

Determination of the Geotechnical Condition of the Subsurface of Ekowe Using Integrated Methods of Geomatics and Geoelectric Survey

¹Oritsebemigho Ulori and ²Ombu Righteous Emmanuel

^{1,2}Department of Science Laboratory Technology; Physics with Electronics Option; Federal Polytechnic Ekowe, Bayelsa State, Nigeria.

Corresponding author: ulorits@physics.org

Abstract

Ekowe a littoral community accessible only by water transport is bewildered with basic environmental issues as getting clean portable underground water as the quality of water is poor and require massive investment for purification and treatment, structural failures like potholes on the few rural roads, cracks in buildings and sinking of buildings in some cases. This study set out to douse mystical beliefs as it relates to these solvable issues by employing Geomatics and Geoelectric methods to ascertain the subsurface condition of the area, so as to prescribe recommendations on reversing the negative trends. The results showed the lithology of the Study area being mainly consisting of clay soil with sandy soil identified at two points within the study area. The identified sandy soil points are viable for borehole citing. The results showed clay soil thickness of 18 – 30 m in line with chargeability results proving that the overburden stratigraphy of the study area consists mainly of clay soil whose porosity is very poor making it impossible to have clear underground water in most parts and the reason the annual flood in the area can only be abated by run off to the nearby rivers. This study is meant to set out a blueprint for further geotechnical investigation for engineering construction and agro – geophysical studies to enhance agricultural revolution in the area.

Keywords: Chargeability, Borehole, Clay, Porosity, Lithology.

Introduction

Ekowe community lies along River Nun and is inaccessible by road. The only access being motorized speed boats, which takes one and a half hours from the state capital Yenagoa. The Community is facing challenges like non-availability of portable water supply as most boreholes yield very turbid water that requires huge investment in terms of filtration and Chlorination facilities that requires regular changing. This has made importation of what from Yenagoa the State capital, the cheapest means of getting portable drinking water.

Also, affecting the community is the issue of structural failures. Most buildings experience cracks and internal roads fail within short periods of time. With no credible lithology available for analysis of the subsurface condition of the Area, this work is intended to come out with the general overburden stratigraphy of the area by employing the geophysical methods of; Resistivity, Induced Polarization, and Self Potential to give the subsurface condition of the area for the purpose of adopting making recommendations for

surmounting the challenges of suspicion of clay soil of large amount in the subsurface of the area.

Statement of the Problem

Ekowe lies along the lower end of River Nun few Kilometers' to the Atlantic Ocean. It is important to note that this community is inaccessible by road. The only access being by motorized speed boats, which takes about One and a half hours from Yenagoa the state capital.

Asides from Ekowe, which serves as host to the Federal Polytechnic, the area is typically not an area for any form of government presence, hence the wanton neglect of the area by any form of Government in terms of basic infrastructure and amenities like water, electricity and connecting roads.

Asides the neglect, the area is home to peculiar forms of vices like, Crude oil bunkering and illegal refineries. These activities have further worsened the ecosystem of a region that hitherto experiences flooding annually between the months of; September – November.

The after effects of these flooding has always resulted in obvious failures on the various internal roads and buildings within the communities, including the infrastructures cited on the campus of The Federal Polytechnic Ekowe.

Further to the after effects of the flooding, is a seeming depression/sinking of structures in the area, giving rise to curiosity on the on the subsurface condition of the area.

Also, water supply in the area is terrible as nearly all the boreholes drilled within the community and its environs yield brownish water, which has to pass through a lot of filtration process at very high cost before it can be put to use. It is clear from the foregoing that every form of infrastructure to be cited in these locations, may not stand the test of time and may be a complete waste of resources, which has further aggravated the neglect of the area, leading to rural urban migration.

This study is aimed at understanding the subsurface condition of the area by Geophysical Methods in order to make recommendations for a development plan for the region.

Justification of the Study

Two main points can be deduced from the statement of the problem in the study area, which are:

- i. Turbid water from the aquifers in the study area
- ii. Foundational failures.

These two challenges can be easily linked to the presence of clay soil in the study area. This is because pore spaces in permeable materials is interconnected throughout rocks or sediment, allowing groundwater to move freely through it.

However, according to, (Wilson & Grace, 1942) high-porosity materials, like mud and clay, have very low permeability. They soak up and hold water, but don't release it easily to wells or other groundwater discharge points, so they are not good aquifer materials. Sandstone,

limestone, fractured granite, glacial sediment and gravel are examples of materials that make good aquifers, and the turbid (coloured) nature of the underground water in the area is most likely a result of dissolved elements in the clay soil trapped in a perceived aquifer by the unskilled drillers, who must have drilled without giving consideration to the facts that will emerge from this study. According to (Kankara & Yunusa, 2020) clay soils have significant geotechnical and structural engineering challenges, accompanied with a lot of damages and costs lost. It was recommended that modern divisive means of modifying the structures of clay soils be adopted to improve their properties.

The expansive nature of the clay is less near the ground surface where the profile is subjected to seasonal and environment changes. The more water they absorb the more their volume increases. Expansive soils also shrink when they dry out. Fissures in a soil can also develop (Chen & He, 1985) these fissures help water to penetrate to deeper layers when water is present. This produces a cycle of shrinkage and swelling that causes the soil to undergo great amount of volume changes. This movement in the soil results in structural damages especially in lightweight structures such as sidewalks, driveways, basement floors, pipelines and foundations (Lee & Ian, 2011).

This study therefore sets out to determine the general overburden stratigraphy as a means to making recommendations for future borehole drilling activities with regards to depth and engineering design that will not give in to the subsurface soil in the study area.

Resistivity, Induced Polarization and Self potential methods are cheap methods relatively compared to other methods, and from literatures these methods are best suited for a terrain as this. The presence of clay greatly influences the value of medium resistivity and chargeability. Research on rock samples showed that resistivity value was smaller exponentially and chargeability increased (Yatini et al, 2016). Chargeability is more likely due to the clay content of the soil undergoing swelling due to increased water (Kiberu, 2002).

It is therefore important that such a study be carried out as a means of guiding further infrastructural activities in the study area, especially on the campus of Federal Polytechnic Ekowe, which boast of multi – billion naira investment by Federal Government of Nigeria, and still attracting more.

Moreover, this study is one of the many developmental activities a tertiary institution should attract to its host communities.

Aims and Objectives of the Study

The following are the aims and objectives of this work;

- To locate groundwater flow pattern within the study area to give relevant information that will guide borehole drilling.
- To map the general overburden stratigraphy of the study area.
- To develop a general conceptual model of the site of investigation.
- To Determine the subsurface condition of the Study Area

- To develop a credible lithology that will be useful for civil and structural engineering activities within the study area.

Literature Review

The low frequency capacitance of rocks and soils is primarily a function of the surface chemical properties of the investigated materials. In non-metallic environments, the IP response is an indicator of surface area and charge density of the material. IP measurements are therefore sensitive to clay content as well as mineralogy and pore fluid composition (Slater, 2002).

Despite the relative simplicity of the SP measurement technique, only in recent decades its application in environmental studies, such as evaluation and monitoring of soil and groundwater pollution risk, has received an increasing interest from the worldwide geophysical community (Revil, 2012) (Revil, 2013).

Theoretical Framework on Electrical Resistivity

The simplest approach to subsurface resistivity measurement is to consider a continuous current flowing through an isotropic homogenous media. If Ohm's law is

$$\vec{E} = \rho \vec{J} \quad (1.01)$$

Where E is electrical field (V/m) and also the potential gradient

ρ = Resistivity of the medium (Ωm), J is current density.

If we introduce the divergence condition, which states that all current going into a material, must leave the other side except there is a source or sink. Thus, the divergence of the current density vector must be zero at every place and for every current source

$$\nabla \cdot \vec{J} = 0 \quad (1.02)$$

Both equations may be combined to obtain the Laplace's equation

$$\nabla \cdot \vec{J} = \frac{1}{\rho} \nabla \cdot \vec{E} = -\frac{1}{\rho} \nabla^2 V = 0 \quad (1.03)$$

Where V is a scalar potential function defined such that E is its gradient. In polar coordinates, the Laplace equation is

$$\frac{\partial}{\partial r} \left(r^2 \frac{\partial V}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial V}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 V}{\partial \psi^2} \quad (1.04)$$

If only a single source of current is considered, complete symmetry of current flow with respect to θ and ψ directions may be assumed, so the derivative taken in these directions maybe eliminated from 1.04;

$$\frac{\partial}{\partial r} \left(r^2 \frac{\partial V}{\partial r} \right) = 0 \quad (1.05)$$

If we integrate 1.05 directly;

$$r^2 \frac{\partial V}{\partial r} = C$$

$$V = -\frac{C}{r} + D \quad (1.06)$$

Defining the level of potential at a great distance from the source as zero, the constant of integration, D must be 0 the other constant C may be evaluated in terms of the total current, I, from the source. Since there is an assumption of symmetry of current flow, current density should be uniform through the surface of a small sphere with radius, a, drawn around the current source. The total current may be expressed as the integral of current density over this surface (Keller C.V and Frischnecht F.C, 1966).

$$I = \int_s \vec{J} \cdot d\vec{s} = \int_s \frac{E}{\rho} \cdot d\vec{s} = \int_s \frac{C}{\rho r^2} d\vec{s} = -\frac{2\pi C}{\rho} \quad (1.07)$$

This equation may be solved for the constant of integration, C, and this value is substituted into 1.10 for the potential function:

$$V = \frac{\rho I}{2\pi r} \quad (1.08)$$

Potential functions are scalars, and so may be added arithmetically. If by any means there are other sources of current other than the one assumed so far, the total potential at an observation point may be calculated by adding the potential contributions from each source considered independently. Thus, for n current sources distributed in a uniform medium, the potential at an observation point, M, will be

$$V_M = \frac{\rho}{2\pi} \left[\frac{I_1}{r_1} + \frac{I_2}{r_2} + \dots + \frac{I_n}{r_n} \right] \quad (1.09)$$

I_n is the current at the nth point in a series of electrodes and, a, is the distance from the nth source at which the potential is being observed. Equation (1.09) is of practical importance in the determination of earth resistivities. The physical quantities measured in the field for determination of resistivity is current, I, flowing between two electrodes; the difference in potential, ΔV in between two measuring points, M and N (Figure 1.1), and the distances between the various electrodes. Thus, the following equation applies for the ordinary four terminal arrays used in measuring resistivity.

$$\rho = \left(\frac{V_M - V_N}{I} \right) \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}} = K \frac{\Delta V}{I} \quad (1.10)$$

The minus sign for two of the four reciprocal distance terms arise since one of the current poles in a normal two electrode current circuits must have a negative sense of current flow compared to the other. Equation (1.10) can be used to compute resistivity of the earth only if the earth is completely uniform. If the earth is not uniform equation (1.10) may be used as a definition for the apparent resistivity of the earth. The apparent resistivity may bear no

relation to the actual relation to the actual value of resistivity in a heterogeneous earth. It may be larger or smaller than the actual resistivity or in rare cases the same as the actual resistivity value in a heterogeneous earth (Keller C.V and Frischnecht F.C, 1966).

Equation (1.10) which represents only the effect of electrode separation distances may be segregated and expressed as a geometric factor;

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}} \quad (1.11)$$

For the schlumberger array which is employed in this study is designed in a way as to measure the potential gradient. In this array two closely spaced measuring electrodes are placed midway between two current electrodes.

The spacing for this array is taken as half the distance between the current electrodes. Using equation (1.11) to determine the geometric factor

$$K = \frac{2\pi}{\frac{1}{\frac{AB}{2} - \frac{MN}{2}} - \frac{1}{\frac{AB}{2} + \frac{MN}{2}} - \frac{1}{\frac{AB}{2} + \frac{MN}{2}} + \frac{1}{\frac{AB}{2} - \frac{MN}{2}}} = \pi \left(\frac{AB^2}{MN} - \frac{MN}{4} \right) \quad (1.12)$$

The potential gradient cannot be determined exactly, since it is defined as the limit of the ratio of voltage to spacing as two measuring electrodes are moved close to each other. In the limiting case of zero separation, no voltage could be measured. In the schlumberger array, the measuring electrodes are placed closely enough together that the ratio of measured voltage to separation approximately equals the voltage gradient at the mid-point of the current spread. The error introduced by having a measurable separation between the measuring electrodes can be evaluated by considering the geometric factor for the case in which the gradient, E , is actually measured.

According to equation (1.13), the potential gradient at a distance a from a single current source in a homogenous isotropic half space is;

$$E = -\frac{\partial V}{\partial r} = \frac{\rho I}{2\pi r^2} \quad (1.13)$$

Chargeability

Chargeability is a physical property related to conductivity. As we learned previously, ionic charges within a rock's pore water begin to move under the influence of an electric field, resulting in electrical current. However, some of the pore ions do not move uninhibited through the rock and begin to accumulate at impermeable boundaries. This build-up of ionic charges is commonly referred to as induced polarization (IP), as it is responsible for generating electric dipole moments within the rock. We use chargeability to characterize the formation and strength of the induced polarization within a rock, under the influence of an electric field (<https://gpg.geosci.xyz/>, 2023) In this particular study Induced Polarization

(Chargeability) is meant to help confirm the thickness of the clay soil underneath the subsurface at points of reference.

Materials and Method

Geology and Hydrogeology of the Study Area

Ekowe is located within the lower delta plain believed to have been formed during the Holocene of the Quaternary period by accumulation of sedimentary deposits. The major geological characteristic of the area is sedimentary alluvium; loamy clay and sandy soil are also common (Reyment, 1965). The main river in the area is River Nun which is interconnected with various creeks in the Niger Delta. The river is very turbid during the wet season due to influx of sediments through surface runoff into it. The river becomes less turbid and clearer during the dry season. It is a tidal environment characterized by alternating flow of the river in the course of each day.



Map of Various Communities along the various tributaries of River Nun (Ekowe – Peremabiri)
Retrieved from *nona.net* (Nona.net, 2023)

Vertical Electrical Sounding (Field Technique)

Vertical electrical sounding (VES) is used to investigate variation in resistivity as a function of depth. The basis for making an electrical sounding irrespective of the electrode array used is that the further way from the current source the measurement of the potential, the deeper the probing will be (Banton, 1997), it has been stated in many references on geophysical prospecting that the depth of probing depends on how far apart the two current electrodes are placed (Nur et al, 2001).

Vertical electrical soundings investigate layering, using arrays in which the distances between some or all of the electrodes are increased systematically. The half-spacing sequence 1, 1.5, 2, 3, 5, 7, 10, 15 . . . is convenient, but some interpretation programs require exact logarithmic spacing. Curves drawn through readings at other spacing's can be resampled but there are obvious advantages in being able to use the field results directly.

Although techniques have been developed for interpreting dipping layers, conventional depth-sounding works well only where the interfaces are roughly horizontal (Milsom, 2003).

Field Procedure

The equipment used includes ABEM Terrameter SAS 1000 using the resistivity mode, induced polarization mode as well as the self-potential mode. The Schlumberger array was employed in carrying out vertical electrical soundings of one hundred metre spacing from each VES point to penetrate to depths of one hundred metres.

Auxiliary equipment for the survey is a global positioning system (GPS), to determine the resistivity survey locations and topography. Also, we have geophysical hammers for driving electrodes in to the ground, measuring tapes, layout tapes and cutlass for clearing.

The array geometry to be used is: AB/2; 1.5, 2.0, 3.0, 4.0, 6.0, 7.0, 8.0, 10.0, 12.0, 14.0, 15.0, 17.0, 20.0, 25.0, 30.0, 35.0, 40.0, 45.0, 60.0, 70.0, 100.0.

Data Analysis

The various data acquired is analyzed with Interpex, IP12WIN, and Microsoft word for clear lithological outlines.

Quantitative and Qualitative Interpretation

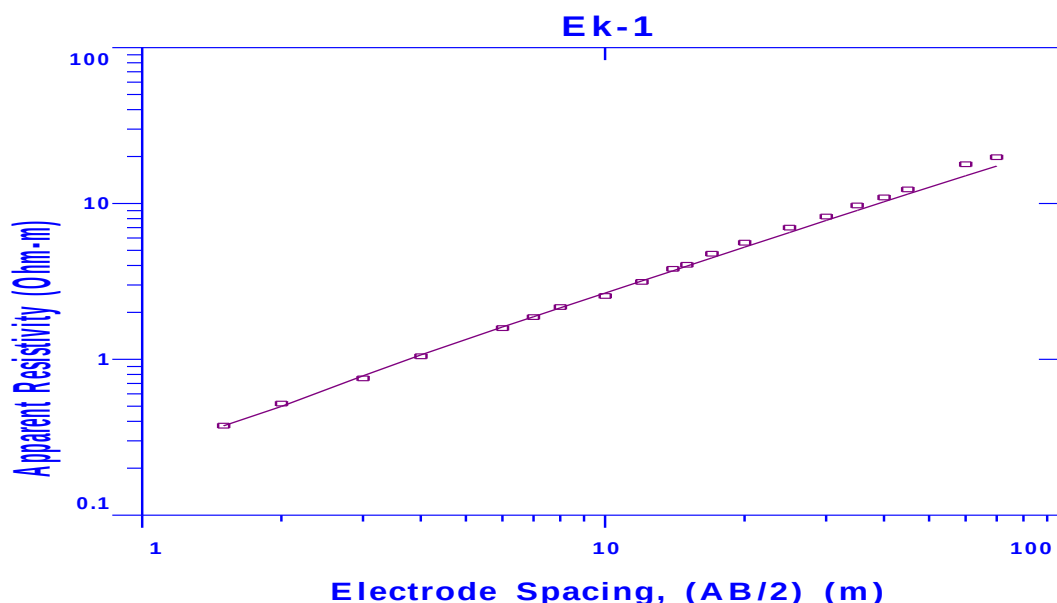


Figure 1: VES 1 Curve with Model Data

Resistivity (Ω m)	Thickness (m)	Depth (m)	Lithology
0.29151	0.99082	0.99082	Top Soil
14.810	29.800	30.7970	Clay
211.51			

Table 1

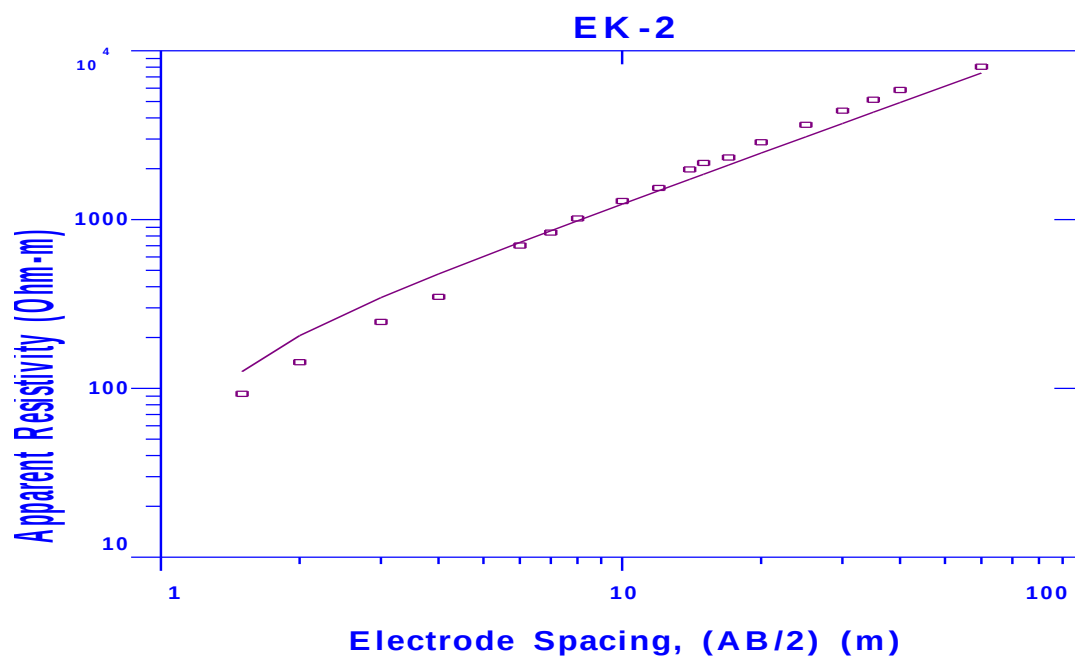


Figure 2: VES 2 Curve with Model Data

Resistivity (Ωm)	Resistivity (Ωm)	Thickness (m)	Lithology
79.396	0.22115	0.22115	<i>Topsoil</i>
396.22	2.44585	2.667	<i>Sand</i>
6714.	33.576	2.667	<i>Sand (Potential Aquifer)</i>
7261234			

Table 2

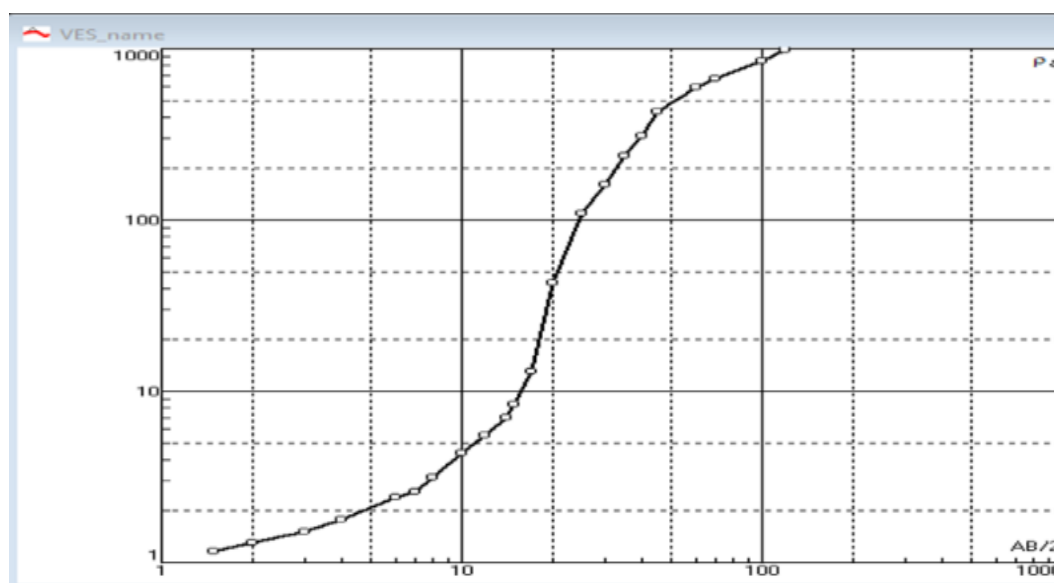


Figure 3: VES 3 Curve with Model Data

Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology
1.3700	1.3300	1.3300	<i>Top Soil</i>
40.7800	7.5400	8.8700	<i>Clay</i>
443.00	19.130	28.000	<i>Sandy (Potential aquifer)</i>
236720			

Table 3

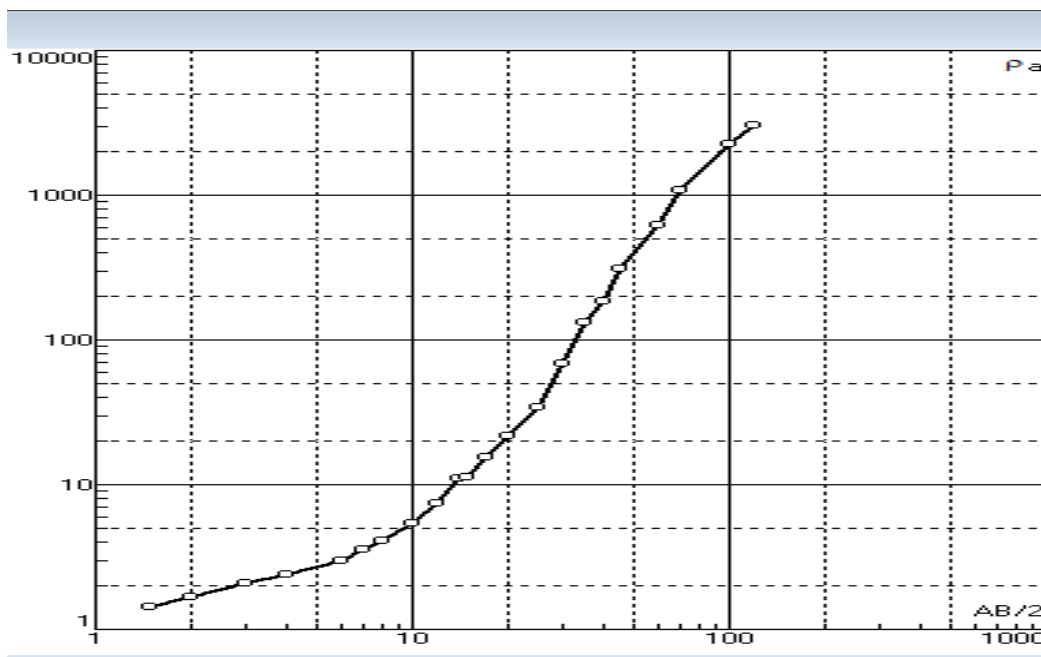


Figure 4: VES 4 Curve with Model Data

Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology
1.4820	0.97300	0.97300	Top Soil
6.2360	1.8470	2.8200	Clay
72.000	16.180	19.000	Sandy-Clay
1147.0	27.000	46.000	<i>Sandy (Potential aquifer)</i>
53189			

Table 4

Material	Resistivity Range (Ωm)
Sandy soil with clay	60-100
Clayey and sandy soil	30-60
Clay	10-50

Table 5: Resistivity of each material below (Reynolds, 1987)

Layers	Resistivity (Ωm)	Material Type
1	95	Very sandy soil
2	32	Clay

Table 6: Table of typical VES Interpretation (Reynolds, 1987)

Layer	Resistivity Range (m)	Type of Material
1	1- 80	Top Soil (Silty sandy soil)
2	6 – 40	Clay
3	45 – 75	Sandy – Clay
4	100 and above	Sandy

Table 7: Derived Resistivity Values

Results

Lithology of the Study Area



Figure 5: Resistivity Pseudo Section of VES 1



Figure 6: Resistivity Pseudo section of VES 2

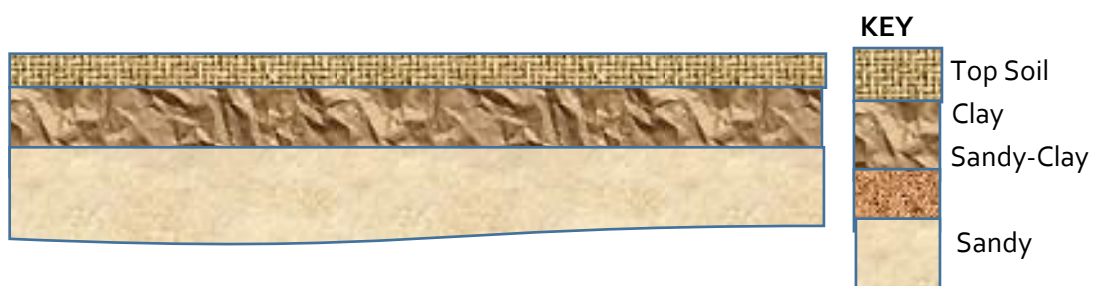


Figure 7: Resistivity Pseudo section of VES 3

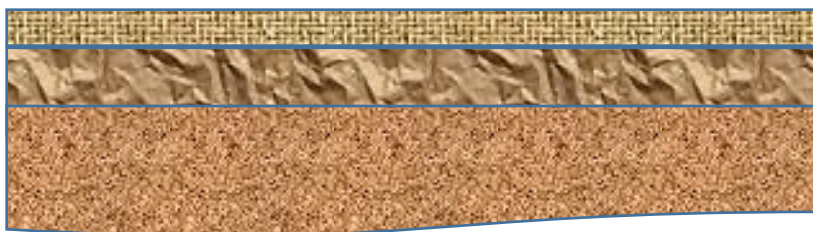


Figure 8: Resistivity Pseudo section of VES 4

Results Discussions

The results show a predominance of clay soil in the lithology of the study area, thus proving right the motivation for the study in the first place.

Research Findings

The study has primarily exposed the study area to the major reason for most of the challenges experienced in terms of structural failures, frequent water treatment and the presence of water long after rainfall and flood, as most of the built up area where the main infrastructures like boreholes, female hostel, and some offices is situated around VES 1 is heavily laden with subsurface clay. It is notable that ground (clay) swells with the effect of ground water rising to ground level and shrinks during a fall in the level of ground water (Wilson & Grace, 1942). This in essence means that except there is an effective drainage system rain/flood water would depend mainly on run off which is not good for the sanitary condition of the environment and the groundwater from boreholes in this area will have a lot of dissolved substances, necessitating regular water treatment schedules.

However, VES 2 and VES 3 are seen to be viable points for quality ground water (Aquifer) as it has the presence of sandy soil underneath the clay upon deeper drilling to depths of at least 30 – 37m at both points and 48m at points around VES 4.

Conclusions

The most outstanding conclusion that can be drawn from this work is for the works and physical planning divisions of the Polytechnic to exert more resources to drilling boreholes around points of viable aquifers as discovered from this work and for the drainage system around the built up areas of the Campus to be overhauled for effectiveness, this will reduce the cost implications arising from the thick clay in the subsurface of the area.

Recommendation

- There is an urgent need for citing a borehole and possible put up a mini drinking water plant around the main auditorium of the campus to stem the tide of water importation from as far as Yenagoa and put to rest the frequent lack of good drinking water around the campus and Ekowe community at large.

- Also, many adoptive measures can be employed to bring the problems of engineering issues to a halt, such as the soil stabilization, which can improve the properties of expansive soils considerably. Possible materials for the stabilization could include lime, pozzolana, lime-pozzolana mixture, cement, resins or fly ash.

References

- (2019, September 1). Retrieved from nona.net.
- Banton, O. (1997). Mapping Field Scale Physical Properties of Soil. *American Journal of Physics*, 1010-1018.
- Chen XO, Lu ZW, He XF. (1985). Moisture movement and deformation of expansive soils. *14th International Conference on Soil Mechanics and Foundation Engineering*, (pp. 4: 2389- 2392). San Francisco, California.
- Kankara, I. A., and Yunusa, L. U. (2020). Behaviour and Effect of Clay Soils on Engineering Constructions in Nigeria: Implications for Geotectonic: *Direct Research Journal of Engineering and Information Technology*, Vol. 7(5), pp. 84-96.
- Keller C.V and Frischnecht F.C. (1966). *Electrical Methods Geophysical Prospecting*. Oxford: Pergamon.
- Kiberu, J. (2002). *Induced Polarization and Resistivity Measurements on a Suite of near Surface Soil Samples and their Empirical Relationship to Selected Measured Engineering Parameters*. International Institute for Geo-Information Science and Earth Observation. Enschede: International Institute for Geo-Information Science and Earth Observation.
- Lee DJ. & Ian Jefferson. (2011). Expansive Soils. *School of Civil Engineering, University of Birmingham, Institution of Civil Engineers Manuals series*, p. Chapter C5.
- Milsom J., (. F. (2003). *Field Geophysics*. Sussex: Wiley and Sons.
- Nur., Obiefuna, Bassey. (2001). *Journal of Environmental Hydrogeology*, 1058-1062.
- Revil, A. J. (2013). *The self-potential method: Theory and applications in Environmental Geosciences*., New York: Cambridge University Press.
- Revil, A. K. (2012). Review: Some low-frequency electrical methods for subsurface characterization and monitoring in hydrogeology. *Hydrogeology Journal*, 20, 617-658.
- Reyment, R. (1965). *Aspects of the Geology of Nigeria*. Ibadan: University Press Ibadan.
- Reynolds. (1987). The role of surface geophysics in the assessment of regional groundwater potentials in Northern Nigeria. *Geological Society of Engineering group*, 185 - 190.
- Roy Chudley and Roger Greene. (2016). *Building Construction Handbook*. London: Routledge.
- Slater, L. L. (2002). *The Induced polarization method*. New Jersey Geological Survey Open-File Report FOR 90-1, 160pp. New Jersey.
- Wilson G., Grace H. (1942). The Settlement of London Due to Under - Drainage of the London Clay. *Journal of Institute of Civil Engineering*, 100-127.
- Yatini, Santoso D., Laesanpura A., Sulistijo B. (2016). Inflence of Physical Parameters to Domain Induced Polarization (TDIP) Response, AIP. *AIP Conference Proceedings*. 1719.