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Estimation of Depth to Water Table within a Tropical University Campus Using Direct Current Resistivity Method

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ABSTRACT

Ensuring access to clean and potable water is a global challenge, especially in regions like Nigeria where it is a pressing concern. Understanding the hydrogeological conditions, particularly the depth of the water table, is crucial for sustainable water resource management. In this study, we employed the direct current (DC) resistivity method to investigate the depth of the water table at the University of Calabar, Nigeria. Our approach involved measuring the electrical resistivity of subsurface materials to delineate the water table depth. The DC resistivity method emerged as a reliable and efficient tool for estimating the water table depth in our study area. By constructing a resistivity profile of the university campus, we uncovered valuable information about the subsurface hydrogeological conditions. Utilizing a multi-electrode resistivity system, we collected data at various depths and locations within the campus. These measurements were then processed using inversion techniques to produce a 2D resistivity image of the subsurface. This image revealed intriguing variations in subsurface resistivity, indicative of changes in composition and saturation of underground materials. Most importantly, our findings shed light on the depth of the water table, which ranged between 5.5m and 34.5m below the mean sea level. This information not only enhances our understanding of the University of Calabar's hydrogeology but also contributes to broader efforts in sustainable water management and development strategies.

INTRODUCTION

Water is the main sustainer of all life forms on the earth. It is the elixir of life; without it, life is impossible (Fetter, 1994). Many environmental factors determine the density and distribution of vegetation and food crops in an area but key among these is the quantity of water supply in the area, mainly precipitation. Water is the main anchor of civilization (Fetter, 1994). Hence the popular saying "Water is life". All living things use water in different forms for different purposes either directly or indirectly, to mature. Human beings for instance; use water for drinking, irrigating crops, feeding animals, domestic chores, and industrial purposes. Animals and plants need water to grow. According to Fetter (1994), a person requires three litres of potable water daily to maintain the body's essential fluids.

Water falls to the earth in different forms such as rain, snow, hail sleet, and sleet. The movement of water on the earth takes one of the following forms: it either runs off on the surface into water bodies, storm drains, or gutters, or it can also seep into the ground where it moves downwards into the ground under the action of gravity. It makes its way through the pore spaces in the ground and gets to a depth where the pore spaces are already filled or saturated with water (Shaw, 1992). The flow of the water on the land is termed land flow (Fetter,1994). When water enters pores already filled with water or the saturated zone it becomes part of the groundwater. The upper part of the saturated zone is called the water table. The ease with which water enters the pore spaces or infiltrates the soil is dependent on the shape and size of soil particles, the density of pore spaces between particles, and the degree of interconnectivity of the pore spaces. Water exists in different forms and different environments such as oceans, seas, lagoons, rivers, streams, lakes, and underground.

Groundwater forms the invisible, subsurface part of the natural water cycle (Earth Science for Society, 2005). Groundwater is water in the pore spaces and fractures in rocks and sediments beneath the earth's surface. It can be found at every depth beneath the earth's surface, but it is normally limited to about 750 m deep from the surface (Zoghbi, 2007). It originates as rainfall or snow and then moves through the soil and rocks into the groundwater system, where it eventually makes its way back to the surface streams, lakes, or oceans. With the situation of water shortage occurring in almost every community in Nigeria and the global community in general, people are drifting towards the use of groundwater as a reliable alternative and secured source of water for domestic use. In fact, in most advanced countries like the US and Canada, groundwater is a major 3 component in their total water consumption (Earth Sciences for Society, 2005).

Groundwater is normally dynamic rather than static. The quantity of water that gets infiltrated into the ground will vary greatly from one place to another. This mainly depends on the gradient of the land, the intensity of the rainfall, and the nature of the ground surface. Lands that are porous and permeable, and lands that contain lots of gravel or sand will allow as much as 50% of rainfall to infiltrate into the ground thus forming groundwater. In

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impermeable non-porous lands, only about 5% can get into the ground (Earth Science for Society, 2005). The rest runs off into other water bodies on the surface or evaporates. Water from the surface features in the form of springs, ponds, lakes, streams, rivers, and run-offs interact with the groundwater in several ways daily. People's lives and livelihoods depend on water (Earth Sciences for Society, 2005). The demand for clean water increases with population growth. For proper development, more secure and low-cost water supplies are needed. Obtaining secure water supplies for domestic and industrial use cannot be done without tapping the groundwater resources of the nation.

Groundwater is the main source of drinking water in many countries and continents. It is up to 80% in Europe and Russia, and even more in North America and the Middle East (Earth Sciences for Society, 2005). Groundwater constitutes about two-thirds of the freshwater resources of the world and if polar ice caps and glaciers are not considered, groundwater accounts for nearly all usable freshwater (Chilton, 1996).

Groundwater primarily originates from precipitation, which includes rain and snowmelt. The water from precipitation infiltrates into the ground, moving through the soil and rock layers until it reaches the saturated zone where all the pores or fractures in the subsurface are filled with water. This saturated zone is known as the groundwater aquifer. The water table is the upper surface of the saturated zone of an unconfined aquifer. It is the surface below which all rocks are saturated with groundwater (Davis & DeWiest, 1996). The water table may be located at or near the land surface, or at some depth below the land surface. The depth of the water table may fluctuate seasonally throughout the year. Wetlands, springs, and seepages may occur where the water table intersects the land surface. The water table itself varies in form and gradient depending on areas of recharge and discharge, pumping from wells, and permeability (Bowen, 1986). Thus, the nature and appearance of the water table are summarized by Fetter (1994), stating that when groundwater flow is absent, the water table looks flat. However, the presence of a sloping water table is an indication of flowing groundwater. Moreover, groundwater discharge zones tend to be topographical low spots and the water table generally has the same shape as the surface topography. These summarizations elucidate the intricate dynamics and interplay of groundwater within the earth's subsurface.

Therefore, the findings of this study will provide valuable insights into the hydrogeological characteristics of the area, which can aid in sustainable water resource management and development. Different methods such as seismic reflection, high-resolution aeromagnetic, and electrical resistivity methods have been employed to carry out water assessment and map the spatial distributions of geologic structures within areas of similar geology and hydrogeology as this study area. In a study conducted by Ekwok *et al.* (2020), the groundwater potential of specific regions on the Calabar Flank was evaluated through the application of vertical electrical sounding (VES) and high-resolution aeromagnetic methods (HRAM). Similarly, George & Okwueze (2003) employed a seismic refraction survey to ascertain the depth of the water table, establishing a robust correlation between seismic interpretation and the lithologic section derived from borehole data in the study area. However, the conventional seismic refraction method does not always give accurate predictions as noted by Desper *et al.* (2015) who used the method to estimate the water table depth. However, the conventional two-layer solution resulted in only 28% of predictions of the measured water table which required a modification to this approach before accurate determination was achieved. Ebong *et al.* (2016) utilized the electrical resistivity method to assess groundwater, and while their findings correlated with geologic logs, the correlation was not entirely satisfactory for delineating lithostratigraphic units. Consequently, the assessment of groundwater quality was based on water samples collected from boreholes within the study area. However, these works did not investigate the depth of the aquifer which has much influence on the water quality. Deep aquifers are generally more isolated and protected from surface contaminants. Therefore, water from deeper aquifers is often of higher quality, as it is less likely to be contaminated by human activities and pollutants compared to shallow aquifers. The depth of aquifers can also affect the salinity and mineral content of the water, as deeper aquifers often contain water that is less saline and has lower mineral concentrations, providing better quality water for consumption or agriculture.

For these reasons, this work seeks to estimate the depth of the water table at sites within the University of Calabar campus, using the Direct Current (DC) Electrical Resistivity method. The technique offers a non-invasive and cost-effective approach for evaluating subsurface hydrogeological conditions, aiding water resource planning, and supporting environmental sustainability efforts. It involves measuring the electrical resistivity of subsurface materials by injecting direct current into the ground and recording the potential difference. The DC method has been used by Sastrawan *et al.* (2020) to estimate the depth of aquifer and subsurface stratigraphy around a university campus in Indonesia applying the Schlumberger configuration to obtain satisfactory results indicating medium to productive aquifer. Also, Kalinski *et al.* (2021) mapped the groundwater depth and water quality in Leogane, Haiti wherein, an approach applying the DC resistivity method was used to successfully aid in groundwater mapping in that tropical country. The DC method is attractive because of its simplicity, low cost, and ease of use. Again, to the best of our knowledge, no previous work has been carried out at the proposed study area using this method. Therefore, this work will contribute to the existing literature on this subject matter.

MATERIALS AND METHOD

Study Area

The University of Calabar is in Cross River State of Nigeria. It lies between longitudes 08011E and 08027E and latitudes 05008N and 04045N. The abandoned dump is about 350m thick inside the UNICAL football field (Black and White field) located along UNICAL Staff Quarters Road and directly opposite the UNICAL Chapel of Redemption, very close to the fence that separates UNICAL from Eastern Highway Street and lies between 04056.954N and longitude 08020.679E.

This study is concerned mainly with the use of the DC Electrical Resistivity method in determining the water table depth in the University of Calabar (UNICAL) campus, as it concerns the aquifer potential. It is restricted only to UNICAL, and findings generated from the study will relate strictly to the study area.

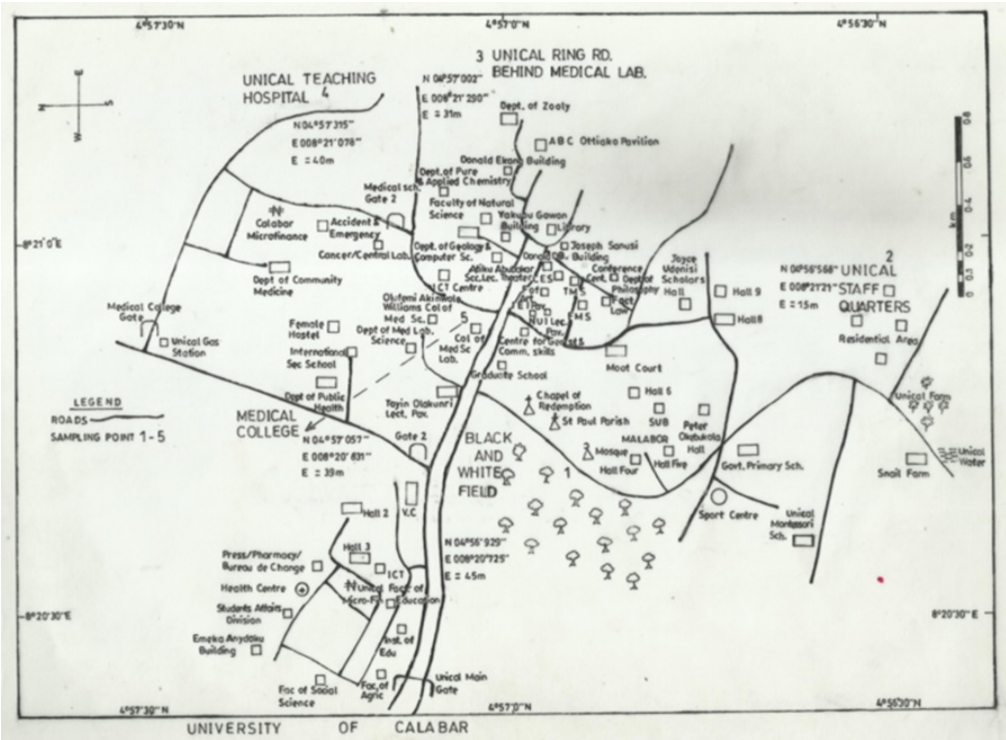

Figure 1: The map of UNICAL

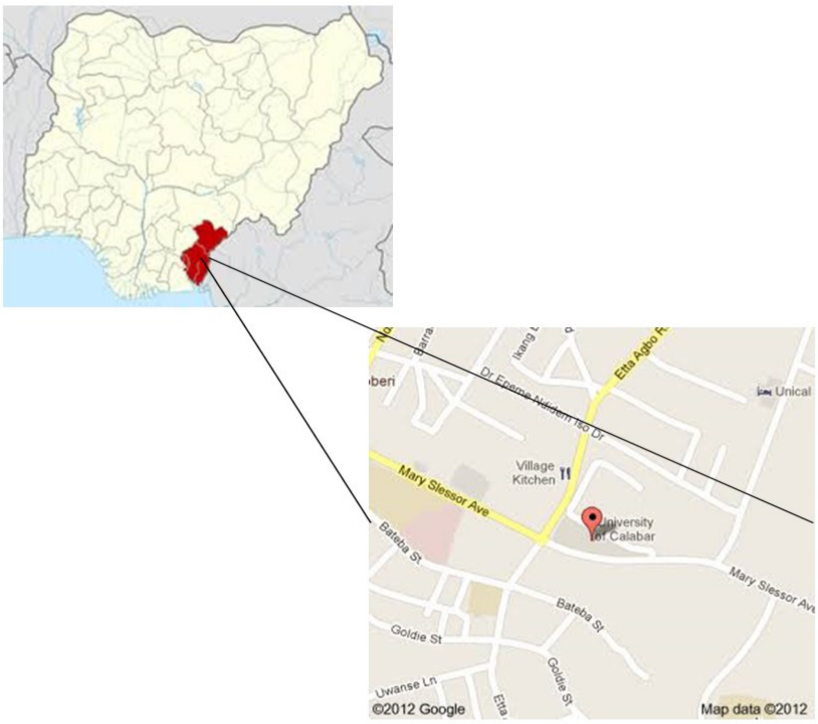

Figure 2: Trace of the study area from the map of Nigeria

Geology

The geology of the study area belongs to the tertiary of recent deposits. The lithology includes plain coaster sands as found behind the Physics Department, light brown-grey and white sand with intercalation of clay mostly found at UNICAL River, and gravelly materials found in Abraham Odiah stadium. The sands from the three sampling points are suitable for building purposes and other construction purposes. On average, groundwater reaches a maximum of 60m from the surface.

The area falls within the subequatorial type of climate, with moderately hot temperatures that do not fluctuate greatly. The temperature fluctuates, between 24℃ and 28℃ with an annual average of about 26.5℃ although with cooler nights. It has a total annual rainfall of about 4000mm per annum which peaks in June and July with a usual 7 months of rainfall (April to October).

Hydrogeology

The hydrogeology of the study area is influenced by various factors such as climate, geology, and human activities.

The study area is located in the coastal region of Nigeria, which experiences a tropical climate with high temperatures and precipitation throughout the year. The rainfall pattern and intensity affect the recharge of groundwater resources on campus. The campus is situated on sedimentary rock formations, primarily consisting of sandstone, shale, and limestone. These rocks have varying permeability, which influences the movement and storage of groundwater. The university campus is traversed by several small streams and rivers, such as the Calabar River. These surface water bodies contribute to the hydrology of the campus and may interact with groundwater resources. The campus primarily relies on groundwater for its water supply. The aquifers in the area are typically composed of weathered and fractured rock, allowing for the storage and movement of groundwater. However, the availability and quality of groundwater may vary across the campus and human activities such as the discharge of effluents from sanitation facilities, industrial waste, and improper waste management practices, could lead to groundwater contamination. Regular monitoring and mitigation measures are necessary to ensure a safe water supply on campus.

Instruments for Field Survey

The basic equipment used for this geophysical survey is the SSR-MP-ATS model IGIS resistivity meter. Also used were four non-polarizing electrodes (two current and two potential), a battery pack, four reels of cable, a measuring tape, a hammer, a Global Positioning System (GPS), and four crocodile clips.

Figure 3: The basic instruments used in the field survey

Experimental Procedure

The electrical resistivity meter IGIS SSR-MP-ATS measures the voltage drop between the current electrodes. The hammer was used to drive the electrodes into the ground and then taped to the cable with the clip. The non-polarized electrode is nearly always metal stakes, which include the current electrode and the potential electrode (used to inject current into the ground and to receive signal too). In some cases, in dry ground, the electrode may have to be hammered into depths of more than 50cm and be watered to improve contact. Battery is used in generating DC which is carried by the cable wires and injected into the ground by the electrode. On the other hand, the measuring tape is used to measure distances of different positions including the distance of the electrodes (current electrode and potential electrode). Also included is the Global Positioning System (GPS), used to take coordinates, latitude, longitude, and elevation, at different locations.

Vertical electrical sounding reading was taken, and this involved keeping the potential electrodes fixed at one location while the current electrodes expanded about a center point. Only when the current electrodes became relatively distant (at an interval of four readings), did the potential electrode spacing need to be expanded to have measurable potentials. At each point of A and B, the current sent, the voltage received, and the distance between AB and MN were recorded. These were the data needed to calculate the apparent resistivity.

The expression for apparent resistivity (ϱ) obtained through the Schlumberger array involves the variation in electrode spacing at a specific location. This is given by

$\varrho_{a(s)} = R\pi(a^2/b - b/4)$ (1)

Where ɑ is the half-current electrode spacing (AB/2), b is the spacing between potential electrodes (MN). The resistance (R) is derived from the current (I) and the potential difference (V) values using the relation

$R = V/I$ (2)

Equation (1) can be expressed in terms of the geometrical factor K

$\varrho_{a(s)} = KR$ (3)

In Ωm unit, where K is given as

$K = \pi(a^2/b - b/4)$

The geometrical factor is influenced by how the electrodes are arranged in the ground and can be determined for any specific configuration.

Data Analysis

The measured resistances were converted to apparent resistivity by multiplying with their respective geometrical factors. This apparent resistivity was plotted against half current electrode spacing (AB/2) on a log-log graph using Microsoft Excel, to generate curves from the field data. Unwanted values that failed to follow the dominant curve trend were expunged by curve smoothening. The maxima and minima on the smoothened VES curves were taken to depict the vertical variation in resistivity with depth.

These resistivity values were further subjected to computer modeling using the inversion technique. This was made possible by geophysical software called Winresis, which involves a modeling approach to generate a computer-modeled curve that shows the measured apparent resistivity, calculated apparent resistivity, and model resistivity section. Due to the geological nature of the study area being a Sedimentary area, there were resistivity values that showed the structure of the study area which is in layers. The layer parameters: resistivity, depth, and thickness for each (VES) point were obtained after a series of iterations to match the field curve with theoretical curves.

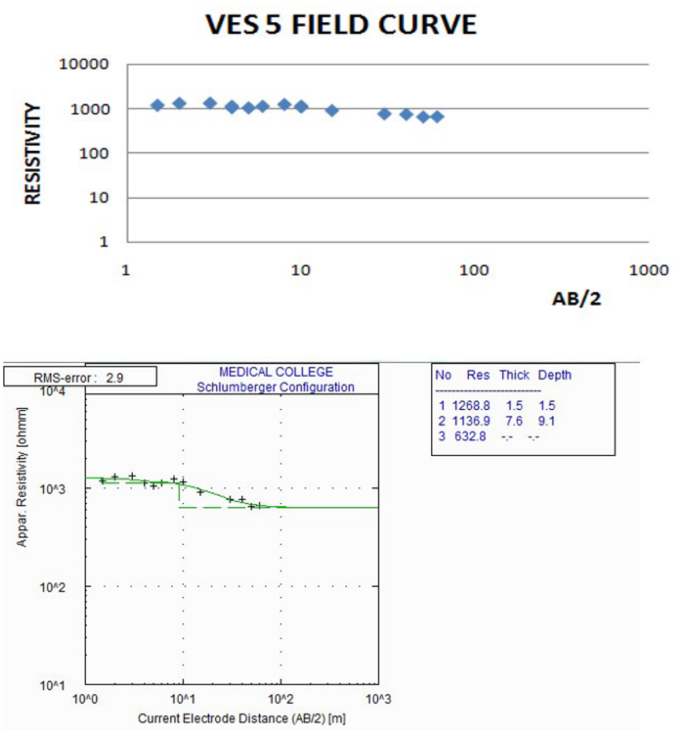

Figure 4: Field data of VES 5 plotted on a log-log graph and modeled using Winresis software; Resistivity plotted against current electrode spacing (AB/2)

RESULTS AND DISCUSSION

Results

From the modeled VES data, it was observed that out of the five (5) VES points, one(1) has four layers while the remaining four(4) have three layers. Three of the VES points have AK curve types while others include AA, and KK curve types dominating. For the 3-layer curves, the estimated layer depth to bottom varies from 1.0 m to 2.7 m for the first layer, 9.1 m to 36.3 m for the second layer, and the depth of the third could not be determined from our data. The mean resistivity value varies from a minimum of 87.8 Ωm to a maximum resistivity of 1268.8 Ωm for the first layer, 920 Ωm to maximum resistivity of 1136.9 Ωm for the second layer, and 157.8 Ωm to maximum resistivity of 4635.9 Ωm for the third layer. For the 4-layer curves, the estimated layer depth-to-bottom varies from 1.3 m to a maximum of 41.7 m in conjunction with a resistivity between 303.8 Ωm and 1638.6 Ωm.

Table 1: Results of mean resistivity values for the various VES points

Location	VES No.	Layers	Resistivity (Ωm)	Depth (m)	Estimated depth to water table (m)	Inferred lithology	Curve type
Unical black/ white field	1	1	303.8	1.3	32.5	Topsoil, fine sand	AK
		2	894.5	11.3		Medium fine sand/clay intercalation	
		3	1638.6	41.7		Coarse gravelly sand	
		4	533.0	- -		Lateritic sand	
Unical staff quarter	2	1	180.2	1.0	15.5	Topsoil, fine sand	AK
		2	920.0	19.8		Medium fine sand/clay intercalation	
		3	157.8	- -		Coarse gravelly sand	
Unical ring road behind medical lab. sc	3	1	606.2	1.8	30.5	Topsoil, fine sand	AA
		2	1007.6	34.0		Medium fine sand/clay intercalation	
		3	4635.9	- -		Coarse gravelly sand	
Unical teaching hospital	4	1	87.8	2.7	34.5	Topsoil, fine sand	AK
		2	996.8	36.3		Medium fine sand/clay intercalation	
		3	330.9	- -		Coarse gravelly sand	
Unical medical college	5	1	1268.8	1.5	5.5	Topsoil, fine sand	KK
		2	1136.9	9.1		Medium fine sand/clay intercalation	
		3	632.8	- -		Coarse gravelly sand	

DISCUSSION

VES 1 (Unical Black/White Field)

Figure 5 shows the geo-electrical section of profile 1. The depth of investigation denotes a maximum of five and a minimum of four layers. The profile was over a gentle slope. The water table took the nature of the terrain after proper data collection. The estimated average depth to the water table was about 32.5 m below mean sea level.

The lithologies are characterized by resistivity signatures. The first layer on this profile is the topsoil with a resistivity value of 303.8 Ωm with a corresponding depth of 1.3 m. The lithologies mainly comprise of sand, coral shells, and other organic matter intercalated with fine sand. The second substratum is mainly medium fine sand and clay intercalation; characterized by a resistivity of 894.5 Ωm at a depth of 11.3 m with a thickness of 10.0 m. This layer serves as a reservoir for surface aquifers and is expected to be unsustainable as they are mainly recharged by precipitation which will be absent during the dry season. The third horizon in this section has a depth of 41.7 m. This layer has a relatively high thickness of 30.7 m and a high resistivity of 1638.6 Ωm, inferring coarse gravelly sand. This region is a freshwater-bearing zone. The region is sustainable and free from saline intrusion because of its confinement overlaying the zone.

The fourth layer on this profile is characterized by a

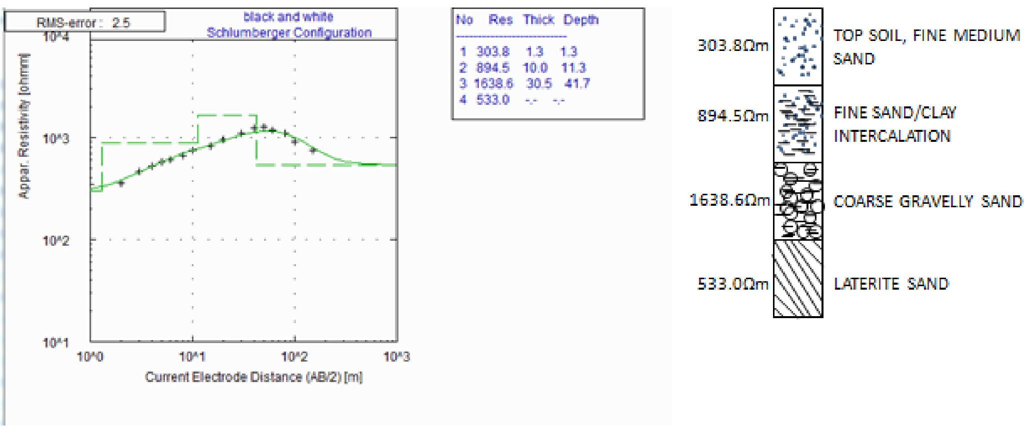

Figure 5: VES 1 Field data showing a model layer curve and geo-electric section

resistivity value of 533.0 Ωm and unknown thickness due to the current which terminated in this region hence further investigation could not be done. This region is the freshwater-bearing zone. The lithology of this layer is inferred to be lateritic sand, which acts as a confinement for the underlain layer.

VES 2 (Unical Staff Quarters)

Figure 6 shows the geo-electrical section of profile 2. The depth of investigation denotes a maximum of four and a minimum of third layers. The water table took the nature of the terrain after proper data collection. The estimated average depth to the water table was about 15.5 m below mean sea level.

The lithologies are characterized by resistivity signatures. The first layer on this profile is the topsoil with a resistivity value of 180.2 Ωm with a corresponding depth of 1.0 m. The lithology mainly comprises of sand, coral shells, and other organic matter intercalated with fine sand. The second substratum is mainly medium fine sand and clay intercalation; characterized by a resistivity of 920.0 Ωm at a depth of 19.8 m with a thickness of 18.8 m. This layer serves as a reservoir for surface aquifers and is expected to be unsustainable as they are mainly recharged by precipitation which will be absent during the dry season. The third layer on this profile is characterized by a resistivity value of 157.8 Ωm and unknown thickness due to the current that terminated in this region hence further investigation could not be done. The lithology of this layer is inferred to be coarse gravelly sand. This region is the freshwater-bearing zone. The region is sustainable and free from saline intrusion because of its confinement overlaying the zone.

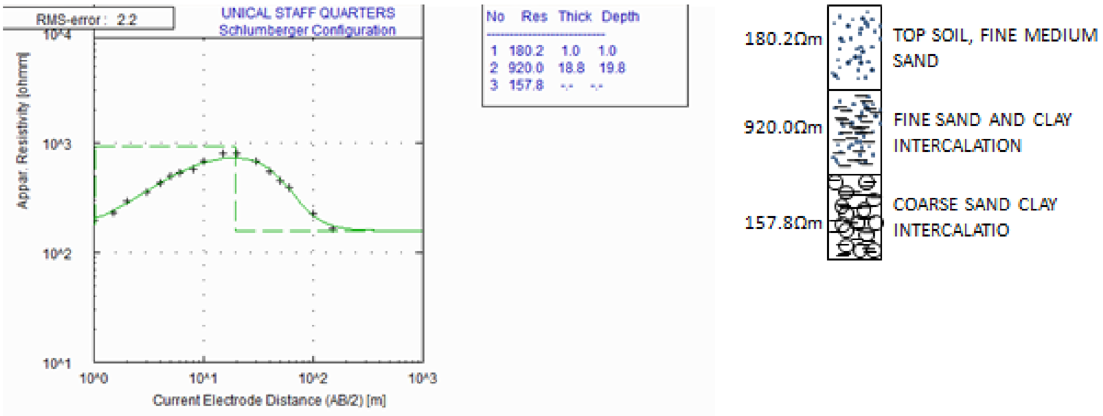

Figure 6: VES 2 Field data showing a model layer curve and geo-electric section

VES 3 (Unical Ring Road Behind Medical Lab. Science)

Figure 7 below shows the geo-electrical section of profile 3. The depth of investigation denotes a maximum of four and a minimum of third layers. The profile was over an undulating terrain. The water table took the nature of the terrain after proper data collection. The estimated average depth to the water table was about 30.5 m below the mean sea level.

The lithologies are characterized by resistivity signatures. The first layer on this profile is the topsoil with a resistivity value of 606.2 Ωm with a corresponding depth of 1.8 m. The lithology mainly comprises of sand, coral shells, and other organic matter intercalated with fine sand. The second substratum is mainly medium fine sand and clay intercalation; characterized by a resistivity of 1007.6 Ωm at a depth of 32.2 m with a thickness of 34.0 m. This layer serves as a reservoir for surface aquifers and is

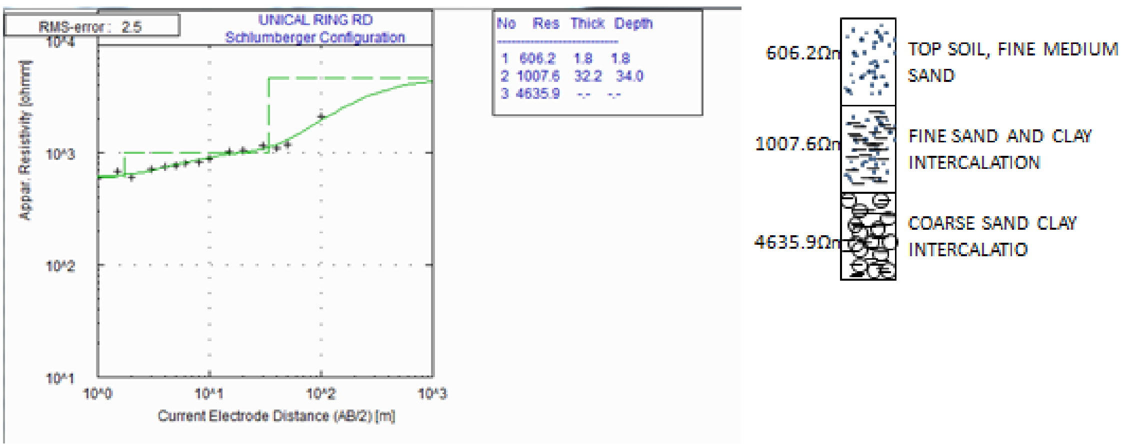

Figure 7: VES 3 Field data showing a model layer curve and geo-electric section

expected to be unsustainable as they are mainly recharged by precipitation which will be absent during the dry season. The third layer on this profile is characterized by a resistivity value of 4635.9 Ωm and unknown thickness due to the current that terminated in this region hence further investigation could not be done. This region is the freshwater-bearing zone due to the lithology of this zone inferring to be coarse gravelly sand. This region is the freshwater-bearing zone. The region is sustainable and free from saline intrusion because of its confinement overlaying the zone.

VES 4 (Unical Teaching Hospital)

Figure 8 below shows the geo-electrical section of profile 4. The depth of investigation denotes a maximum of four and a minimum of third layers. The profile was over another gentle slope. The water table took the nature of the terrain after proper data collection. The estimated average depth to the water table was about 34.5 m below mean sea level.

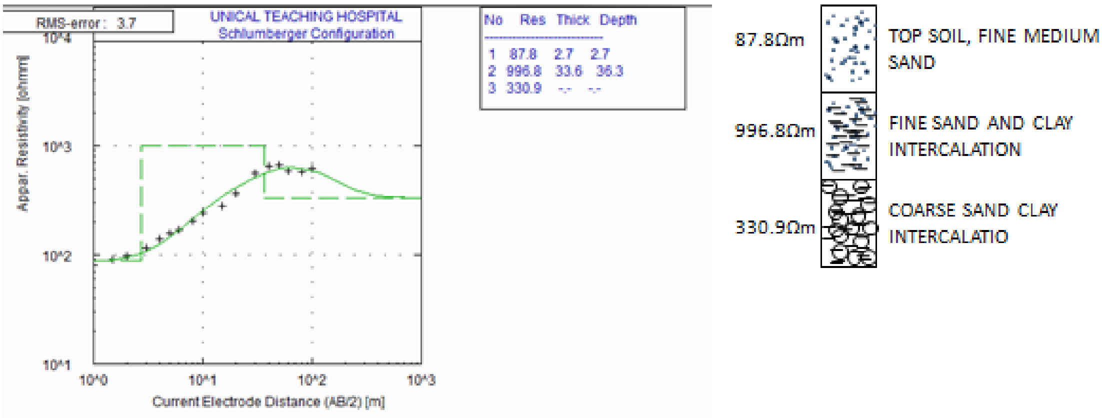

Figure 8: VES 4 Field data showing a model layer curve and geo-electric section

The lithologies are characterized by resistivity signatures. The first layer on this profile is the topsoil with a resistivity value of 87.8 Ωm with a corresponding depth of 2.7 m. The lithology mainly comprises of sand, coral shells, and other organic matter intercalated with fine sand. The second substratum is mainly medium fine sand and clay intercalation; characterized by a resistivity of 996.8 Ωm at a depth of 36.3 m with a thickness of 33.6 m. This layer serves as a reservoir for surface aquifers and is expected to be unsustainable as they are mainly recharged by precipitation which will be absent during the dry season. The third layer on this profile is characterized by a resistivity value of 330.9 Ωm and unknown thickness due to the current that terminated in this region hence further investigation could not be done. This region is the freshwater-bearing zone due to the lithology of this zone inferring to be coarse gravelly sand. This region is a freshwater-bearing zone. The region is sustainable and free from saline intrusion because of its confinement overlaying the zone.

VES 5 (Unical Medical College)

Figure 9 below shows the geo-electrical section of profile 5. The depth of investigation denotes a maximum of four and a minimum of third layers. The profile was over another undulating slope. The water table took the nature of the terrain after proper data collection. The estimated average depth to the water table was about 5.5 m below mean sea level.

The lithologies are characterized by resistivity signatures. The first layer on this profile is the topsoil with a resistivity value of 1268.8 Ωm with a corresponding depth of 1.5

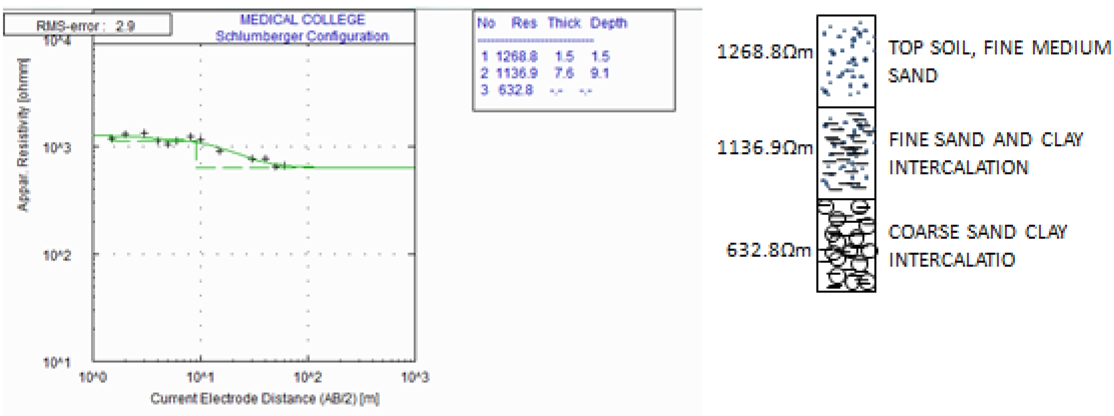

Figure 9: VES 5 Field data showing a model layer curve and Geo-electric section

m. The lithology mainly comprises of sand, coral shells, and other organic matter intercalated with fine sand. The second substratum is mainly medium fine sand and clay intercalation; characterized by a resistivity of 1136.9 Ωm at a depth of 9.1 m with a thickness of 7.6 m. This layer serves as a reservoir for surface aquifers and is expected to be unsustainable as they are mainly recharged by precipitation which will be absent during the dry season. The third layer on this profile is characterized by a resistivity value of 632.8 Ωm and unknown thickness due to the current that terminated in this region hence further investigation could not be done. This region is the freshwater-bearing zone due to the lithology of this zone inferring to be coarse gravelly sand. This region is a freshwater-bearing zone. The region is sustainable and free from saline intrusion because of its confinement overlaying the zone.

CONCLUSION

The water demand has drastically increased due to rapid urbanization, industrialization, and agricultural-related activities in the study area. To meet this demand, there was a need to estimate the water table depth, and the groundwater situation at the University of Calabar was studied. The DC Resistivity method successfully mapped the water table depth below the mean sea level. The estimated average water table depth in UNICAL ranged between 5.5m and 34.5m below the mean sea level depth from the ground surface. This information is valuable for understanding the hydrological characteristics of the study area and has implications for various aspects of water resource management in the region.

The DC Resistivity technique provides a better alternative to mapping the water table in a rapid, less costly non-invasive, and non-intrusive manner as compared to the traditional methods such as the seismic method.

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