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APPLICATION OF ELECTRICAL RESISTIVITY METHOD IN QUANTITATIVE ASSESSMENT OF GROUNDWATER RESERVE OF UNCONFINED AQUIFERS

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ABSTRACT
Application of Electrical Resistivity Method in Quantitative Assessment of Groundwater Reserve of Unconfined Aquifers was carried out at Port Harcourt and Obio/Akpor Local Government Areas, Rivers State, Nigeria, in order to locate, delineate subsurface water resources and estimate its reserve. A Wenner electrode configuration was employed. The field survey was conducted along thirteen profiles providing continuous coverage. Color-modulated sections of resistivity versus depth were plotted for, giving an approximate image of the subsurface. The field survey was accompanied by a laboratory work. Resistivity of rock and soil samples taken from the field were measured and the resistivity formation factors were obtained. The porosities and hydraulic conductivities of the same samples were calculated. A relationship between the porosity and the formation factor has been established. The laboratory established relationship was applied to the data obtained in the field to calculate the porosity values of the formation present within the investigated area. The porosity values were contoured and plotted. Depth to the bedrock for each line was obtained. A commercial computer software was used to enable the computation of groundwater reserve within the investigated area. The results showed that the layers associated with the aquifers have resistivities between 345 Ω.m and 8286 Ω.m, and are located at depths varying from 6 to 51 m. The layers have porosity between 18% and 35%. The results obtained from the electrical resistivity profiles indicate that the aquifers occupy a surface area of about 15977900 m^2 with a mean depth and net volume of 29 m and 204610000 m^3 respectively. The average aquifer porosity was revealed to be 30%, suggesting a usable capacity of about 61,383,000 ± 7,980,440 m^3 reserve of groundwater.

Key words: Obio/Akpor, Groundwater, Unconfined aquifer, Porosity, Resistivity

INTRODUCTION
Groundwater is a major source of clean drinking water all over the world. It has been an important resource especially in the dry part of the world. Groundwater has been used in Port Harcourt and Obio/Akpor metropolis for many decades. Increased demands for water have provoked development of underground water resources. As a result, techniques for investigating the occurrence and flow of groundwater have been improved, better equipment for extracting has been developed, concepts for resource management have been established, and researches have contributed to a better understanding of the subject (Groundwater).
Since geophysical exploration is the scientific measurement of physical properties of the earth crust for investigation of mineral deposits or geologic structure, the present project is conducted mainly to apply electrical resistivity method in groundwater exploration, in particular to estimate the groundwater reserve within the unconfined aquifer. In any hydrogeological investigation of an area knowledge about the relationship between petrophysical properties of the rock formation and the hydrogeological characteristics is very important to enable the full potential of the aquifer to be assessed (Mendosa *et al.,* 2003). In the present work emphasis has been placed on the application of electrical resistivity method in the quantitative assessment of groundwater reserve. It is known that features such as porosity, density, clay content, cementation, pore water saturation, the quality of pore water and others affect

geophysical measurements on geological deposits. In order to arrive at this information using geophysical methods, the relationship between the geophysical characteristics and the geological and hydrogeological parameters must be determined (Mendosa *et al.,* 2003). However, before this can be done, the underlying petrophysical properties of the rock formation and their relationships should be known. The formation properties investigated include the effective porosity, intergranular hydraulic conductivity and electrical resistivity (with the associated true formation factor). This work resulted in the discovery of the relationships between these petrophysical properties of the formation within the study area. The difficulty encountered in the development of both rural and urban water projects and periodical borehole failures recorded in the areas of the study may have resulted from the fact that no detailed geophysical survey for mapping groundwater flow patterns has been carried out. However, the hydraulic characteristics of these aquifers such as hydraulic conductivity and storage potentials are not fully known and it has not been possible to design accurate management strategies for optimal exploitation of these aquifers. This problem is further compounded by the inadequate knowledge of the aquifers being tapped. Although numerous boreholes have been drilled at various parts of the study areas, there has not been any systematic and comprehensive study to establish the nature, distribution and reserves of the aquifers beneath. This study is therefore aimed at locating, delineating subsurface water resources and estimating its reserve. The study among others will therefore assist government agencies in the planning, development and management of the groundwater reserve within the study areas. It will also help scientist design management strategies for optional protection of groundwater resource (aquifer).

The Study Area

The urban area (Port Harcourt metropolis), on the other hand, is made up of the local government area itself and parts of Obio-Akpor and Eleme accordingly (Ogbonna *et al*., 2007). Port Harcourt City is the capital of Rivers State and one of the rapidly growing urban centers in the South South geopolitical region of Nigeria. The city and its environs hosts the Rivers State University, University of Port Harcourt, Ignatius Ajuru University of Education, production industries and most oil and gas servicing companies. The topography is invariably gentle. Plant type is generally mangrove except in the mainland areas where large areas are covered with oil palm and large trees.

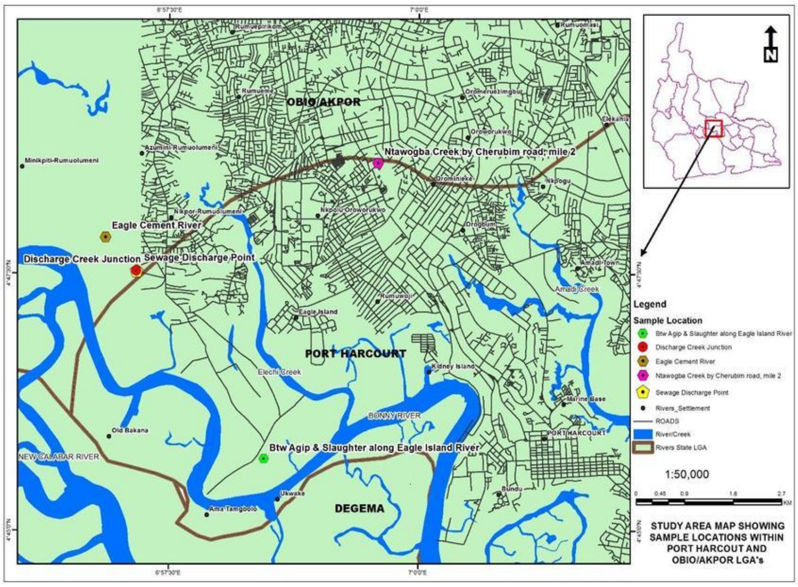
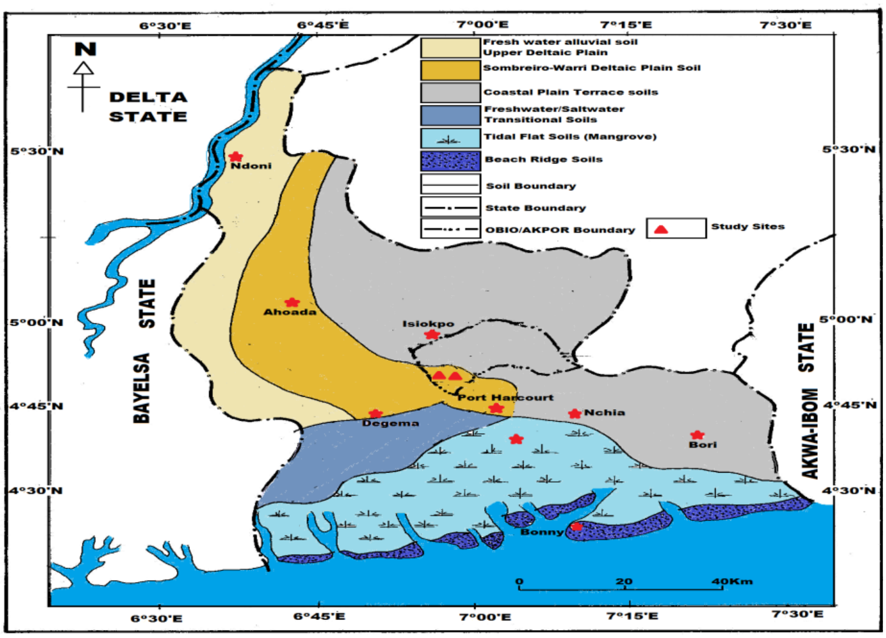


Figure 1: Map of Study Area Showing Sample Locations within Port Harcourt and Obio/Akpor LGAs

Port Harcourt features a tropical wet climate with lengthy and heavy rainy seasons and very short dry seasons. Only the months of December to February truly qualifies as dry season months in the city. The harmatan, which climatically influences many cities in West Africa, is less pronounced in Port Harcourt. Port Harcourt's heaviest precipitation occurs during September with an average of 367 mm of rain. December on average is the driest month of the year, with an average rainfall of 20 mm. Temperatures throughout the year in the city are relatively constant, showing little variation throughout the course of the year. Average temperatures are typically between 25°C – 28^{0}C in the city (Ogbonna *et al.*, 2007).
There may be wide spread occurrence of flooding during the wet season due to high amount of monthly rainfall. This amount of rainfall influences the water table of the area which fluctuates at different seasons. Water in the soil will definitely affect the in-situ moisture content and equally affect the strength value or geotechnical properties by reducing the shear strength of foundation soil in this area (Abam, 1999).

Geology and Hydrogeology of the Study Area
The geology and geomorphology of the Niger Delta have been described in details by various authors (Short and Stauble 1965; Etu-Efeotor and Akpokoje, 1990). The formation of the present day Niger Delta started during Early Paleocene and it resulted mainly from the build-up of fine grained sediments eroded and transported by the River Niger and its tributaries.
Stratigraphically, three formations are locally designated in the Niger Delta Basin (from the bottom) as Akata Formation, Agbada Formation and Benin Formation respectively which are in turn overlain by quaternary sediments (Fatoke, 2010; Short and Stauble, 1965).



(Adapted from Ehirim and Nwankwo, 2010)

The topmost unit is the Benin formation; it is comprised of over 90% sandstone with shale intercalations. It is coarse grained, gravely, locally fine grained, poorly sorted, sub angular to well-rounded and bears lignite streaks and wood fragments (Allen, 1965). The thickness of the Formation ranged from 0 to 2,100 m (Tuttle et al., 2015). The unit is thickest in the central area of the Delta. The contact with the underlying Agbada formation is defined by the base of sandstones which also corresponds to the base of the fresh water bearing strata. The Benin Formation has been described as "Coastal Plain Sands" which outcrop in Benin, Onitsha and Owerri provinces and elsewhere in the delta area. The sediments present upper deltaic deposits. The sand may represent braided stream point bars and channel fills and or crevasse splay deposits. The shales are few and thin and they may represent back swamp deposits. It is the main source of potable groundwater in the Niger Delta area.

Materials and Methods of Investigations

Thirteen (13) electrical resistivity imaging surveys were carried out in the area using the Wenner configuration. The resistivity measurements are normally made by ejecting current into the ground through two current electrodes, C_1 and C_2, and measuring the resulting voltage difference at two potential electrodes, P_1 and P_2. From the current (I) and the voltage (V) values, an apparent resistivity (ρ_a) value is calculated using an equation such as:

$$\rho_a = \frac{K\Delta V}{I} = 2\pi a\left(\frac{\Delta V}{I}\right) = 2\pi aR = KR \qquad (1)$$

where K is geometric factor which depends on the arrangement of the four electrodes, a is the electrode spacing for the Wenner configuration and R the resistance. In this work, the physical parameters that have been used to assess groundwater reserve are the electrical resistivity and formation factor and the potential groundwater reserve is indicated by porosity. The laboratory established relationship between the formation factor and porosity was adopted to the results of 2D electrical resistivity imaging survey of the area to obtain the subsurface distribution of porosity of the area under investigation. Hydraulic conductivity of rock and soil samples were determined in the laboratory to know the rate of flow of the groundwater. The depth to the bedrock is determined by using the result of subsurface electrical resistivity and porosity distribution along each line. The elevation of the top of the bedrock throughout the area is viewed by using the coordinates and the depth to the bedrock of each line.

Formation Factor

For a rock saturated with water, Archie (1942) established an empirical relationship linking the resistivity of the rock, the porosity, the nature of distribution and resistivity of the electrolyte:

$$R_{rock} = R_w a\emptyset^{-m} \qquad (2)$$

Where R_{rock} is the bulk resistivity of the rock in ohm.m; R_w the resistivity of the formation water in ohm.m; $\emptyset$ the porosity in %; m the cementation factor and 'a' the factor which depends on the lithology.

Generally, the parameters in the above equation characterizing the texture of the rock are known as the Formation Factor, F:

$$F = \frac{R_0}{R_w} = a\emptyset^{-m} \qquad (3)$$

where R_0 is the resistivity of the formation with 100% saturation of brine of resistivity R_w. Equation (3) established the relationship between the formation factor and the effective porosity.

From observations in the Niger Delta, the value of 'm' (cementation factor) is between 1.8 and 2 (Schlumberger, 1989). In this work, we adopt 'a' as 0.62 and 'm' as 2. Equation (4) was adopted in this work.

$$F = \frac{0.62}{\emptyset^{2.15}}, \quad for\ sands \qquad (4)$$

Determination of Effective Porosity and Hydraulic Conductivity of the Core Samples

For the purpose of this study, rock samples within the study area were obtained. These samples were cored using a coring-machine with sample corer of 570 mm diameter, and then cut into cylindrical shape in order to calculate their volume. The length range from 2 to 4 cm.

Importantly, prior to the determination of porosity and permeability, the liquid and salt originally present in the pore spaces of the core material is removed, the samples were put into a vacuum desiccator and evacuated at a pressure of 0.3 mbar for a period of *one hour*, following the method suggested by Emerson (1969). At the end of the period, deaerated distilled water was introduced into the desiccator until the water completely covers the samples. The samples were soaked for

24 hours, to allow salts within the samples to diffuse into the surrounding solution (Emerson, 1969).

The cleaned samples were dried in a conventional temperature-controlled oven utilizing a constant temperature of 105^{0}C for 16 hours (API, 1960; Emerson, 1969; Galehouse, 1971).
The dried core samples were put into the desiccator to cool off to the ambient air temperature prior to being weighed. An electronic top-pan balance, preferably the Sartorius model 1264 MP with 0.01 g accuracy, was used to weigh the samples. Before measurement of the wet weight of the samples, the diameter and lengths were taken with a vernier caliper (0.05 mm accuracy). Several measurements of the diameter and lengths of the samples were taken and the average values noted.
The next stage in the procedure is to determine the wet weight of the sample. Under an ideal condition, the vacuum pump used in the present work is capable of evacuating the system up to 0.01 mbar.
The effective porosity *Ø* of each sample was calculated using the following relationship:-

$$\emptyset = \frac{W_w - W_d}{V} \quad (5)$$

where *Ø* is the porosity, W_w is the wet weight in gm, W_d is the dry weight in gm, and V is the volume in cm^3.

The Hydraulic Conductivity of the Cored Samples were determined using the falling (or variable) head method. In the determination of the hydraulic conductivity using the falling head method, the hydraulic conductivity K in this work has been calculated from equation (6).

$$K = 2.3 * L\left(\frac{\mu}{\mu_0}\right) * \left(\frac{r_{t2}}{r_{s2}}\right) * \left(\frac{L}{t}\right) * m \quad (6)$$

where μ is kinematics viscosity of the water at temperature T; μ_0 is kinematics viscosity of the water at standard temperature; r_t is the radius of manometer tube; r_s is radius of rock specimen; L is length of specimen; t is time taken for the manometer column to fall a reference height h_0 to length h_1, and m the gradient of the line using the method of least square regression of logh_1 against t.

Determination of Electrical Resistivity of the Core Sample

The resistance of the core samples was measured with OYO McOhm Resistivity Meter, Model – 2115, and using a 4 – electrode electrolyte – buffered horizontal cell system. The electrode system included spiral coil copper current electrodes, and non-polarizing calomel electrodes were used for potential measurements and were connected directly across each sample (Ibrahim, 1988). The resistance R of the sample was measured by the OYO McOhm Resistivity Meter and the resistivity ρ of the sample of length L and cross-sectional area A was computed from the relationship:

$$\rho = \frac{R * A}{L} \quad (7)$$

The resistance R_w of the saturating electrolyte was measured using the same cells arrangement and computed in a manner as above.

Determination of Porosity and Hydraulic Conductivity of Soil Samples

For the purpose of this study, soil samples from selected locations were obtained. In practice the porosity *Ø*, as defined previously, would be most easily measured by saturating a sample, measuring its total volume V_T, weighing it and then oven drying it to constant weight at 105^{0}C. The weight of water removed could be converted to a volume, knowing the density of water. This volume is equivalent to the volume of the void space V_v, and the porosity *Ø* could be calculated (Todd, 1980) using the equation:

$$\emptyset = \frac{V_v}{V_T} \quad (8)$$

In practice, it is quite difficult to exactly and completely saturate a sample of given volume. It is more useful to make use of the relationship

$$\emptyset = 1 - \frac{d_b}{d_p} \qquad (9)$$

which can be developed by simple arithmetic manipulation of the basic definition of porosity, where d_b is the bulk mass density of the sample, and d_p is the particle mass density. The bulk density is oven-dried mass of the sample divided by its field volume.

Hydraulic Conductivity

The hydraulic conductivity in this work was determined by a permeameter I which flow is maintained through a small sample of material while measurements of flow rate and head loss are made (Todd, 1980). The constant-head permeameter was used in this work. From Darcy's law, the hydraulic conductivity was obtained from:

$$K = \frac{VL}{tAh} \qquad (10)$$

where V is the flow volume in time t; L is the length of the sample; A is the horizontal area of the sample; h is a constant-head differential.

Results and Discussion

The main objective of this research work is to adopt electrical resistivity method in groundwater exploration specifically in the quantitative assessment of groundwater reserve. In order to delineate and locate the various layers that could contain water. To appreciate the significance of the resistivity values measured in the field, laboratory measurements on effective porosity, electrical resistivity (an associated formation factor) was conducted.

Effective Porosity

Porosity measurements on core samples and soil were conducted. Tables 1 & 2 in the appendix show the porosity values of the rock and soil respectively. Laboratory investigation indicated that the porosity of the rock sample of the area ranged between 3.95 and 11.15% while that of the soil has porosity ranging from 35 to 43%.

Variation of Formation Factor against the Porosity of Rock and Soil Samples

Electrical resistivity measurements were conducted on both rock and soil samples from the study area in order to obtain resistivity formation factor. A relationship between the formation factors and the porosities has been established. Figure 3 shows the variation of formation factor against the fractional porosity of the rock samples, while figure 4 shows the variation of formation factor against the porosity of the soil samples.

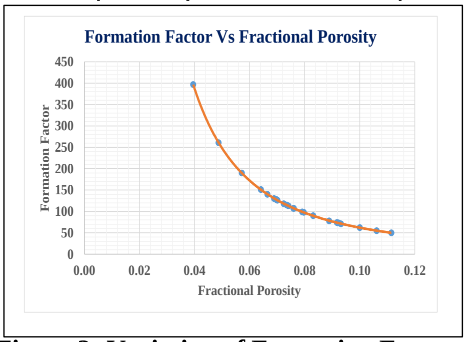


Figure 3: Variation of Formation Factor Against Fractional Porosity of Rock Sample

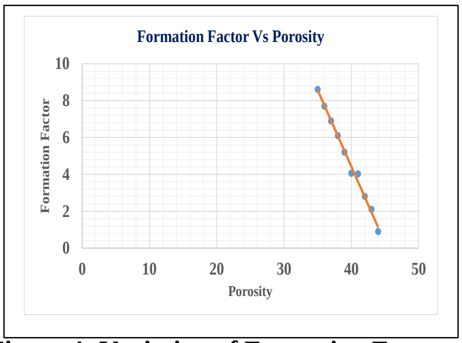


Figure 4: Variation of Formation Factor against Porosity of Rock sample

In order to relate the formation factor and the fractional porosity of the earth material encountered in the study area, results from rocks and soil measurements have been integrated. The purpose of this integration is to obtain a single equation, which describes how the formation factor will vary as the fractional porosity of the earth varies within the study area. This equation was then used to calculate the subsurface porosity of the earth as indicated by the results of 2D electrical resistivity imaging survey carried out in the area. The results of laboratory investigation on fractional porosity *Ø* and formation factor *F* of the study area is as shown in the appendix (table 5 and table 6) combined. Figure 5 shows the variation of formation factor against porosity of rock and soil samples.

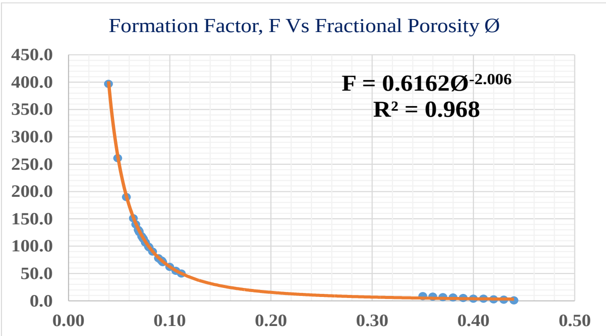


Figure 5: Variation of Formation Factor against Porosity of Rock and Soil Samples

The power regression of data points obtained in the present investigation yield an equation:

$$F = 0.6162\emptyset^{-2.006} \qquad (11)$$

With

$R^2 = 0.968$ (R = 0.9838)

This equation was used to calculate the porosity of subsurface material once the resistivity and formation factor of the area were obtained from the application of resistivity modeling using RES2DINV.

Hydraulic Conductivity

Hydraulic conductivity of rock and soil samples taken from the study area was investigated in order to assess the rate of groundwater flow within the unconfined aquifer (i.e. the soil) and the bedrock. The relationship between formation factor and hydraulic conductivity was also investigated. The results of hydraulic conductivity investigation on unfissured hard rock samples indicated that hydraulic conductivity of the rock material varies between 0.8×10^{-8} ms^{-1} to 9.6×10^{-8} ms^{-1} with an average value of 4.07×10^{-8} ms^{-1} as shown in the appendix, table 3. The hydraulic conductivity of soil samples taken from the study area shows a variation between 5.2×10^{-7} ms^{-1} and 23.0×10^{-7} ms^{-1} with an average value of 12.6×10^{-7} ms^{-1} as shown in appendix, table 4. This shows that groundwater flow in the soil varies between 24 to 65 times faster than that of hard rock. This is to be expected since there are more voids in the soil matrix as compared to the hard rock. Figure 6 show the variation of formation factor against hydraulic conductivity of rock samples, while figure 7 show the variation of formation factor against hydraulic conductivity of soil samples respectively.

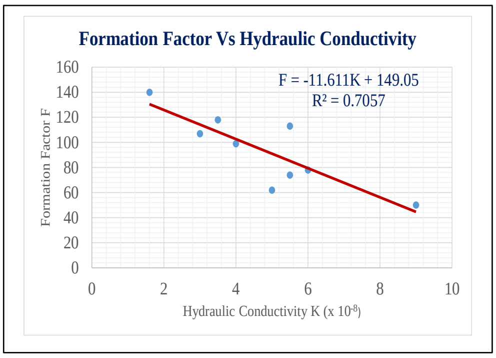


Figure 6: Variation of Formation factor against Hydraulic Conductivity of Rock Sample

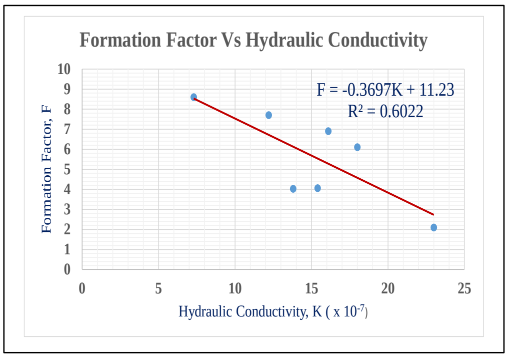


Figure 7: Variation of Formation factor against Hydraulic Conductivity of Soil

Distribution of 2D Electrical Resistivity Imaging

Seven (7) lines of 225 m each of electrical survey was carried out in Port Harcourt local Government Area of the survey area. Figure 8 shows the average distribution of the electrical resistivity along the lines. The figure shows high resistivity regions 216 Ω.m to 8695 Ω.m in the top left and at the bottom of the image. Field observation indicated that the top resistive zone are related to hard cover material while the bottom resistive part is interpreted as the weathered and fresh bedrock of Benin Formation in the bottom of the image. Materials having resistivities between 29.7 Ω.m and 216 Ω.m situated between 3 m and 11 m depth are mixture of soils constituting the porous unconfined aquifer.

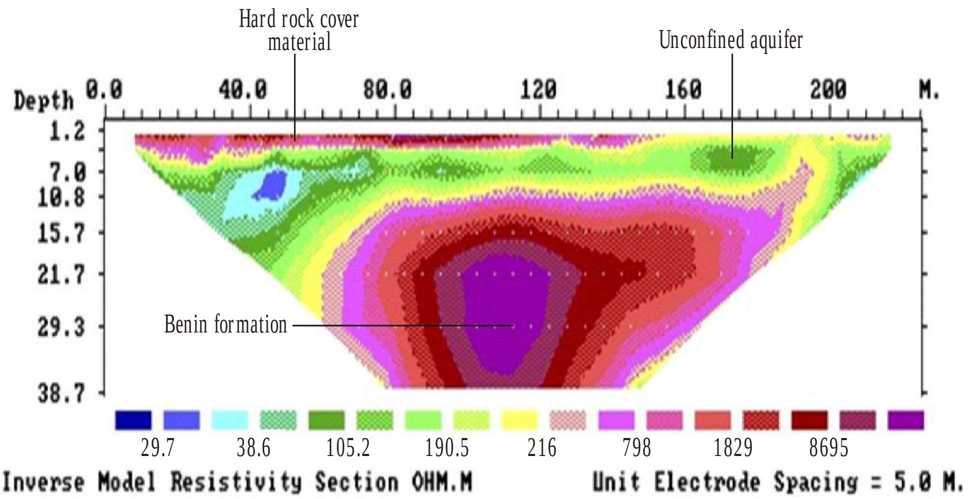


Figure 8: Average Distribution of Electrical Resistivity Values, PHLGA Lines.

Similarly, Six (6) lines of 225 m each of electrical survey was carried out in Obio/Akpor local Government Area of the survey area. Figure 9 shows the average distribution of the electrical resistivity along the lines. The area surveyed consists of sandstone member of the Benin Formation with resistivity 87.8 Ω.m to 6288 Ω.m which constitutes the central part of the image from the depth 15 m until to a depth of about 40m. The clayel with resistivity between 87.8 Ω.m and 204 Ω.m underlies the sandstone. Hard cover materials with resistivity 475 Ω.m to 6288 Ω.m are found in the top central part of the image. 16.2 Ω.m to 87.8 Ω.m is the unconfined aquifer of the area.

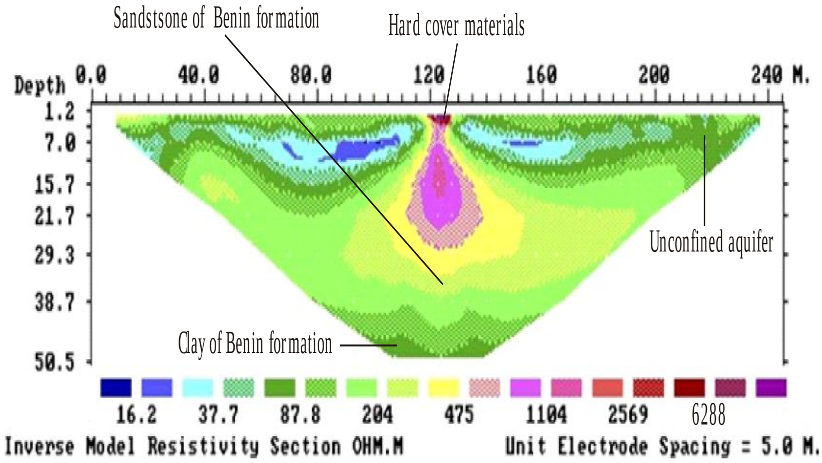


Figure 9: Average Distribution of Electrical Resistivity Values, OBALGA Lines.

Porosity Distribution

The ultimate objective of the present investigation is to determine the subsurface distribution of porosities within the unconsolidated soil (i.e. tin tailing and residual soil) which formed the unconfined aquifer. The study has also yield information on the porosity distribution within the fresh and weathered bedrock. To obtain the true resistivity of the formation, inversion of apparent resistivity field data was carried out using RES2DINV. The procedure to use the RES2DINV essentially involves the reading of field data, inversion of the data to get the true resistivity and true depth of the field resistivity image. After the reading and inversion of the data, the x position, depth and true resistivity are saved in XYZ format. The calculated resistivity is divided by the formation water resistivity to get resistivity formation factors. The previous laboratory established relationship between the formation factor and porosity (i.e. equation 11) was applied to the field data to calculate the porosity distribution of the formation. A computer software called DIPIX-PLUS was used to plot and contour the porosity values (Stoyer, 1987). The figures below are the average porosity distribution along electrical resistivity imaging lines in PHLGA and OBALGA respectively.
The porosity of the lines in Port Harcourt Local Government Area (PHLGA) ranges between 8% and 35%. The average subsurface porosity distribution of the area is shown in Figure 10. The area consists of hard cover material in the top part of the traverse and Benin Formation is situated in the bottom of the traverse with porosity ranging between 8% and 14%. Unconfined aquifer with porosity ranging between 21% and 35 is located between the top hard cover and the underlying Benin Formation.

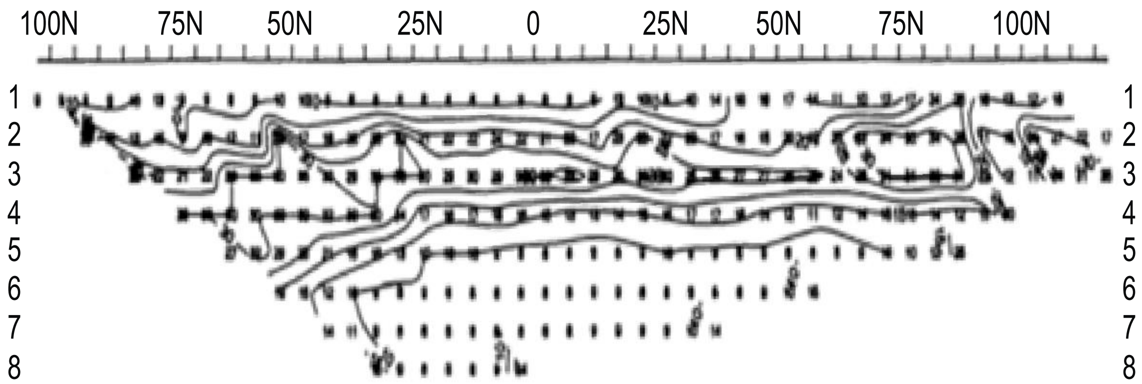
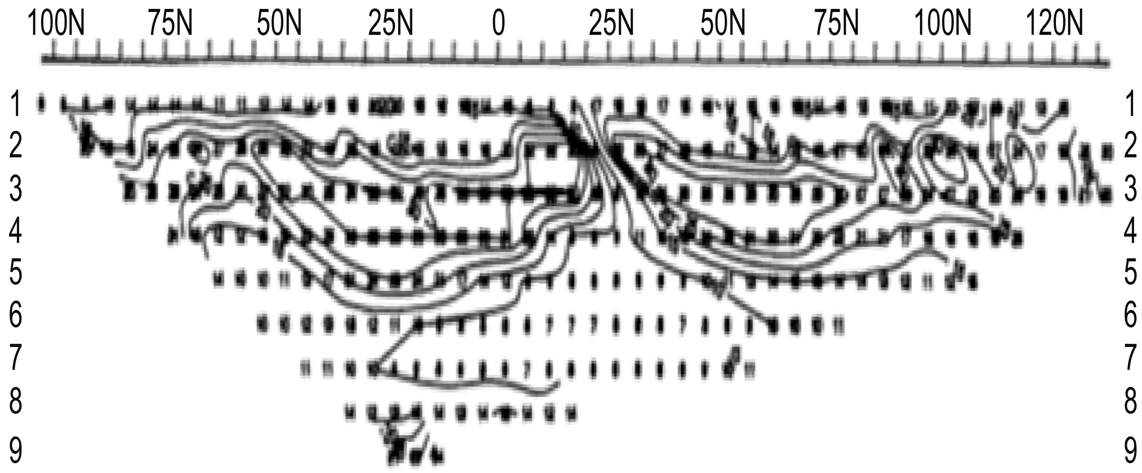


Figure 10: Average Subsurface Porosity Distribution, PHLGA Lines.

The porosity of the lines in Obio/Akpor Local Government Area (OBALGA) ranges between 7% and 35%. Figure 11 shows the average subsurface porosity distribution of the area. The top central part of the traverse having porosity between 7% and 8% interpreted as hard cover material. Materials having porosity from 10% to 14% are sandstone of Benin Formation underlain by the clay of the same formation. Unconfined aquifer having porosity ranging from 16% to 35% is located in the right and left-hands sides of the traverse ranging in depth from 10 m to 20 m.



Bedrock Elevation and Estimation of Groundwater Reserve
The main objective of this study is to estimate the groundwater reserve. Subsurface electrical resistivity distribution and subsurface porosity distribution were determined (as described in the proceeding sections) to locate water-bearing zones and to determine the depth to the bedrock. The use of SURFER programme is very essential in the present investigation since it enable the determination of the total volume of unconfined aquifer investigated within the study area.
The volume of unconfined aquifer has been obtained using the depth to the bedrock data as shown in the appendix, table 9. The volume of the layer that could contain water is calculated for the whole area. The net volume of the aquifer calculated using SURFER programme is found to be 204610000 m^3. The average porosity of the unconfined aquifer is 30%. Therefore, the approximate volume of porous zone is 30% of the net volume of the aquifer (61,383,000 m^3). To calculate the error in volume, we used the following equation;

$$\frac{\Delta V}{V} = \left(\frac{\Delta l}{l}\right) + \left(\frac{\Delta w}{w}\right) + \left(\frac{\Delta d}{d}\right) + \left(\frac{\Delta \emptyset}{\emptyset}\right) \qquad (12)$$

where, ΔV is the error in volume V; Δl is the error in length; Δw is the error in width; Δd is the error in depth and $\Delta \emptyset$ is the error in porosity. Δl *and* Δw are almost negligible. Then,

$\Delta V/V = 0 + 0 + (3/25) + (0.3/30)$
$\Delta V/V = 0 + 0 + 0.12 + 0.01 = 0.13$
$\Delta V = V \times 0.13 = 61{,}383{,}000 \times 0.13 = 7{,}980440$ (13)
From this information we can conclude that there exist 61,383,000 ± 7,980,440 m^3 of water residing within the study area.

Conclusion
Thirteen Wenner electrical resistivity imaging surveys were conducted throughout the study area. The apparent resistivity data obtained from these imaging surveys were analyzed to determine the aquifer boundaries and estimate its reserve. The laboratory investigation on the porosity, resistivity and hydraulic conductivity indicated that the hard rock within the study area having porosity ranging from 3.95% to 11.15%, while the soil porosity is between 35% and 43%. Resistivity of the hard rock varies from 173 Ω.m to 1219 Ω.m, whereas in soil the resistivity varies between 9

Ω.m and 83 Ω.m. Hard rock have hydraulic conductivity ranging between $0.8x10^{-8}$ ms^{-1} and $11x10^{-8}$ ms^{-1}, while in the soil hydraulic conductivity varies between 5.2 x 10^{-7} ms^{-1} to 23.0 x 10^{-7} ms^{-1}. The formation factor *F* and fractional porosity Ø relationship which was used to calculate the subsurface porosities of earth materials was found to be: -$F = 0.6162Ø^{-2.006}$

Field investigation carried out in the present study have shown that the layers associated with the aquifers have resistivities between 345 Ω.m and 8286 Ω.m and are located at depths varying from 6 to 51 m. The layers have porosity between 18% and 35%. The results obtained from the electrical resistivity profiles indicate that the aquifers occupy a surface area of about 15977900 m^2 with a mean depth and net volume of 29 m and 204610000 m^3 respectively. The average aquifer porosity was revealed to be 30%, suggesting a usable capacity of about 61,383,000 ± 7,980,440 m^3 reserve of groundwater. Though this figure is only an approximate and is open to further refinement, it provides a useful guideline to be taken into account in exploitation of the groundwater present in the area.

Combination of the 2-D resistivity images obtained from the thirteen lines, with the results of the laboratory measurements, boreholes information and geological data shows a general agreement and suggests that electrical imaging surveys can be used as a fast and efficient exploration tool to determine the aquifer boundaries and estimate its reserve. However, it is advisable to use other geophysical methods such as seismic refraction method to probe the subsurface for bed rock measurement for comparison.

References

Abam, T.K.S. (1999). Dynamics and quality of water resources in the Niger delta. Impacts of urban growth on surface water and groundwater quality. Preceedings of IUGG Symposium, Birmigham, Publication no. 259.

Allen, J.R.L. (1965). Late Quaternary Niger Delta and Adja- cent Areas: Sedimentary Environments and Lithofacies. American Association of Petroleum Geologists Bulletin 49(5), 549 – 600.

American Petroleum Institute, API. (1960). Recommended practice for core analysis procedure. Rp No. 40. Pp 55.

Archie, G.E. (1942). The electrical resistivity logs as aid in determining some reservoir characteristics. Trans. Am. Inst. Min. Metall., Engineers 146, 54 – 62.

Ehirim, C.N. & Nwankwo, C.N. (2010). Evaluation of aquifer characteristics and groundwater quality using geoelectric method in Choba, Port Harcourt. Archives of Applied Science Research, 2(2), 396 – 403.

Emerson, D.W. (1969). Laboratory electrical resistivity measurements of rocks. Proc. Aust. Inst. Mining and Metall. 230, 51 – 62.

Etu-Efeotor, J.O. & Akpokoje, E. G. (1990). Aquifer systems of the Niger Delta. Journal of Mining and Geology 26(2), 279 – 284.

Fatoke, O.A. (2010). Sequence stratigraphy of the pliocene-pleistocene strata and shelf-margin deltas of the Eastern Niger Delta, Nigeria (PhD). University of Houston.

Galehouse, J.S. (1971). Sedimentation Analysis in R.F. carver (ed). Procedures in Sedimentary Petology. New York: Willey-Interscience. Pp.653.

Mendosa, F.G., Steenhuis, S.T., Todd Walter, M., & Parlange, J.Y. (2003). Estimating basin-wide hydraulic parameters of a semi-arid mountainous watershed by recession-flow analysis. Journal of Hydrology 279, 57 – 69.

Ogbonna, D.N., Amangabara, G. & Okere, T.O. (2007). Urban solid waste generation in Port Harcourt metropolis and its implications for waste management. Management of environmental quality. An International Journal, 18(1), 71– 88.

Schlumberger, (1989). Well evaluation conference Nigeria: Schlumberger Technical Services Inc.

Short K. & Stauble, A. J. (1965). Outline of geology of Niger Delta. American Association of Petroleum Geologists 51(5), 761 – 779.

Todd, D.K. (1980). Groundwater hydrology (2nd edition). New York: John Wiley. Pp 535.

Tuttle, M., Charpenter, R. & Brownfield, M. (2015). The Niger Delta Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa. United States Geologic Survey

Wenner, F. (1915). A method of measuring earth resistivity: U.S. Bur. Standards Bull. 12, Sci. Paper, 469 – 478.

Appendix

Table 1: Calculation of Porosity "Ø" for Rock Samples

Sample No.	W_d (gm)	W_w (gm)	$W_w - W_d$ (gm)	V (cm^3)	Ø (%)
1	227.67	237.21	9.54	89.85	10.62
2	210.37	219.57	9.20	82.50	11.15
3	241.44	248.38	6.94	93.56	7.41
4	259.68	266.56	6.88	99.71	6.89
5	241.21	247.93	6.72	95.86	7.01
6	125.52	128.79	3.27	46.78	6.99
7	174.63	179.99	5.36	67.71	7.92
8	231.57	237.91	6.35	91.10	6.96
9	237.17	244.09	6.92	91.10	7.60
10	215.07	222.76	7.69	82.50	9.32
11	227.10	233.25	6.16	84.95	7.25
12	231.62	238.36	6.75	88.65	7.61
13	241.23	244.73	3.51	88.65	3.95
14	238.67	243.05	4.39	89.90	4.88
15	245.38	254.47	9.09	98.48	9.23
16	275.21	285.22	10.01	108.33	9.24
17	266.38	276.09	9.72	105.87	9.18
18	262.99	269.75	6.77	101.70	6.65
19	261.18	268.41	7.24	98.48	7.35
20	260.05	269.03	8.98	100.95	8.89
21	265.89	272.37	6.48	100.94	6.41
22	252.89	258.31	5.42	94.79	5.72
23	263.40	271.40	8.00	100.33	7.97
24	246.81	256.60	9.79	97.86	10.00
25	237.66	245.44	7.78	93.56	8.31

Table 2: Calculation of Porosity "Ø" for Soil Samples

Sample No.	(d_b)	(d_p)	$1-\left(\frac{d_b}{d_p}\right)$	Ø (%)
1	1.42	2.5	0.42	42
2	1.41	2.5	0.42	42
3	1.42	2.4	0.41	41
4	1.44	2.4	0.40	40
5	1.41	2.4	0.41	41
6	1.38	2.4	0.42	42
7	1.42	2.4	0.41	41
8	1.38	2.4	0.42	42
9	1.36	2.4	0.43	43
10	1.38	2.3	0.42	42
11	1.53	2.5	0.39	39
12	1.57	2.4	0.35	35
13	1.61	2.5	0.36	36
14	1.55	2.4	0.35	35
15	1.57	2.4	0.35	35
16	1.52	2.4	0.37	37
17	1.53	2.5	0.39	39
18	1.52	2.5	0.39	39
19	1.51	2.4	0.37	37
20	1.55	2.5	0.38	38
21	1.50	2.5	0.40	40
22	1.53	2.5	0.39	39
23	1.51	2.4	0.37	37
24	1.48	2.4	0.38	38
25	1.45	2.4	0.40	40

Table 3: Calculation of Hydraulic Conductivity "K" for Rock Samples

Sample No.	L (m)	$\left(\frac{\mu}{\mu_0}\right)$	$\left(\frac{r_{t2}}{r_{s2}}\right)$	m (x 10^{-6})	K (x 10^{-8}) ms^{-1}
2	0.036	0.896	0.02	60	9
3	0.04	0.896	0.02	33	5.5
4	0.041	0.896	0.02	4.8	0.8
5	0.039	0.896	0.02	5.6	0.9
7	0.036	0.896	0.02	27	4
9	0.038	0.896	0.02	5.8	0.9
10	0.035	0.896	0.02	6.2	0.9
11	0.035	0.896	0.02	24	3.5
12	0.037	0.896	0.02	19.7	3
13	0.038	0.896	0.02	5.1	0.8
14	0.035	0.896	0.02	5.5	0.8
15	0.038	0.896	0.02	5.8	0.9
16	0.043	0.896	0.02	40	7
17	0.046	0.896	0.02	29	5.5
18	0.041	0.896	0.02	9.5	1.6
19	0.039	0.896	0.02	43	7
20	0.043	0.896	0.02	34	6
21	0.038	0.896	0.02	9.6	1.5
22	0.039	0.896	0.02	12.4	2
23	0.042	0.896	0.02	35	6
24	0.041	0.896	0.02	30	5
25	0.041	0.896	0.02	30	5
26	0.043	0.896	0.02	45	8
27	0.041	0.896	0.02	57	9.6
28	0.039	0.896	0.02	31	5
29	0.04	0.896	0.02	6	1
30	0.042	0.896	0.02	64	11
31	0.039	0.896	0.02	11	1.8

Table 4: Calculation of Hydraulic Conductivity "K" for Soil Samples

Sample No.	(t) sec	V (m^3)	L (m)	A (m^2)	h (m)	K ($x\ 10^{-7}$) ms^{-1}
1	3309	0.0001	0.064	0.001194	0.938	17.3
2	3521	"	"	"	"	16.2
3	3708	"	"	"	"	15.4
4	4530	"	"	"	"	12.6
5	4200	"	"	"	"	13.6
6	4140	"	"	"	"	13.8
7	4300	"	"	"	"	13.3
8	4100	"	"	"	"	13.9
9	3807	"	"	"	"	15.0
10	3500	"	"	"	"	16.3
11	7786	"	"	"	"	7.3
12	9807	"	"	"	"	5.2
13	4623	"	"	"	"	12.4
14	7902	"	"	"	"	7.2
15	2485	"	"	"	"	23.0
16	5514	"	"	"	"	10.4
17	6624	"	"	"	"	8.6
18	6180	"	"	"	"	9.2
19	7907	"	"	"	"	7.3
20	4668	"	"	"	"	12.2
21	6120	"	"	"	"	9.3
22	3540	"	"	"	"	16.1
23	5160	"	"	"	"	11.1
24	5760	"	"	"	"	9.9
25	3180	"	"	"	"	18.0

Table 5: Variation of formation Factor against Porosity of Rock Samples

Sample No.	ρ_a (Ω.m)	Ø	F
1	173.0	0.10618	55
2	168.0	0.11152	50
3	552.0	0.07412	113
4	667.5	0.06895	130
5	681.5	0.07010	126
6	696.0	0.06990	127
7	528.0	0.07916	99
8	653.0	0.06965	128
9	537.5	0.07596	107
10	408.0	0.09321	71
11	639.5	0.07245	118
12	552.0	0.07609	107
13	1219.0	0.03954	397
14	964.5	0.04878	261
15	340.5	0.09225	73
16	340.5	0.09241	73
17	336.0	0.09177	74
18	557.0	0.06652	140
19	504.0	0.07352	115
20	350.5	0.08891	78

Table 6: Variation of Formation Factor against Porosity of Soil Samples

Sample No.	ρ_a ($\Omega.m$)	Ø (%)	F
1	9	44	0.90
3	39	40	4.06
6	39	41	4.03
12	27	42	2.80
15	20	43	2.10
17	50	39	5.20
19	83	35	8.6
20	74	36	7.70
22	66	37	6.90
25	59	38	6.10

Table 7: Variation of Formation factor against Hydraulic Conductivity of Rock Samples

Sample No.	**K (x 10^{-8}) ms^{-1}**	**F**
2	9	50
3	5.5	113
7	4	99
11	3.5	118
12	3	107
17	5.5	74
18	1.6	140
20	6	78
24	5	62

Table 8: Variation of Formation factor against Hydraulic Conductivity of Soil Samples

Sample No.	**K (x 10^{-8}) ms^{-1}**	**F**
3	15.4	4.06
6	13.8	4.03
15	23.0	2.10

21	571.0	0.06415	151
22	648.0	0.05718	190
23	427.0	0.07969	98
24	304.5	0.10004	62
25	453.5	0.08314	90

19	7.3	8.60
20	12.2	7.70
22	16.1	6.90
25	18.0	6.10

Table 9: Depth and Elevation of the bedrock

Line	Longitude	Latitude	Depth to Bed Rock d(m)	Elevation of Bed Rock (m)
1	4.7783	7.0137	17.4	35.4
2	4.7773	7.0114	22.3	38.8
3	4.7703	7.0216	38.7	49.5
4	4.8873	7.9179	32.3	49.7
5	4.8061	7.9336	50.7	54.1
6	4.8086	7.0720	48.6	74.1
7	4.8188	7.0507	33.3	42.9
8	4.8673	7.0015	36.0	46.8
9	4.7980	7.0451	16.7	34.1
10	4.7402	7.0349	21.9	31.5
11	4.7920	7.0112	23.1	46.5
12	4.7893	6.9787	33.4	48.7
13	4.7644	7.0197	06.4	21.1