)

Geology has been observed to be responsible for the complex groundwater distribution, extractability and quality in the Niger Delta. Unfortunately, the current state of knowledge of the true geological condition of the groundwater bearing domain of the Niger Delta is limited. The progress in the improved understanding of the geology of the delta has been due largely to the investments and data yields of the oil industry. Understandably therefore, researches in the delta have been skewed towards petroleum geology. This explains why the present knowledge of the Benin Formation is limited, compared with that of the Akata and Agbada Formations. (Ofodile, 2002)

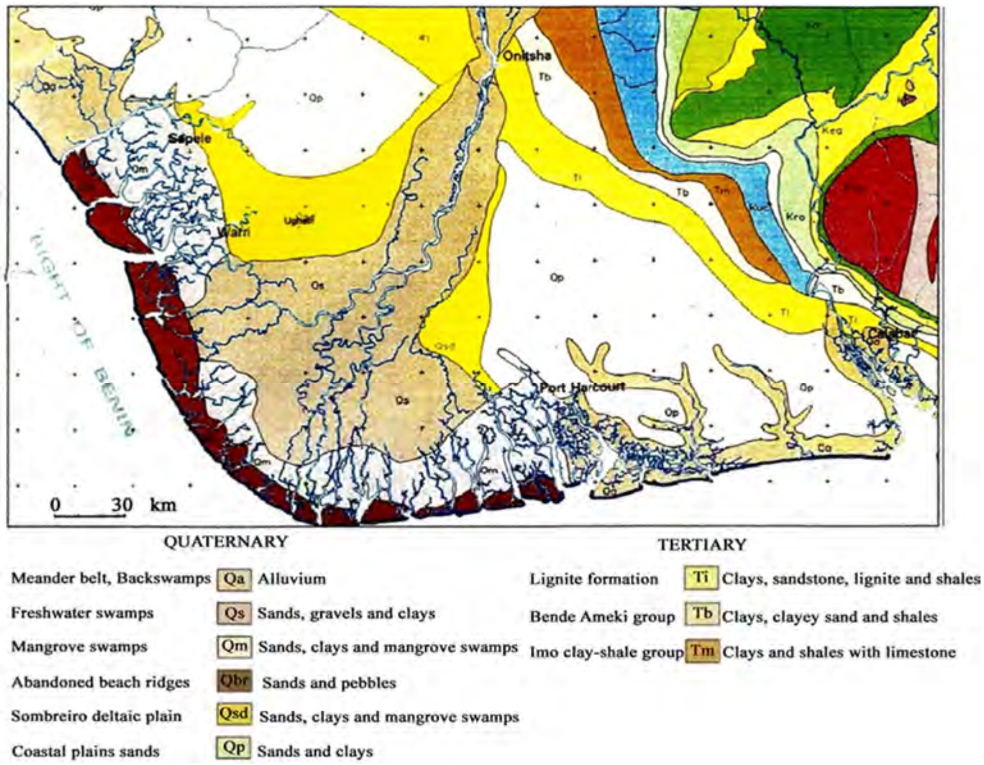
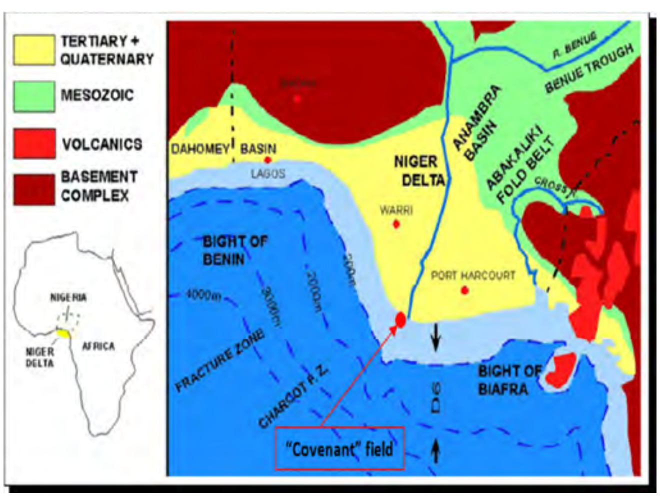


Fig 2 Geological map of the Niger Delta (after Reijers, T.J.A. 2011)



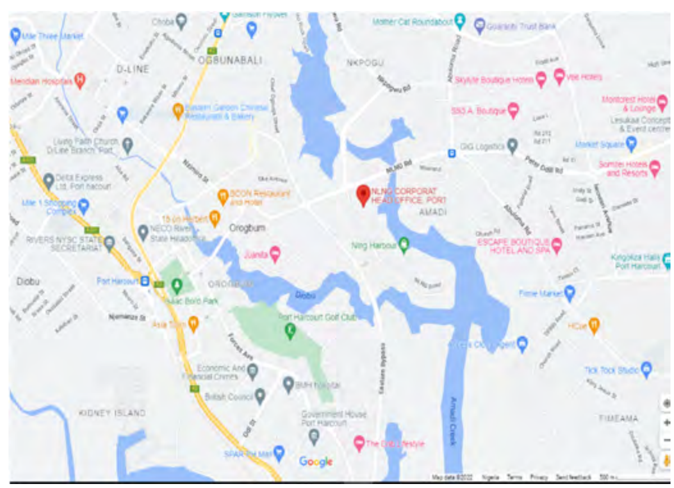


Fig 3. Niger Delta geological map (Ajisafe and Ako)

Fig.4 locations map of the survey (Google map)

Data Acquisition

A. Vertical Electrical Sounding

The earth resistivity (ER) survey was conducted using Schlumberger configuration for data acquisition. The Schlumberger array offers advantage over the Wenner array in that the former is more convenient from an operational point of view and local inhomogeneities. Schlumberger array used in the field survey is found to be more suitable for this study (Amechi et al 2018). This is because the array minimizes the lateral variation changes in geology as well as the near surface effect and increases the depth of the current penetration. The potential electrodes can be rapidly located on the apparent resistivity curves and theoretical computation can be performed with less assumption than similar computations for the Wenner array. Besides compensating for the effects of local shallow inhomogeneities the method is quick, cheap and current penetration is at greater depth.

The equipment used for this investigation is a self – averaging digital resistivity meter ABEM SAS 300 terrameter log 200B. It has the special characteristics of the ability to display the resistivity, portability and ability to automatically compensate for

(i) Polarization at the electrodes
(ii) Induced polarization of the earth materials and
(iii) Instrumental drifts effect

Field data was acquired at the proposed site astride the profile. The potential electrodes separation which is increased in steps is assured to be less than $1/3^{th}$ of the current electrodes separation, i.e. $P_1 P_2 < {}^1/_3 C_1 C_2$. A total current electrode separation of 700m for both surveys was marked out in this work. In each measurement, the digital averaging instrument displayed the resistance of the various formations. The electrodes layout is as shown in Figure 5 The measurements for the Schlumberger array commences with ${}^{AB}/_2$ (or $C_1 C_2$) = 1.0m and ${}^{MN}/_2$ ($P_1 P_2$) = 0.3m; which was gradually and symmetrically increased in steps complying with the relation $3\ {}^{MN}/_2 < {}^{AB}/_2$. With this procedure often called electric drilling the properties of the subsurface was explored. The figures below show the schematics of current flow into the ground and the electrode configuration, as well as the field crew at the project site yard

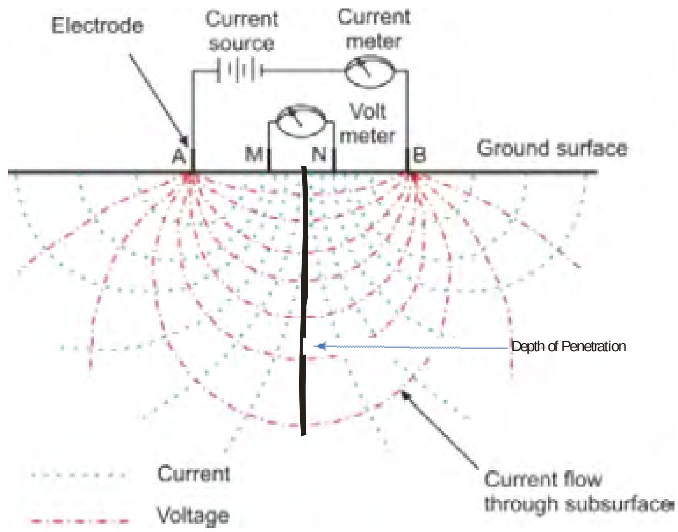


Fig 5. Current flow in the ground for resistivity determination

Fig 6. Field crew at the study area for data acquisition

B. Downhole logging

Three down hole log parameters were conducted in the drilled uncased well (Fig. 6). After the drilling has been completed but before casing the well, it was desirable to obtain more detailed data on the subsurface geology by taking geophysical measurements in the borehole. ABEM Terrameter SAS 300B log 200 was used to measure the electrical resistance and the spontaneous potential of the geological material along the open borehole wall. The logging was conducted by lowering the sonde of the logger into the mud filled uncased borehole after placing the surface return electrodes as specified; measuring and recording the values of the parameter against the corresponding depth.

A total depth of 190m was logged; the parameters recorded and analyze using the appropriate software. (Amechi, et al 2015)

The Spontaneous-potential (SP) logs record potentials or voltages developed between the borehole fluid and the surrounding rock and fluids. Spontaneous-potential logs can be used in the determination of lithology and water quality. Collection of spontaneous-potential logs is limited to water- or mud-filled open holes.

The **Normal-resistivity logs** record the electrical resistivity of the borehole environment and surrounding rocks and water as measured by variably spaced potential electrodes on the logging probe. Typical spacing for potential electrodes are 16 inches for short-normal resistivity and 64 inches for long-normal resistivity. Normal-resistivity logs are affected by bed thickness, borehole diameter, and borehole fluid and can only be collected in water- or mud-filled open holes.

Fig 7. Downhole logging process at NLNG borehole site.

Results and Discussions

A Analysis and Interpretation of VES Data

The profile survey carried out is interpreted on the foundation of VES-IP software program. Here field data for a profile is treated as a unity representing the geological structure of the survey area as a whole, rather than a set of independent objects dealt separately. The field data was transferred to the computer using spread sheet and a forward modelling subroutine was used to calculate the non-linear least square optimization. The software (IP12win) is capable of solving resistivity electrical prospecting 1D forward and inverse problems for a variety of commonly used arrays for the cross section with resistivity contrasts within the range of 0.00001 to 10000 ohm-m. The model parameters for the current sounding point (the resistivity, (in VES-IP mode) the thickness and upper boundary depth and altitude) are presented by blue line of the pseudo-log type in the window curve. They are also listed in the separate window table titled with fitting error values. The theoretical sounding curve for the current model parameters values is plotted in red in the curve window. The fitting error values represent the relative difference between the theoretical and field apparent resistivity curves. However, the geoelectrical cross-section thus obtained is actually regarded as the first-order approximation of the model of the geological structure along the observation line. This cross-section is analyzed taking its geological sense into account and matching of the result obtained and a priory data available.

From the VES results, five and six geoelectric layers were delineated with resistivity values ranging from 74.8Ωm to 11083 Ωm, and layer thickness of 1.17m (at first layer) to 194m in the first survey indicating high profile fresh water potentials in the area. (Fig 8). The first and second layers consist of consolidated sand with high resistivity and fresh water at shallow depth of 7.08m. The third layer has low resistivity probably sandy clay or brackish water. The fourth layer has high resistivity depicting fresh water aquifer at the depth of 254m and thickness of 194m sufficient enough to sustain high capacity yield. This result is considered in this report following the large spread.

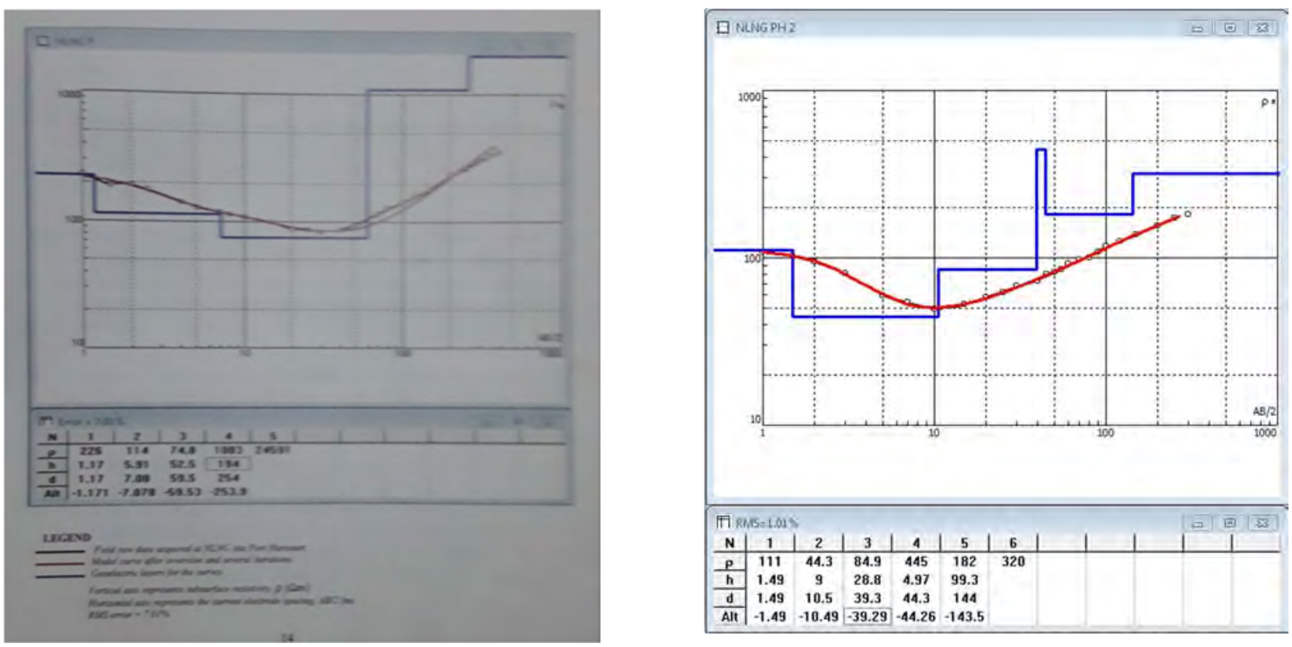
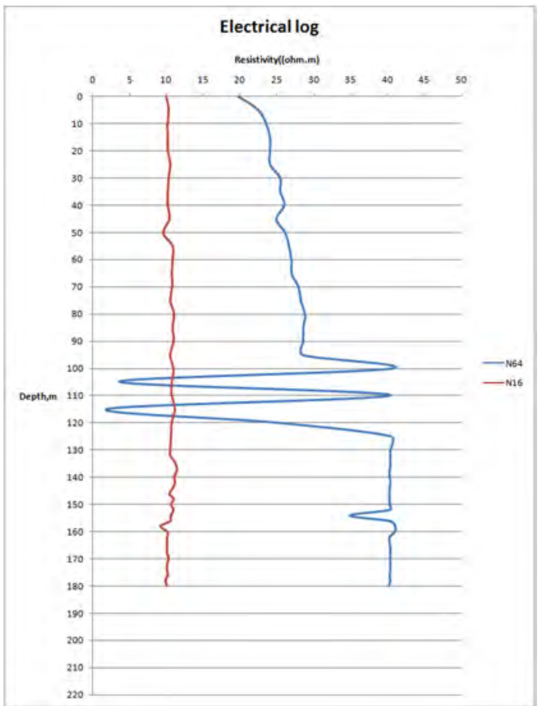


Fig 8. VES curves for the NLNG surveys 1 & 2

B Analysis of Downhole log

The drilled log sections present predominantly sand sequence with minimal clay intercalations throughout the drilled depth. According to log samples, total drilled depth was 230m, logged depth is 180m as a result of sand backfill during pulling. All logs were carried out in the uncased well. The three log curves began at 0m at ground surface, because the well is artesian. The logged SP and

Resistivity data were plotted using the appropriate chanting software. The low resistivity at the beginning is an indication of muddy top sands encountered in the borehole. The logged depth indicated relatively high resistivity values which depicts groundwater potential in the area. However, intercalation of clay was also noticed along the logged depth. According to local geology, mineralized iron is very prominent in the area at shallow depth. The log ‘kicks’ between 100 – 140m indicates saline water zone. The prospect therefore in this report is the sand bed lying between **140 – 230m** depth.



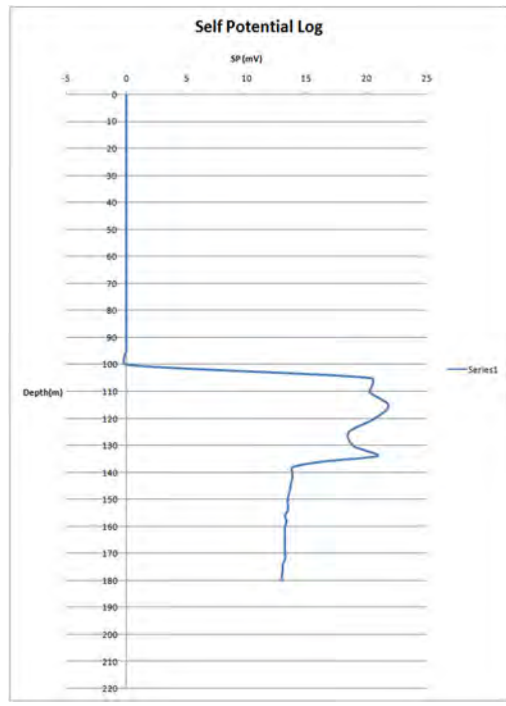


Fig 9. The downhole log curve of the study area

Correlation of Well Lithologies, logs and VES results

Integration of borehole-geophysics logging with VES results and sand sampling provides a more complete picture, to develop a water-supply well from a fresh water aquifer. To validate our VES interpretation for the study area, two soundings were executed near astride wells with known lithology. The wells (1 & 2) are located far apart within the study area, one very close to the shoreline was logged for this study. The 1D interpretation results and the correlation to the corresponding subsurface lithology showed perfect correlation at depth 230m.

Table 1 Drill soil sample logs for the project site

Depth (m)	Description	Remark
0 - 25	Sand, Top soil	
25 - 30	Sand, silt dark brown	
30 - 50	Sand, silt brownish	
50 - 95	Sand, fine grayish	
95 - 102	Sand, fine-medium coarse gray	
102 - 105	Sand, clay gray	SALINE WATER ZONE
105 - 115	Sand, fine-medium gray	
115 - 125	Sand, Coarse	
125 - 140	Sand, clay	
140 - 180	Sand, coarse	FRESH WATER AQUIFER
180 - 200	Sand, medium coarse	
200 - 230	Sand, coarse	

Conclusion.

The hydrogeology of the Niger delta is dominated by the Benin Formation, which serves not only as aquifer but also facilitates recharge of groundwater in the region. Consequently, the distribution and availability of groundwater depend on the occurrence and characteristics of Benin Formation in the locality. This study demonstrates the important contribution of the surface geoelectric and subsurface investigations for fresh water supply in saline terrain of Port Harcourt. The resistivity and the downhole techniques is effective geophysical tools for exploring deep aquifers, a principal source of groundwater in the sedimentary basin of Niger Delta region. The validity of the hydrogeological interpretation of the geophysical data is proved by several agreements between the resistivity distribution with depth and the aquiferous zone of the area.

The electrical resistivity log data show that the depth to the freshwater interface varies across the study area occurring between 150 and 230 m. The variations in depth of the freshwater interfaces are attributed to the extent of saline/brackish water contamination and distribution of rock types revealed at a depth of 100 – 140m. This deeper aquifers are less vulnerable as they enjoy some degree of protection of the intervening clay interaction embodied within the aquifer system. These deeper aquifers are considered safe and relatively free from pollution except in the coastal areas. However, there is the danger that over-pumping of groundwater could increase the already deep salinity depth thereby reducing the effective column of fresh water.

References

1. Allen J. R. L., (1965) "Late Quaternary Niger Delta and Adjacent Areas: Sedimentary Environments and Lithofacies," American Association of Petroleum Geologists Bulletin, Vol. 49, No. 5, 1965, pp. 549-600.
2. Amajor, L.C. (1991) Aquifers in the Benin Formation (Miocene Recent), Eastern Niger Delta, Nigeria: Lithostratigraphy, Hydraulics, and Water Quality. Environmental Geology and Water Sciences, 17, 851-860. https://doi.org/10.1007/BF01701565
3. Amechi, Bright U and Horsfall, J.O (2015). Well design, construction and downhole logs for prolific fresh water aquifer delineation at the Rivers State University of Science and Technology, Nkpolu. Port Harcourt. Nigeria. *World Journal of Applied Science and Technology, Vol. 7 No.2 (2015).*
4. Amechi Bright U, Tamunubereton-ari .I., Womuru E.N (2018). Application of Earth Resistivity Measurement in the North Eastern Rivers State (a geoelectric based study) Journal of scientific and Engineering Research, 2018, 5(2): 18-24
5. Etu-Efeotor, J.O. and Akpokodje, E.G. (1990) Aquifer Systems of the Niger Delta. Journal of Mining and Geology, 26, 279-285.
6. Nwankwoala, H.O. and Ngah, S.A. (2014) Groundwater Resources of the Niger Delta: Quality Implications and Management Considerations. International Journal of Water Resources and Environmental Engineering, 6, 155-163. https://doi.org/10.5897/IJWREE2014.0500.
7. Offodile, M.E. (2002) Groundwater Study and Development in Nigeria. 2nd Edition, Mecon Geology and Engineering Services Ltd., Jos, 453 p.
8. Onuoha, K. M. and. Mbazi, F. C. C (1988). Aquifer Transmissvity from Electrical Sounding Data: The Case of the Ajali Sandstone Aquifers South-West Enugu, Nigeria," In: C. O. Ofoegbu, Ed., Groundwater and Mineral Resources of Nigeria, F. Vieweg, Braunschweig/Wiesbaden, 1988, pp. 17-30
9. O. Anomohanran (2013). Geophysical investigation of groundwater potential in Ukelegbe, Nigeria. Appl. Sci., 13 (2013), pp. 119-125.
10. Short, K.C. and Stauble, A.J. (1967). Outline of Geology of Niger Delta: American Association of Petroleum Geologists Bulletin, Volume 51, pp 761-799.
11. Reijers, T.J.A. (2011) Stratigraphy and Sedimentology of the Niger Delta. Geologos, 17, 133-162. https://doi.org/10.2478/v10118-011-0008-3
12. T.C. Ajisafe and B.D. Ako, 3-D seismic attributes for reservoir characterization of "Y" field Niger Delta, Nigeria, IOSR Journal of Applied Geology and Geophysics 1 (2) (2013), 23 – 31