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INVESTIGATION OF FRESH WATER AQUIFER DELINEATION USING INTEGRATED GEOPHYSICAL METHODS AT LA SIEN WATER PRODUCTION FACTORY ALONG AZIKIWE ROAD, PORT HARCOURT, NIGERIA.

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ABSTRACT

An integrated geophysical investigation for freshwater aquifer delineation was carried out along Azikiwe road opposite BUA factories in Port Harcourt, Rivers State. The study integrates the electrical, well drilling and downhole logs for the delineation of freshwater aquifer for potable drinking water production and supply. Drill samples using rotary rig were collected for correlation with the log data. Electrical downhole log using ABEM SAS 200 log was used for the spontaneous and normal resistivity logs, to determine the appropriate position of the sand screen. Log results perfectly correlated with the earth resistivity measurements. The vertical electrical survey (VES) employed using Schlumberger array is an effective, quick, reliable, and economic means of obtaining details about the electrical characteristics of the subsurface. The pre-drilling investigation is aimed at furnishing information on the nature and thickness of different subsurface layers in order to assess the potability of the aquifer for water production and supply. The results obtained in this work show that apparent resistivities of the formation vary with certain aquifer characteristics. The topsoil is mainly made up of sandy materials with different degrees of compaction and saturation. The sub soil indicates varying degrees of resistance which increase with the spread. The drill depth of 70 m, resistivity of 324 ohm-meter and thickness of 42.1m were recommended.

Key words: Resistivity, downhole logs, vertical electrical sounding, groundwater, borehole drilling.

INTRODUCTION

Groundwater is an important natural resource and vital for many people as their only source of daily drinking) water. However, groundwater resources are unequally distributed in the world due to differences in the geological setting, especially in the shallow part of the subsurface, the first few hundred meters, where often the main groundwater resources are located. The groundwater occurrence in the subsurface is mainly related to the distribution of permeable layers, e.g. sand, gravel, unconsolidated, fractured, or weathered rocks, and impermeable or low-permeable layers, e.g. clay, consolidated sediments, or solid rocks. The key physical properties used to describe these permeable and impermeable layers are porosity, permeability, or hydraulic conductivity (Ibim and Womuru, 2018). Porosity (Φ) describes the percentage of pore space between the grains or minerals of a sediment or rock, which can be filled with air or with (ground) water, usually in percent or part of 1. Permeability (k) describes the ability of a rock or sediment to transmit a fluid or gas through its pore space, either in the old unit of Darcy or SI unit of m^2. However, it is important to note that clean sand saturated with fresh water show relatively high resistivity whereas dirty sand containing clay or even salt or iron show low resistivity.

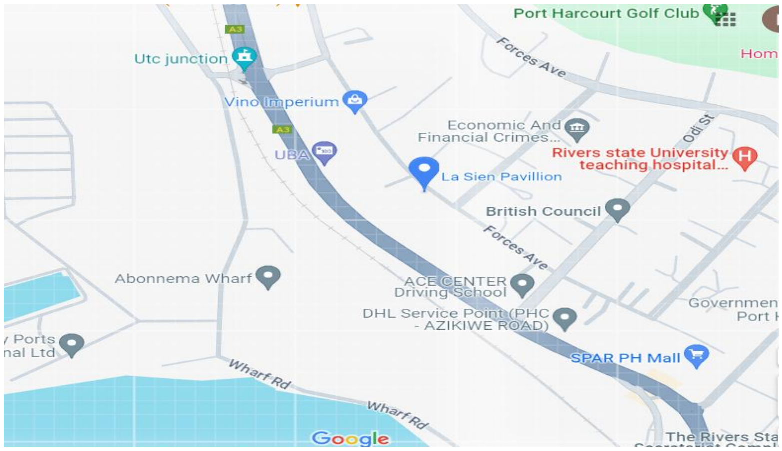


Figure 1. Location map of the study area (after Google map data 2023)

Geology and Hydrogeology of the Study Area.

The study area is geographically positioned between latitude 4.90^{0}N and longitude 7.08^{0}E and lies within the Niger Delta region of Nigeria. This region is characterized by two major seasons - wet and dry seasons. The wet season begins in March and ends in October, with a peak in June and July. The study area is characterized by high temperature and humidity as is common with humid tropical climate. Average annual temperature in the area is about 27°C with maximum values in the months of March and April, and the lowest in July and August. The main drainage pattern around Port Harcourt is largely controlled by the Bonny River, its tributaries, and creeks. It is a major feeder to several creeks and creek lets, which together drain the various "outcrops" of relatively higher land, which are largely surrounded by the mangrove swamps (Amaechi et al., 2022). These creeks can be sub-divided into three sections: the headwaters, which are usually freshwater streams, the brackish in between them and the saltwater. Due to the discharge of clay and silt into the river channels, rivers are mostly turbid during the wet season. The major aquiferous formation in the study area is the Benin Formation. It is about 2100 m thick at the basin centre and consists of coarse to medium grained sandstones, thick shales, and gravels. The upper section of the Benin Formation is the quaternary deposits which is about 40 - 150 m thick and comprises sand and silt/clay with the later becoming increasingly more prominent seawards (Etu-Efeotor and Akpokodje, 1990). The formation consists of predominantly freshwater continental friable sands and gravel that have excellent aquifer properties with occasional intercalations of claystone/shales (Olabaniyi and Oweyemi, 2006). According to Etu-Efeotor (1981), Etu-Efeotor and Akpokodje (1990), Offodile (2002), and Udom et al. (2002), the main source of recharge is through direct precipitation where annual rainfall is as high as 2000 - 2400 mm. Groundwater in the study area occurs principally under water table conditions. Multi-aquifer systems occur in the study area and the upper aquifers are generally unconfined (Offodile, 2002; Udom, 2004).

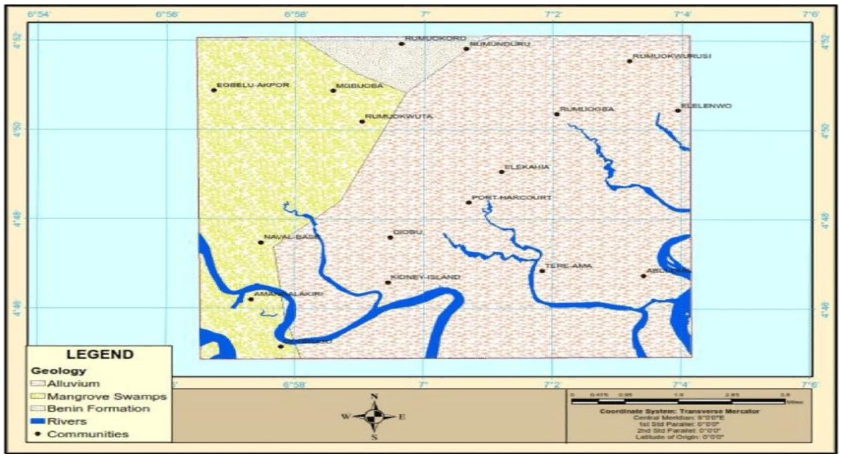


Figure 2: Geologic map of Port Harcourt and environs (After NGSA, 2006)

Geologically, Port Harcourt area is overlain by the Niger Delta sedimentary rocks. Litho-stratigraphically, these rocks are divided into the oldest Akata Formation (Paleocene), the Agbada Formation (Eocene) and the Youngest Benin Formation (Miocene to Recent). Generally, the present knowledge of the geology of the Niger Delta is derived from the works of the following researchers (Reyment, 1965; Short and Stauble, 1967; Olatunji et al., 2005) as well as the exploration activities of the oil and gas companies in Nigeria. The formation of the proto-Niger Delta occurred during the second depositional cycle (Campanian- Maastrichtian) of the southern Nigerian basin. However, the modern Niger Delta was formed during the third and last depositional cycle of the southern Nigerian basin which started in the Paleocene. The geologic sequence of the Niger Delta consists of three main Tertiary subsurface lithostratigraphic units (Short and Stauble, 1967) which are overlain by various types of Quaternary deposits.

Materials and Methods

Principles of Earth Resistivity Measurement

Electrical geophysical prospecting methods detect the surface effects produced by electric current flow in the ground. Using electrical methods, one may measure potentials, currents, and electromagnetic fields that occur naturally or are introduced artificially in the ground. In addition, the measurements can be made in a variety of ways to determine a variety of results. There is a much greater variety of electrical techniques available than in the other prospecting methods, where only a single field of force or anomalous property is used. Basically, however, it is the enormous variation in electrical resistivity found in different rocks and minerals that makes these techniques possible (Telford et al., 1976). The Electrical Resistivity of a geologic unit or target is measured in ohmmeters, and depends on its porosity, permeability, water saturation and the concentration of dissolved solids in pore fluids within the subsurface. Electrical Resistivity methods measures the bulk resistivity of the subsurface.

The basic principle used in resistivity method is the ohms law (V = IR). Resistance R, in ohms of a wire is directly proportional to its length L and is inversely proportional to it cross area A. That is:

$$R \propto \frac{L}{A} \; or \; R = \rho\frac{L}{A} \qquad (1)$$

where ρ is the constant of proportionality and is known as electrical resistivity and is a characteristic of the material which is independent of its shape and size (Zohdy, 1989). As earlier stated, most rock- forming minerals are insulators, thus electrical current is carried through rocks mainly by the passage of ion in pore waters. This means that porosity is the major controlling factor of the resistivity of rocks and resistivity increases as porosity decreases. Archie's Law gives an equation which establishes the relationship between the resistivity of a porous rock and the fluid saturation factor. This law is true for certain types of rocks and sediments, particularly those that have a low clay content. The electrical conduction is assumed to be through the fluids filling the pores of the rock. The relationship between pore-water resistivity (ρ_w) and bulk resistivity (ρ_o) is given by the formation factor (F) give as:

$$F = \frac{\rho_0}{\rho_w} \qquad (2)$$

The formation factor is related to porosity (∅) by this equation:

$$F = \alpha\emptyset^{-m} \qquad (3)$$

where, ∅ = Porosity, α = Constant ranging from 0.47 to 2.2 m = Cementation constant ranging from 1.3 to 2.6.
Combining equation 2 and 3, we have

$$\rho_o = \alpha\rho_w\emptyset^{-m} \qquad (4)$$

The equation (4) represents the Archie's Law. The potential V_0 at an internal electrode C is given by;

$$V_o = V_A + V_B \qquad (5)$$

For the Schlumberger configuration, Figure 3, if: *A:* The positive current electrode, *B:* The negative current electrode, *M* and *N*: Potential / voltage electrode; then, the resistivity formula using Schlumberger array (Fig 3) becomes:

$$\rho = \pi \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} * \frac{\Delta V}{I} \qquad (6)$$

where the Geometric factor, K, and resistance, R are given as

$$K = \pi \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \, and \; R = \frac{\Delta V}{I}$$

Or

$\rho_a = KR$, where ρ_a is the apparent resistivity.

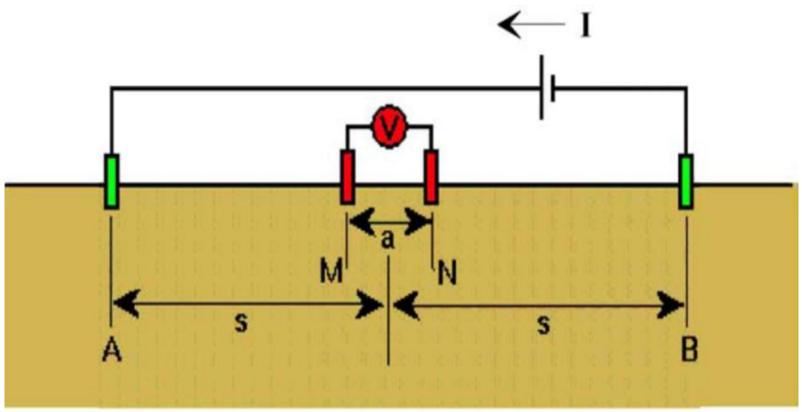


Figure 3: Sketch diagram of Schlumberger array

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 (Zohdy, 1989). 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 Terameter. It has the special characteristics of the ability to display the resistivity, portability, and ability to automatically compensate for *polarization at the electrodes, induced polarization of the earth materials and instrumental drifts effects.*

Borehole drilling process

Though every process will have its own individual requirements, the process of water borehole drilling generally follows the same steps. It starts with hydrogeologist visiting the site for an assessment. They can identify where the water is, if any and the best way to access it. It is important to have an expert to assess the geophysical properties of the site and soil, using a range of techniques to determine the conditions. This means no drilling will take place until we are certain that the site is suitable, and we know exactly which method and equipment to use. After mapping the site and planning the borehole, we can proceed with the drilling in line with the hydrogeologist's recommendation. We subsequently reinforce the borehole with a casting of steel, PVC, or both to securely maintain its structure through challenging outdoor conditions. Next, we install a test pump, which we use to run a series of test on a range of variables. The results will reveal how the drilled borehole will impact the water level, and which measures are required to control these changes (Amaechi and Horsfall, 2015). This will inform the final choice of water pumping system to install. Last, but not least, we install the appropriate pipework and pump in the borehole. At Teckna Group, we use a variety of high-quality systems, including Grundfos, Caprarl, and Lowara. We can also install the water borehole head at ground level or above ground in a protective chamber.

Geophysical Downhole logging

The work was in cooperation with the Regional Office of the Department of Groundwater Resources (DGR). DGR drilled the wells and usually shortly after drilling the geophysical logging was performed using an MGX II logger from Mount Sopris, U.S.A. The probe, also called tool, comprises nine parameters measured at the same time, with more details given by Rider (2002) and Ariyo et al. (2024).

Earth Resistivity Measurements

Field data was acquired on the 3rd November, 2023 at the proposed site astride the profile using ABEM SAS 300C. The potential electrodes separation which is increased in steps assured to be less than 1/5th of the separation of the current electrodes, i.e. $P_1 P_2 < C_1 C_2 /5$. A total current electrode separation of 240 m was marked out in this work due to limited space. In each measurement, the signal averaging instrument displayed the resistance of the various formations.

The measurements for the Schlumberger array commence with AB/2 or C_1 C_2 = 1.0m and MN/2 or P_1 P_2 = 0.3m; which was gradually and symmetrically increased in steps complying with the relation $5\ {}^{MN}/_2 < {}^{AB}/_2$. With this procedure often called electric drilling the properties of the subsurface were explored. The figure below shows the schematic of current flow into the ground and the electrode configuration used.

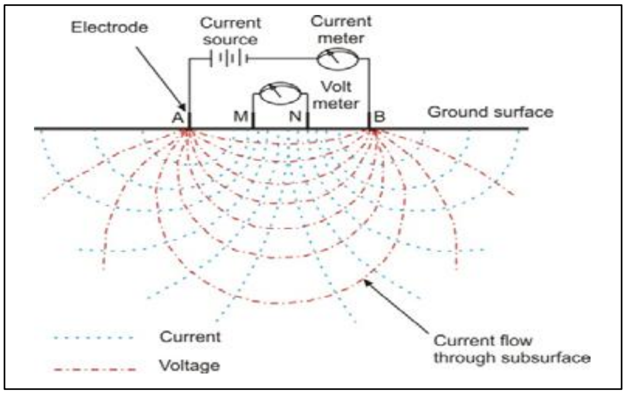


Figure 4: Electrical circuit for R*e*sistivity determination

Spontaneous Potential (SP)

Spontaneous potential logs are a record of the natural potential developed between borehole fluid and the surrounding rock materials. The spontaneous potential log is a graphic plot of small differences in voltage, measured in millivolts (mV) that develop at the contacts between the borehole fluid, the shale or clay and the water in the aquifer. Shale baseline readings against shale/clays formations are relatively constant and are referred as 'shale baseline'. Opposite permeable formations the SP curve typically shows deflections to the left (negative SP) or to the right (positive SP) of shale-base line depending upon the relative salinity of the drilling mud and formation water.

Log data was achieved by lowering the SONDE or probe down the drilled uncased mud filled open well. The data was acquired on 10th Dec 2023 in the presence of the representative of the client Mr. Tony and other staff and drillers. The surface current and potential electrodes were placed at specified distance apart. Measurements of the varying values of the parameters were made against corresponding depths. The field data were used as the initial model for the computer aided interpretation using the appropriate chanting software.

Normal Resistivity (16 and 64)

Normal resistivity (R) curves are derived from a four-electrode system, using two current electrodes A and B, and two potential electrodes, M and N. as only two electrodes, A and B, are effective in measuring the apparent resistivity, the normal devices are sometimes called the two-electrode method. Spacing between electrode A and M gives the name of the four normal curves, the 8-inch, 16-inch, 32-inch, 64-inch normal. A and M are relatively close together, whereas B and N are not only far from each other, but are also distant from the electrode group

AM. This means that the apparent resistivity is determined primarily by the potential of the measuring electrode M (Nwankwoala and Udom, 2011). Resistivity values are shown in ohm-meter.

Geophysical logging was carried out in seven boreholes in the study area, selected and accessed in cooperation with the DGR, with four wells having a final depth between 52 m to 76 m and the three other wells have final depth values between 44 and 72 m.

Results

Table 1: Cutting description from the depth (m)

Depth (m)	Description
0 – 10	Sand, Top lateritic brownish
10 – 20	Sand, fine large brown
20 – 30	Sand, grained grayish
30 – 60	Sand, large grained light gray
60 – 70	Sand, medium coarse
70 – 73	Sand, fine gray

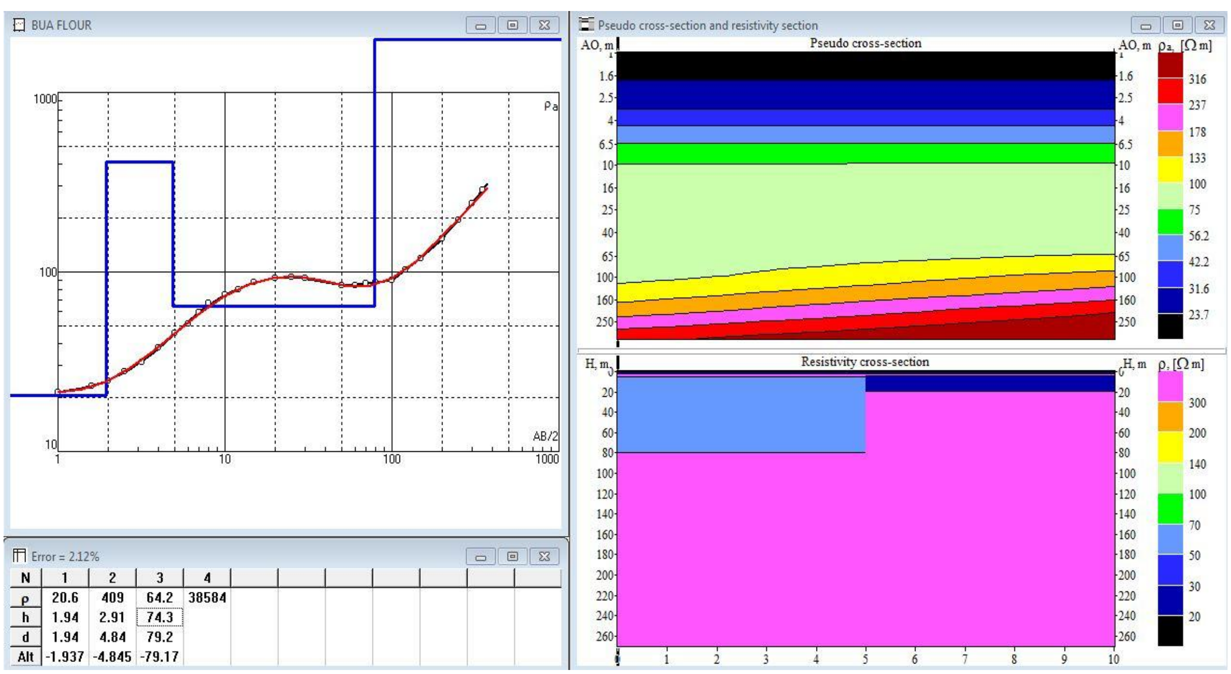
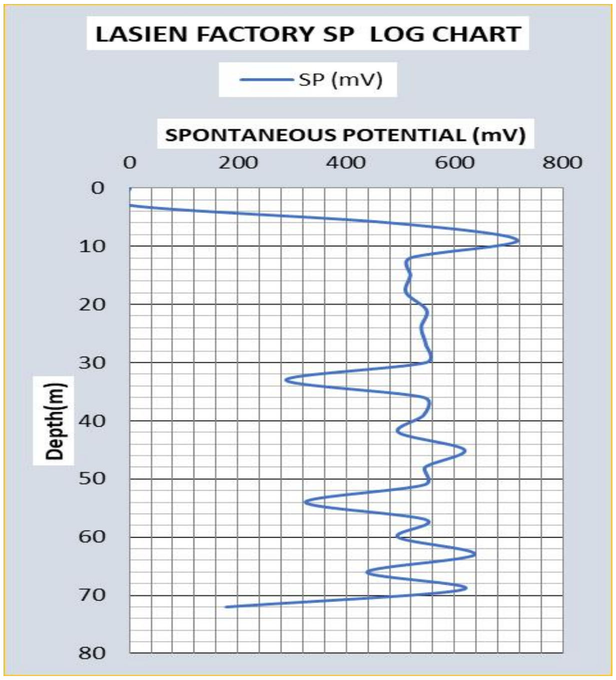


Figure 3: VES curves at La-Sien opposite BUA complex



No

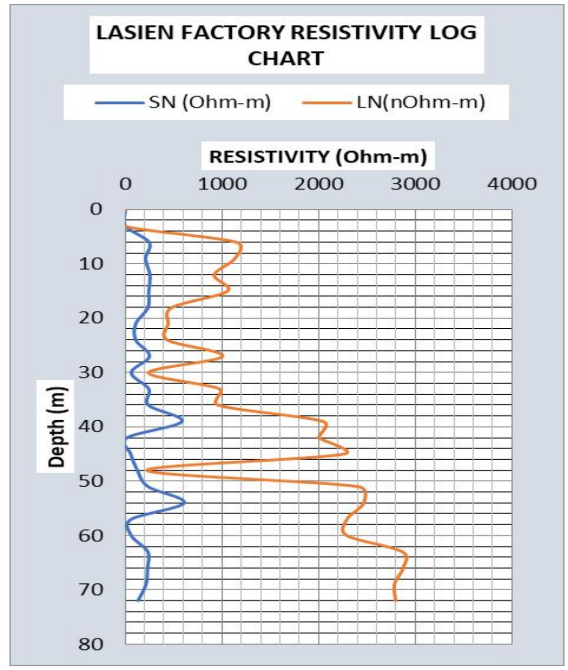


Figure 4: Geophysical log curves for SP and normal resistivity

DISCUSSION

The drilled log sections present predominantly sand sequence with some undefined clay intercalations. The three log curves begin at 6m from ground level. The high resistivity at the beginning is an indication of top sand fill encountered in the borehole. (fig. 4). The rest of the logged depth indicated resistivity values which depicts groundwater potential of area. According to local geology, mineralized iron is very minimal in the area. The prospect therefore in this report is sand bed lying between 50 – 72m depth.

An important first step in the interpretation of the spontaneous potential data is whether a shale/clay baseline can be established. If this is not possible any further analysis and interpretation is more difficult and uncertain. If a baseline can be established any deflection to the left indicate a permeable groundwater bearing zone, usually a sand or sandstone Udom and Amah, 2006). Further, the SP deflections are correlated with normal resistivity data. If a deflection corresponds with an increase in resistivity, this indicates fresh groundwater with lower TDS, whereas a SP deflection correlates with no changes in R is likely an indicator for salty groundwater or groundwater with higher TDS (Ofoma et al., 2008).

The raw field were processed by using the appropriate chanting ID inverse computer software program. The VES data are presented as sounding curves which are obtained by plotting graphs of apparent resistivity versus half-current electrode spacing on double logarithmic graph sheets. However, the geoelectrical cross-section thus obtained is 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.

CONCLUSION

An integrated geophysical investigation for freshwater aquifer delineation was carried out along Azikiwe road opposite BUA factories in Port Harcourt, Rivers State. The study integrates the electrical, well drilling and downhole logs for the delineation of freshwater aquifer for potable drinking water production and supply. The vertical electrical survey (VES) employed using Schlumberger array is an effective, quick, reliable, and economic means of obtaining details about the electrical characteristics of the subsurface. The pre-drilling investigation is aimed at furnishing information on the nature and thickness of different subsurface layers in order to assess the potability of the aquifer for water production and supply. The results obtained in this work show that apparent resistivities of the formation vary with certain aquifer characteristics. The topsoil is mainly made up of sandy materials with different degrees of compaction and saturation. The sub soil indicates varying degrees of resistance which increase with the spread. The drill depth of 70 m, resistivity of 324 ohm-meter and thickness of 42.1m were recommended. Drill samples using rotary rig were collected for correlation with the log data. Electrical downhole log using ABEM SAS 200 log was used for the spontaneous and normal resistivity logs, to determine the appropriate position of the sand screen. Log results perfectly correlated with the earth resistivity measurements.

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