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Assessment of Subsurface Sustainability for Civil Engineering Structures in Awka North, Anambra State Southeast Nigeria, Using Electrical Resistivity Method

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ABSTRACT

Electrical resistivity data were analyzed for assessment of subsurface sustainability for civil engineering structures in the communities of Awka North. Information such as Apparent resistivity, thickness of the layers, depth of the layers and lithology delineated. Also, Depth to Competent Rocks, Depth to weathered zones and Thickness to Weathered Layers were revealed. The modelled VES profile confirmed predominant lithological sequence of four (4) – six (6) layers of mainly shale, shaly sandstone and alternating sandstone. The porous sandstone layer has an apparent resistivity range of $\rho a < 14k\Omega m$ - $\rho a > 30k\Omega m$. Various depth and thickness of each layers were obtained and the last layer depth of every location is the addition of the thickness and depth upper layer while the thickness of the last layer is undetermined. From the layer thickness and depth delineation the depth to competent zones revealed some locations like Ugbu – enu, Achalla, Isuaniocha and Amanuke have high competent zones with less weathering rate on the range of 10 - > 46 meters. The average locations with competent zones revealed the formation of the study area being predominately shale, shaly sand with lens of sandstone units. Structures in the study area experience little of no weathering due to stability of subsurface layers.

Keywords: Foundation Design, Vertical Electrical Sounding, Electrical Resistivity, Competent Rock, Weathered Layer, Schlumberger Array and Win-Resistivity Plots.

1. INTRODUCTION

Electrical resistivity investigation can be used in engineering site investigations (Kearey *et al*, 2002). Geophysical methods are applied in civil engineering construction related projects ranging from pre-construction feasibility studies to post construction integrity assessment (Soupios, 2007). Geophysical methods are used for the delineation of subsurface sequence, identification of geological structures and determination of physical parameters of rock. This information enhances rapid characterization of subsurface formations, identification of competent subsurface layers, determination of thickness and depth required for the design of civil engineering foundation. By understanding these, site engineers and geologists make informed decisions regarding site selection, foundation design, and construction methodologies, ensuring the long-term sustainability and safety of infrastructure projects. Reliable infrastructure development is essential for economic growth and improved quality of life. Building sustainable infrastructure necessitates a thorough understanding of subsurface conditions. Huge amount of resources apportioned towards maintenance of infrastructures could be reduced if proper geophysical investigation were conducted prior to the development of structures. It is therefore important to undertake a study that will probe the subsurface and reveal subsurface features that could support or retard infrastructural development. Electrical resistivity (ER) offers a geophysical technique to address the environmental issue by providing valuable information about the subsurface.

2. LOCATION AND GEOLOGICAL SETTING THE STUDY AREA

Awka North Local Government Area (LGA) is situated in the southeastern part of Anambra State, Nigeria, within the West African sub-region. Geographically, the area is located approximately between latitudes 6°00′N and 6°25′N and longitudes 6°45′E and 7°00′E (Akujieze et al., 2007). The accessibility of Awka North LGA is facilitated by its position within the state and the road network that connects it to other regions. Major urban centers within the LGA, such as Awka, the capital city of Anambra State, serve as administrative, commercial, and transportation hubs for the surrounding communities. Awka North is a Local Government Area and one of the geographical areas in Anambra central, Anambra State, southeast Nigeria. The study covered nine (8) towns of Awka North; Ebenebe, Achalla, Urum, Amansea, Amanuke, Isu Aniocha, Mgbakwu and Ugbenu (Fig. 1). Awka North has it's headquarter situated at Achalla. Awka North Local Government Area lies. Geplogically, Awak North is underlain by Imo shale predominantly. The Imo Formation is mainly composed of sandstones, shales, and claystones. This formation is of Eocene age and records a continental depositional environment (Nwajide & Ezeigbo, 2017). The topography of Awka North LGA is characterized by undulating terrain, with elevations ranging from low-lying plains to hills and valleys. The undulating topography reveals a significant role in shaping various aspects of the local environment, including water drainage, soil formation, and vegetation distribution.

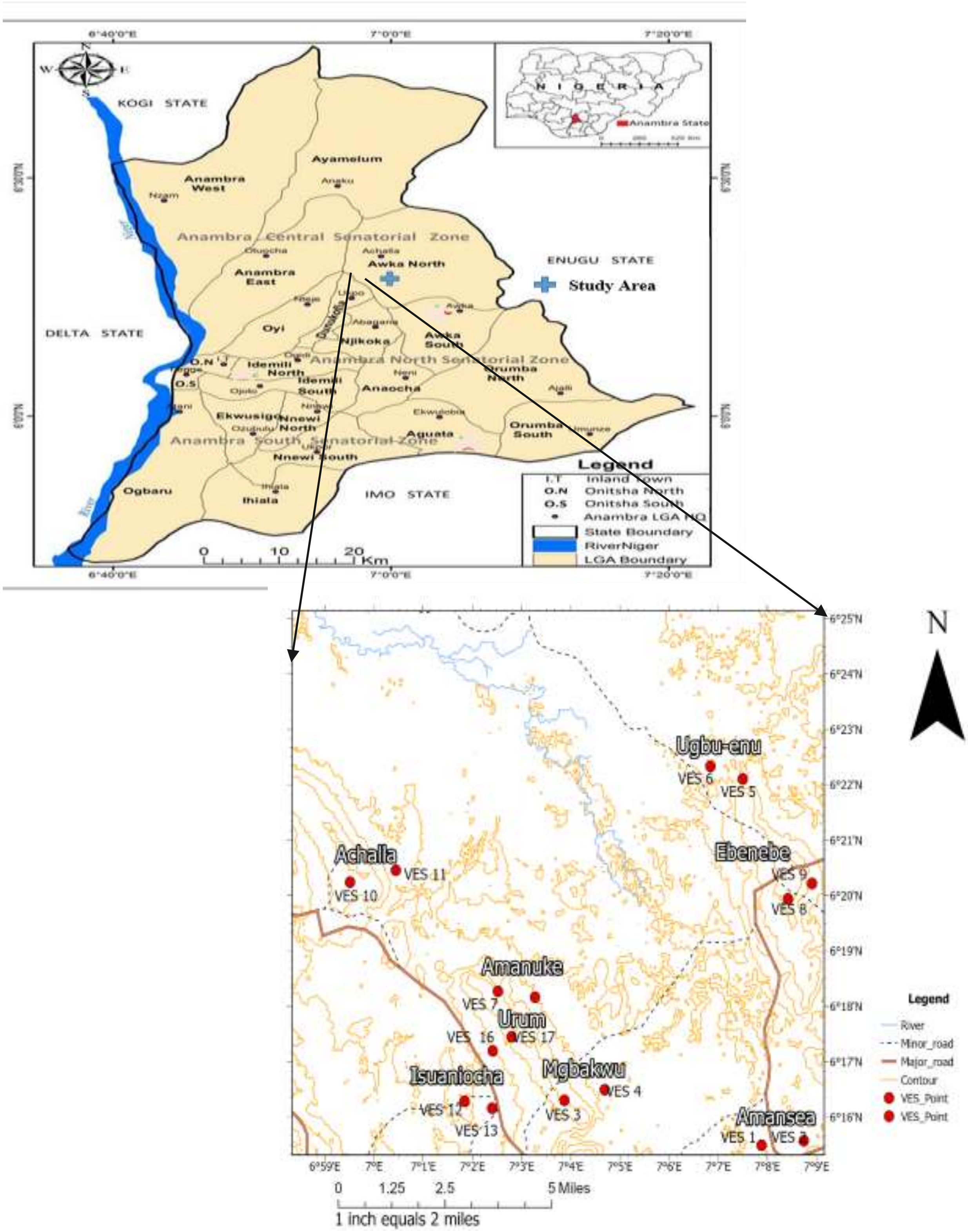


Fig. 1: Map of Anambra State and Topographic Map showing the study area and VES locations modelled with ArcGIS Software

3. METHODOLOGY

The field approach is the use of schlumberger array to conduct electrical resistivity survey, four electrodes are the key. The potential electrodes (MN) are located in between the current electrodes (AB) where mid-point is established. The two current electrodes are usually separated outwards starting from the lowest arbitrary number while the potential electrode remains in place. The potential electrodes will be adjusted only when the observed voltage tends to become too small for measurable potentials and this will ensure that the voltage did not drop in the course of survey. Schlumberger array used in the field work helped to determine the vertical variations of resistivity within the ground.

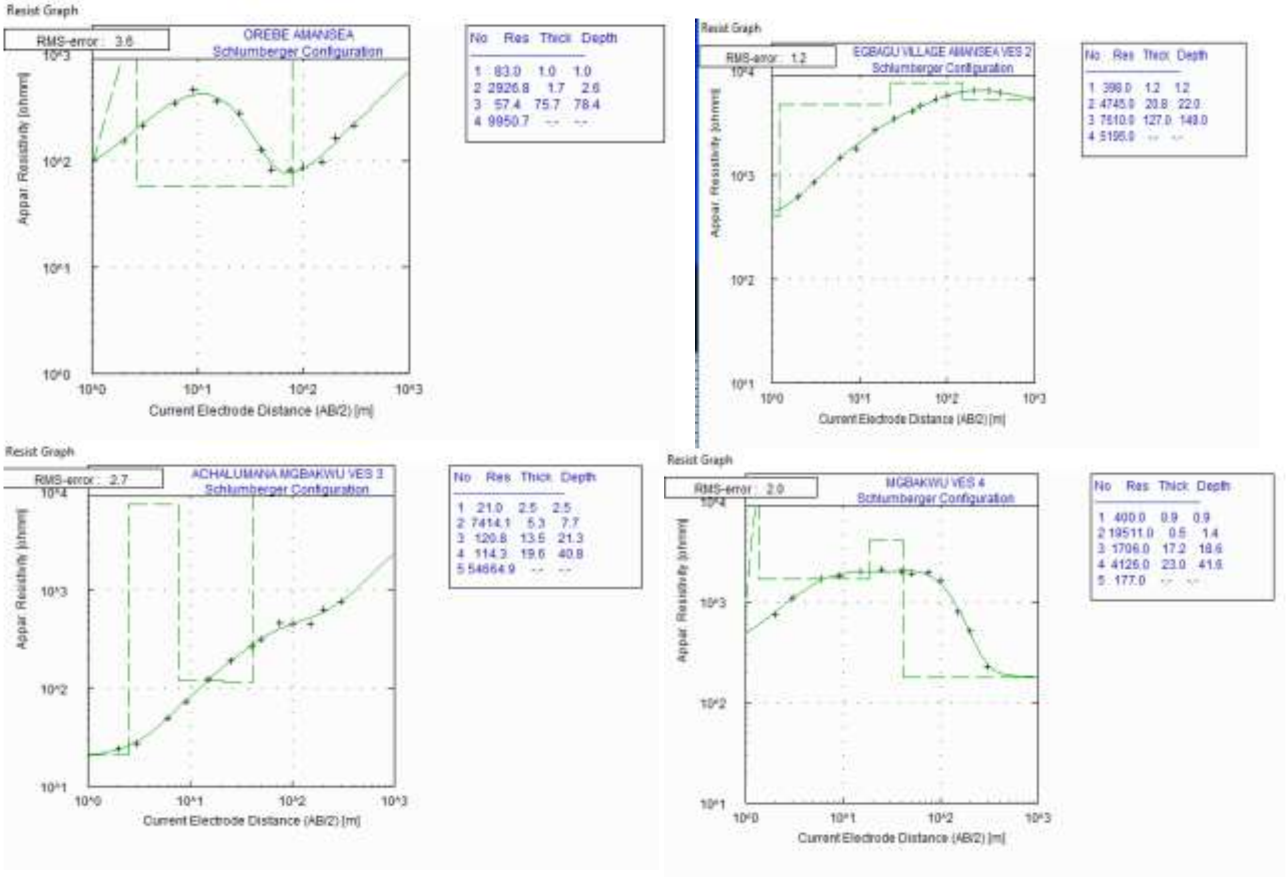
The apparent resistivity values can be deduced from the measured voltage and the other parameters of the survey result specifically the geometric factor, K. In schlumberger configuration the apparent resistivity can be calculated using the given equation below, Ogungbemi, et al. (2013).

$k = \pi (L^2 - b^2) R/2$ -- (a)

But, $\rho_a = K \times R\alpha$ -- (b)

The product of geometric factor (K) and resistance is equal to apparent resistivity.

Where L = current electrode spacing (AB/2), b = potential electrode spacing (MN/2), ρa = the apparent resistivity in ohm-m, and $R\alpha$ = resistance reading in ohm.



No	Res	Thick	Depth
1	83.0	1.0	1.0
2	2926.8	1.7	2.6
3	57.4	75.7	78.4
4	9950.7	--	--

No	Res	Thick	Depth
1	398.0	1.2	1.2
2	4745.0	20.8	22.0
3	7510.0	127.0	149.0
4	5195.0	--	--

No	Res	Thick	Depth
1	21.0	2.5	2.5
2	7414.1	5.3	7.7
3	120.8	13.5	21.3
4	114.3	19.6	40.8
5	54664.9	--	--

No	Res	Thick	Depth
1	400.0	0.9	0.9
2	19511.0	0.5	1.4
3	1706.0	17.2	18.6
4	4126.0	23.0	41.6
5	177.0	--	--

Fig. 2 The plots of Apparent Resistivity against Current Electrode distance/spacing of selected locations in the study area.

The above profiles are modelled from the resulting apparent resistivity against the specific current electrode of each location. There are recommendable professional softwares used in plotting apparent resistivity which model the subsurface layers with respect to the sounding (Vertical Electrical Sounding) or configuration. The above plots (Fig. 2) are modelled using win-resistivity software which revealed the curve representing the number of layers and the lithology compositions. The configuration of the curves obtained strategized the lithology inferences as the current is passed into the subsurface. Win-resistivity inversion computer software is so improved to display the root mean square error level which must be lower than 5% to confirming the layer resistivity and thicknesses for every sounding location (Adeniji, et al., 2013). The selected of the surveyed locations distinguished as follow; VES 1(RMS: 3.6%) **(**OREBE AMANSEA) KH ($\rho1< \rho2>\rho3< \rho4$), VES 2 (RMS: 1.2%) (EGBAGU VILLAGE AMANSEA) AK ($\rho1< \rho2< \rho3>\rho4$), VES 3 (AKWA) (RMS: 3.8%) AHK ($\rho1< \rho2< \rho3< \rho4>\rho5$), VES 4 (RMS: 2.0%) (MGBAKWU) AHK ($\rho1< \rho2< \rho3< \rho4> \rho5$). The table 1 and fig. 3 below represent the detailed subsurface characteristics of the profiles in the surveyed locations.

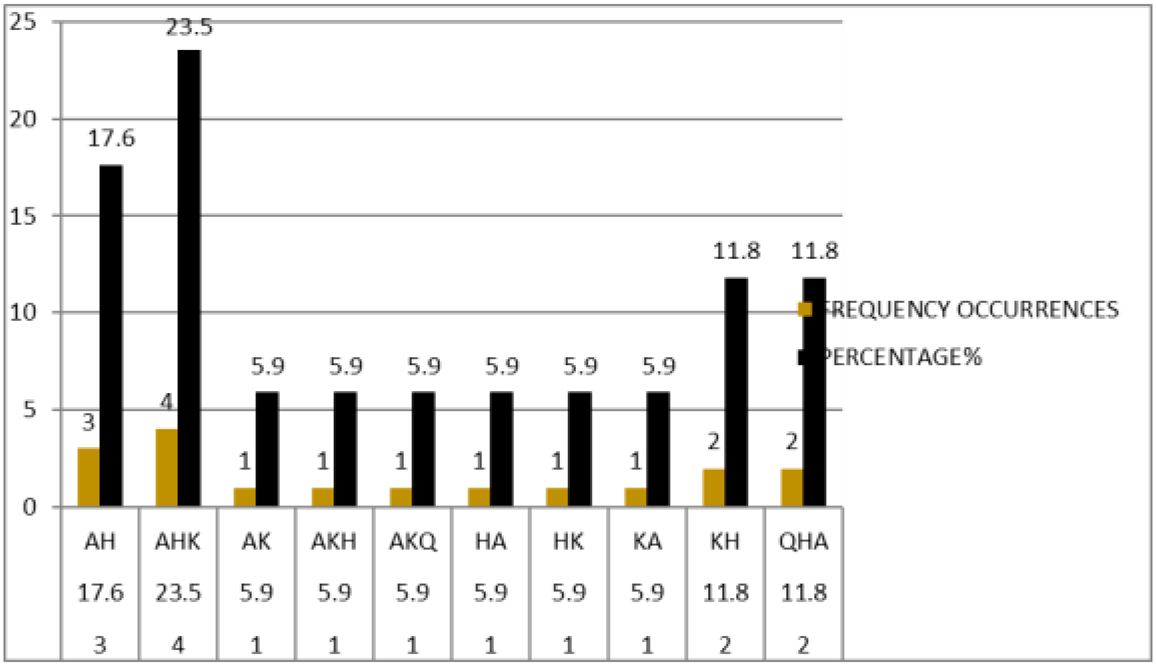


Fig. 3: Shows Curve Type Frequency and Percentage Occurrence in Awka North Surveyed Locations.

Table; 1. Station ID/ Layers	**App Res (Ωm)**	**Thickness (m)**	**Depth (m)**	***Description***
VES 1(OREBE AMANSEA) (RMS: 3.6%)				***CURVE TYPE KH($\rho1<\rho2>\rho3<\rho4$)***
1	83.0	1.0	1.0	*Top layer/Laterite*
2	2926.0	1.7	2.6	*Sandstone*
3	57.4	75.7	78.4	*Shale*
4	9950.7	Undetermined	154.1	*Water-Saturated Sand*
VES 2(EGBAGU VILLAGE AMANSEA) (RMS: 1.2%)				***CURVE TYPE AK($\rho1<\rho2<\rho3>\rho4$)***
1	398.0	1.2	1.2	*Top layer/Laterite*
2	4745.0	20.8	22.0	*Shalysand*
3	7610.0	127.0	149.0	*Water-Saturated Sand*
4	5195.0	Undetermined	276.0	*Sandstone*
VES 3(AKWA) (RMS: 3.8%)				***CURVE TYPE AHK($\rho1<\rho2<\rho3<\rho4>\rho5$)***
1	21.0	0.8	1.8	*Top layer/Laterite*
2	7414.0	1.6	2.3	*Sandstone*
3	120.8	40.1	42.5	*Shalysand*
4	114.3	25.9	68.3	*Sandshale*
5	50664.9	40.7	109.0	*Water-Saturated Sand*
VES 4(MGBAKWU) (RMS: 2.0%)				***CURVE TYPE AHK(($\rho1<\rho2<\rho3<\rho4>\rho5$)***
1	400.0	0.9	0.9	*Top layer/Laterite*
2	19511.0	0.5	1.4	*Sandstone*
3	1706.0	17.2	18.6	*Shalysand*
4	4126.0	23.0	41.6	*Sandstone*
5	177.0	Undetermined	64.6	*Water-Saturated Sand*
VES 5(UGBENE) (RMS: 2.3%)				***CURVE TYPE QHA(($\rho1>\rho2>\rho3<\rho4<\rho5$)***
1	18969.0	0.5	0.5	*Top layer/Laterite*
2	3568.0	4.0	4.5	*Sandstone*
3	955.0	16.5	21.0	*Shalysand*
4	16.2	38.1	59.1	*Shale*
5	5213.0	Undetermined	97.2	*Water-Saturated Sand*
VES 6(UGBENE) (RMS: 1.4%)				***CURVE TYPE AKQ($\rho1<\rho<\rho3>\rho4>\rho5$)***
1	3217.0	1.2	1.2	*Top layer/Laterite*
2	8107.0	5.0	6.2	*Shalysand*
3	56070.0	7.4	13.6	*Sandstone*
4	10366.0	16.6	30.2	*Water-Saturated Sand*
5	52746.0	37.1	67.3	*Sandstone*
6	54.6	Undetermined	104.4	*Shale*

VES 7 (COMMUNITY SEC.SCH.AMANUKE) (RMS: 3.3%)				***CURVE TYPE AH(ρ1<ρ2<ρ3< ρ4)***
1	4282.6	2.8	2.8	*Top layer/Laterite*
2	34349.6	49.8	52.7	*Sandstone*
3	984.9	53.2	105.9	*Water-Saturated Sand*
4	66533.4	Undetermined	159.1	*Sandstone*
VES 8(OBUNNO EBENEBE) (RMS: 1.7%)				***CURVE TYPE AHK(ρ1< ρ< ρ3< ρ4> ρ5)***
1	7.1	0.9	0.9	*Top layer/Laterite*
2	89.4	15.4	16.2	*Sandyshale*
3	199.1	13.9	30.1	*Shalysand*
4	3624.5	25.6	55.7	*Water-Saturated Sand*
5	7.3	Undetermined	81.3	*Shale*
VES 9(UMUALOR KINDRED EBENEBE) (RMS: 2.0%)				***CURVE TYPE AKH(ρ1< ρ2<ρ3>ρ4< ρ5)***
1	141.0	0.8	0.8	*Top layer/Laterite*
2	731.5	3.5	4.4	*Sandyshale*
3	1113.8	9.8	14.1	*Shalysand*
4	74975.9	26.7	40.8	*Sandstone*
5	183.7	Undetermined	68.3	*Water-Saturated Sand*
VES 10(UMUDIANA ACHALLA) (RMS: 2.5%)				***CURVE TYPE AKH(ρ1< ρ2<ρ3>ρ4< ρ5)***
1	210.2	0.4	0.4	*Top layer/Laterite*
2	761.9	5.9	6.4	*Shalysand*
3	49208.8	16.6	22.9	*Sandstone*
4	149.9	56.3	79.2	*Sandyshale*
5	52738.1	Undetermined	135.5	*Water-Saturated Sand*
VES 11(UMUDIANA) (RMS: 3.7%)				***CURVE TYPE KH(ρ1< ρ2> ρ3< ρ4)***
1	2076.5	4.5	4.5	*Top layer/Laterite*
2	82923.6	23.1	27.6	*Sandstone*
3	1013.9	47.2	74.7	*Water-Saturated Sand*
4	64804.6	Undetermined	121.9	*Sandstone*
VES 12(OTOKO ISUANIOCHA) (RMS: 3.2%)				***CURVE TYPE KA(ρ1< ρ2>ρ3< ρ4)***
1	41.3	0.9	0.9	*Top layer/Laterite*
2	178.9	1.0	1.9	*Sandyshale*
3	7.1	7.2	9.1	*Shale*
4	737.0	Undetermined	16.4	*Water-Saturated Sand*
VES 13(OCHUKWU NWOSU ST.ISUANIOCHA) (RMS: 3.2%)				***CURVE TYPE HA(ρ1>ρ2< ρ3<ρ4)***
1	153.8	4.1	4.1	*Top layer/Laterite*
2	17.2	7.3	11.5	*Shale*
3	231.8	101.3	112.8	*Sandyshale*
4	13041.7	Undetermined	214.1	*Water-Saturated Sand*

VES 14 (UGBU-ENU) ***(RMS: 2.8%)***				***CURVE TYPE*** ***AH(ρ1<ρ< ρ3<ρ4)***
1	58.0	2.4	2.4	*Top layer/Laterite*
2	576.7	8.3	10.7	*Shalysand*
3	22187.3	12.6	23.3	*Water-Saturated Sand*
4	143.2	Undetermined	35.9	*Sandyshale*
VES 15(UGBE-ENU) ***(RMS: 1.8%)***				***CURVE TYPE*** ***AH(ρ1<ρ2< ρ3< ρ4)***
1	98.3	0.7	0.7	*Top layer/Laterite*
2	12870.0	1.8	2.5	*Sandstone*
3	150.0	8.6	11.1	*Sandyshale*
4	680.0	Undetermined	19.7	*Water-Saturated Sand*
VES 16(URUM) ***(RMS: 2.4%)***				***CURVE TYPE*** ***QHA(ρ1> ρ2> ρ3< ρ4<ρ5)***
1	1027.0	0.5	0.5	*Top layer/Laterite*
2	474.5	4.5	5.0	*Shalysand*
3	2.9	6.6	11.6	*Shale*
4	72.9	90.0	101.6	*Sandyshale*
5	9069.0	Undetermined	191.6	*Water-Saturated Sand*
VES 17(URUM) ***(RMS: 4.2)***				***CURVE TYPE*** ***HK(ρ1> ρ2< ρ3> ρ4)***
1	424.2	2.9	2.9	*Top layer/Laterite*
2	170.6	8.0	10.9	*Sandyshale*
3	19.7	105.3	116.3	*Shale*
4	3810.3	Undetermined	221.6	*Water-Saturated sand*

4. RESULTS AND INTERPRETATIONS

From modelled profiles the resistivity competent zones were tabulated, measured in ohms meter. Depth to competent rocks is the depth (m) corresponding to the top of the layer considered competent from the profile. Thickness of weathered zones is the thickness of layers considered as weathered zones while weathered zones are the weak zones in the modelled profile of apparent resistivity and current electrodes. Depth to weathered zones is the depth of the bottom of the weathered zones by adding the thickness of the weathered zones to the depth of the topmost layer.

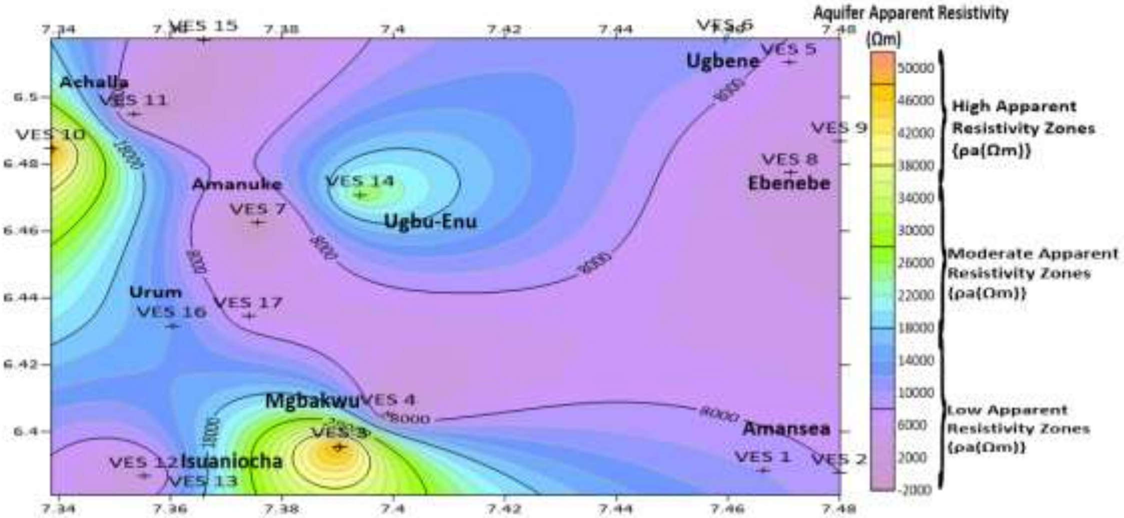


Fig. 4. **Aquifer Apparent Resistivity Map of Awka North Local Government Area**

Electrical Resistivity of Aquifers: Influence on Infrastructure Projects

The electrical resistivity of aquifers, is an important parameter that determines their resistance to the flow of electrical current, plays a visible role in assessing the suitability of geological formations for infrastructure development. By evaluating the electrical resistivity.

we will consider three electrical resistivity ranges:

Fig. 4, Low Electrical Resistivity Zones (ρa < 14kΩm): Low electrical resistivity often indicates the presence of highly conductive materials, such as saturated clay or saline groundwater, which can present challenges for infrastructure development. These zones (VES 1,2,4,5,6,7,8,9,11,12,15,16 and 17) may require additional geotechnical and hydrogeological investigations to identify potential issues, such as soil swelling, corrosion, or aggressive water conditions. Respective location of the zones is Amansea, Partly Mgbakwu, Ugbene, Amanuke, Ebenebe, Achalla, Partly Isuaniocha and Urum.

Intermediate /Moderate Electrical Resistivity Zones (14kΩm < ρa < 30kΩm): Aquifers with intermediate electrical resistivity frequently comprise materials with moderate resistance to current flow, such as sand or silty soils. These zones (VES 13 and 14) may necessitate careful consideration of groundwater conditions and the potential for water-related geotechnical hazards, such as liquefaction or settlement. Understanding of aquifer characteristics, including composition, grain size distribution, and degree of saturation, is essential for designing suitable foundation systems and construction methodologies. The respective zone locations are Partly Isuanniocha and Ugbu-Enu

High Electrical Resistivity Zones (ρa > 30kΩm): High electrical resistivity is typically associated with low-conductivity materials, such as bedrock or unsaturated soils, which can offer a stable environment for infrastructure development. However, potential impacts of limited water availability and the presence of low-permeability materials on construction activities should be assessed.

By examining the electrical resistivity of aquifers across various geological formations. This knowledge from the topo map can help refine project designs, reduce construction risks, and promote sustainable development practices that account for the unique characteristics of local geology and groundwater conditions. The zone VES 3 and 10(Partly Ugbakwu and Achalla) have a significant high electrical resistivity values.

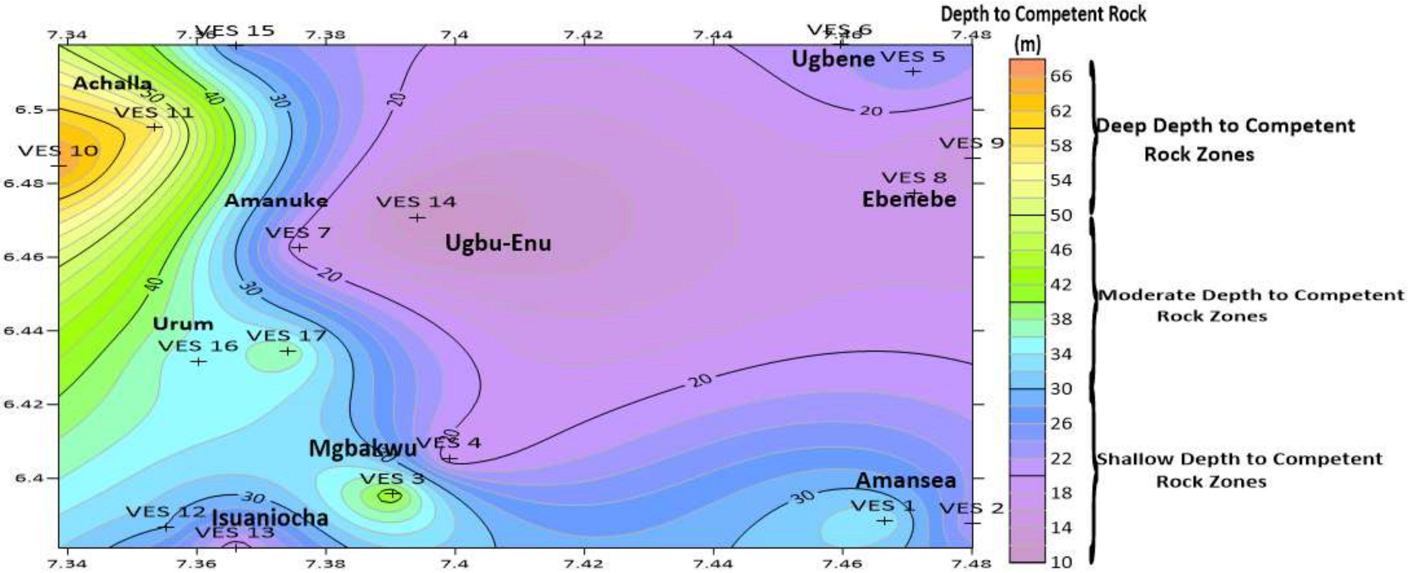


Fig. 5: Depth to Competent Rocks Map of Awka North Local Government Area

Subsurface Bedrock Depth: Implications for Infrastructure Development

The depth at which competent bedrock is encountered beneath the Earth's surface is a critical factor for assessing the suitability of geological formations for infrastructure development.

In this discussion, we will consider three depth ranges for competent bedrock occurrence:

Fig. 5, Shallow Bedrock Zones or Low depth to competent Rock (10-26 meters): Areas (VES 2,4,5,6,7,8,9,12,13,14 and 15 with shallow bedrock depths provide a stable foundation for infrastructure development, as competent bedrock offers higher material strength and reduced susceptibility to water-induced damage. However, construction in these zones may require specialized techniques for excavating and anchoring structures to the bedrock, ensuring adequate load transfer and minimizing potential settlement issues. The above zone is situated I the following locations Partly (Amansea, Mgbakwu), Ugbu-Enu, Amanuke, Ebenebe, Isuaniocha and Ugbene.

Moderate Bedrock Zones (26-46 meters): These zones (VES 1,3,16 and 17) can present a mix of advantages and challenges for infrastructure development. While bedrock is not as close to the surface as in shallow zones, construction in these areas may still necessitate careful consideration of factors such as excavation depth, foundation design, and potential interaction between overlying soil layers and bedrock. An understanding of the geological characteristics, composition, and structural features of the bedrock is crucial for designing suitable foundation systems and construction methodologies. The resulting zones are located within the respective locations locations Partly (Amansea, Mgbakwu) and Urum.

Deep Bedrock Zones (>46 meters): Areas (VES 10 and 11) with deep bedrock depths can pose significant challenges for infrastructure development, as they require more extensive and costly engineering interventions, such as deep foundations or ground improvement techniques, to ensure structural stability and mitigate potential risks. It is essential to evaluate the properties and behavior of the overlying soil layers and consider potential impacts on construction activities, project timeline, and overall costs. Those zones are location in Achalla, Isuaniocha and Ugbene).

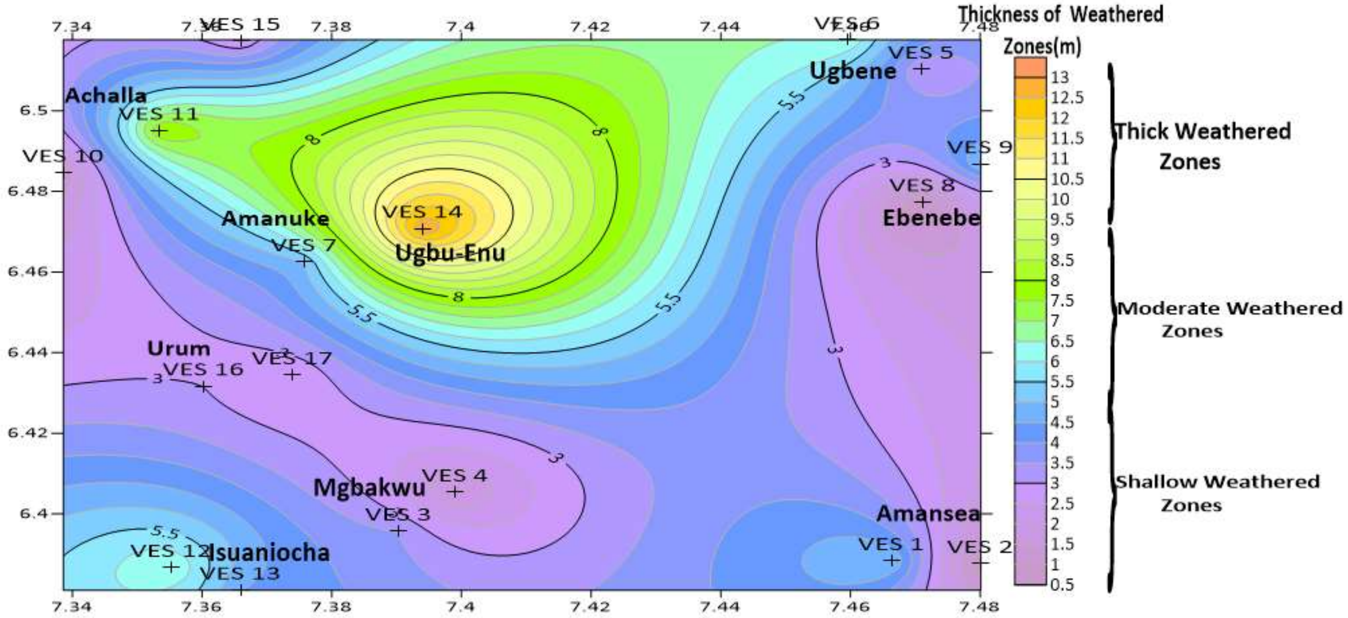


Fig. 6: Thickness to Weathered Layers Map of Awka North Local Government Area

Subsurface Alteration Layer Extent: Implications for Infrastructure Planning

The extent or thickness of the subsurface alteration layer, commonly referred to as the weathered zone, above unaltered bedrock is a vital factor in determining the suitability of geological settings for infrastructure projects.

Fig. 6, Thin Weathered Zones (0.5-4.5 meters): Sites (VES 2,3,4,5,8,10,13,15,16 and 17) with a thin weathered zone generally provide easier access to competent bedrock for foundation support, making them advantageous for infrastructure development. However, these zones may necessitate careful attention to aspects such as erosion, slope stability, and potential bedrock weathering, which could affect the performance of structures. Additionally, the limited thickness of the weathered zone might not provide enough cushioning for structures, potentially resulting in increased foundation stress. The zones are respectively located at partly Amansea, Mgbakwu, partly (Ugbu-Enu, Ebenebe, Achalla, Isuaniocha, Ugbene) and Urum.

Moderate Weathered Zones (4.5-8.5meters): These (VES 1, 6, 7, 9, 11 and 12) present both benefits and challenges for infrastructure development. While a moderate thickness of the weathered zone can provide cushioning and reduce bedrock weathering, construction in these areas might require deeper foundations or ground improvement techniques for structural stability, particularly if the weathered materials are weak or highly compressible. Understanding the properties of the weathered zone, including its composition, compaction, and hydraulic conductivity, is crucial for designing suitable foundation systems and construction techniques. The following Zones are located at Partly Amansea, partly Ugbu-Enu, Amanuke, partly (Ebenebe, Achalla and Isuaniocha)

Thick Weathered Zones (>8.5meters): Areas (VES 12 and 14) with a thick weathered zone present considerable challenges for infrastructure development. Construction in these zones often demands significant engineering interventions, such as deep foundations, advanced excavation methods, or ground improvement techniques, to ensure structural integrity. Assessing the properties and behavior of the weathered zone is essential for developing cost-effective and sustainable solutions for construction projects. The zones are located at Isuaniocha and Ugbene.

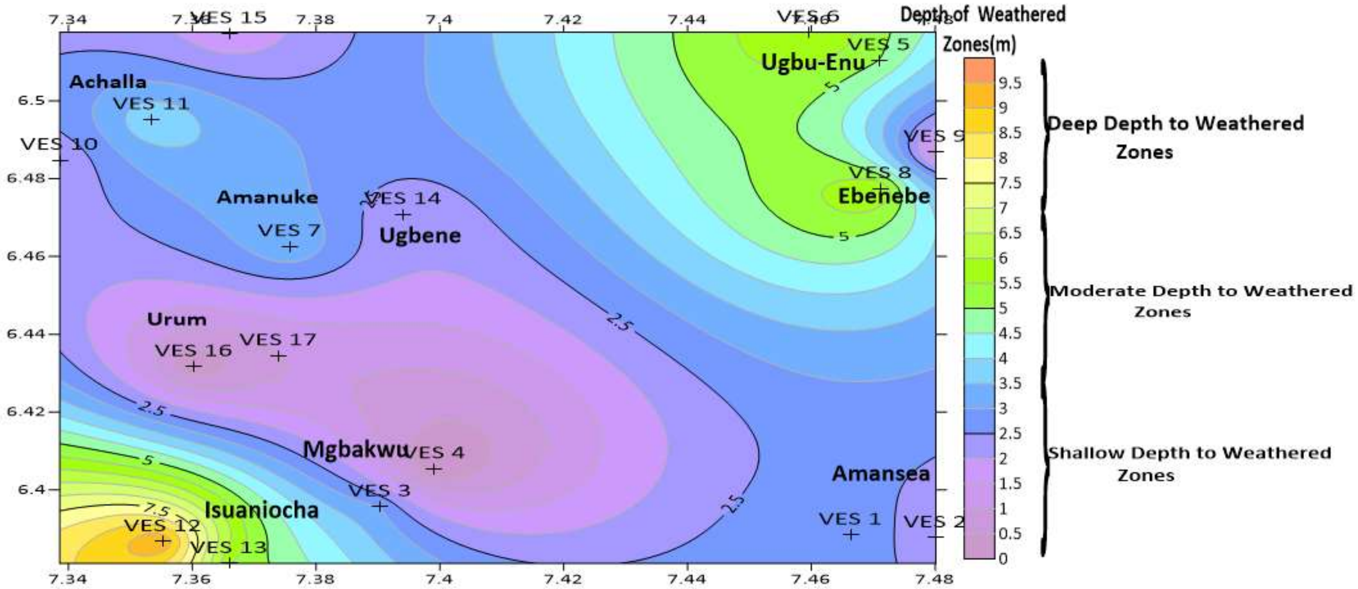


Fig. 7: Depth to Weathered Layers Map of Awka North Local Government Area

Subsurface Weathering Layer Depth: Consequences for Infrastructure Planning

The depth of the subsurface weathering layer, often referred to as the weathered zone, above unaltered bedrock plays a critical role in determining the suitability of geological settings for infrastructure projects.

Fig. 7, Shallow Weathered Zones (0.5 to 3meters): Sites (1,2,3,4,9,10,14,15,16 and 17) with shallow weathered zones typically offer easier access to competent bedrock for foundation support, making them advantageous for infrastructure development. However, these zones may require careful attention to factors such as erosion, slope stability, and potential bedrock weathering, which could impact the performance of structures. Additionally, a shallow weathered zone might not provide sufficient cushioning for structures, potentially leading to higher foundation stress. Respective location for the zones are as follows Amansea, Mgbakwu, partly (Ebenebe, Achalla), Ugbene and Urum.

Moderately Deep Weathered Zones (3-6meters): These zones (VES 5,6,7,8,11 and 13) present both advantages and challenges for infrastructure development. While a moderately deep weathered zone can offer cushioning and reduce bedrock weathering, construction in these areas might necessitate deeper foundations or ground improvement techniques to ensure structural stability, particularly if the weathered materials are weak or highly compressible. A thorough understanding of the weathered zone properties, such as composition, compaction, and hydraulic conductivity, is essential for designing appropriate foundation systems and construction methodologies. The zones are respectively located as follows Ugbu-EnuAmanuke, partly (Ebenebe, Achalla and Isuaniocha)

Deep Weathered Zones (>20 meters): Areas with deep weathered zone VES 12 (partly Isuaniocha) present considerable challenges for infrastructure development. Construction in these zones typically requires thorough interventions of the expertise, such as deep foundations, advanced excavation methods, or ground improvement techniques, to ensure structural integrity. Assessing the properties and behavior of the weathered zone is vital for developing cost-effective and sustainable construction solutions.

5. CONCLUSION

The study summarized that subsurface lithological profile of the soil underlying a structure is important for design and construction. Structures are found either on soil or within the subsurface soil or rock. The soil and rocks constitute the foundation support below the superstructure. From the results locations with low weathering rates are sustainable for siting any engineering structures while areas of less competency are advised to be monitored and sitting any civil structures. Apparent resistivity of the study area ranged ρa < 14kΩm - ρa > 30kΩm. locations like Ugbu – enu, Achalla, Isuaniocha and Amanuke showed high competent zones with less weathering rate ranging 0 - > 46 meters. The research recommends that before carrying out civil engineering constructions, basic professionals should provide soil lithological profile of the subsurface for better understanding of the subsurface.

CONFLICT OF INTEREST

Author(s) hereby declare that no conflict of interest in the writing of this paper.

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