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Aquifer Delineation and Subsurface Investigation for Engineering Structures In Parts Of Awka North, Anambra State Nigeria, Using Vertical Electrical Sounding Method

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ABSTRACT
The study investigates the subsurface for groundwater potentials and engineering structures deploying geoelectrical sounding (vertical electrical sounding). Using schlumberger electrode configuration and Terrameter SAS 3000 and other geophysical accessories seventeen (17) vertical electrical sounding (VES) profiles were conducted and modelled with win-resistivity software. Detailed findings from the study reveal promising subsurface features for better sustainable groundwater exploration and technical investigation and constructing engineering structures. The water saturated depth and resistivity of each locations at a negligible root mean square (RMS) of ≤ 5% showed;154.1 m and 9950.7 Ωm (RMS: 3.6%) VES 1(Orebe Amansea), 149.0 m and 7610.0 Ωm (RMS: 1.2%) VES 2(Egbagu Village Amansea), 109.0 m and 50664.9 Ωm (RMS: 3.8%) VES 3(Akwa), 64.6 m and 177.0 Ωm (RMS: 2.0%) VES 4(Mgbakwu), 97.2 m and 5213.0 Ωm (RMS: 2.3%) VES 5(Ugbene), 30.2 m and 10366.0 Ωm (RMS: 1.4%) VES 6(Ugbene), 105.9 m and 984.9 Ωm (RMS: 3.3%) VES 7 (Community Sec.Sch.Amanuke), 55.7 m and 3624.5 Ωm (RMS: 1.7%) VES 8(Obunno Ebenebe), 68.3 m and 183.7 Ωm (RMS: 2.0%) VES 9(Umualor Kindred Ebenebe) ,135.5 m and 52738.1 Ωm (RMS: 2.5%) VES 10 (Umudiana Achalla), 74.7 m and 1013.9 Ωm (RMS: 3.7%) VES 11(Umudiana), 16.4 m and 737.0 Ωm (RMS: 3.2%) VES 12 (Otoko Isuaniocha), 214.1 m and 13041.7 Ωm (RMS: 3.2%) VES 13(Ochukwu Nwosu St.Isuaniocha), 23.3 m and 22187.3 Ωm (RMS: 2.8%) VES 14 (Ugbu-Enu), 19.7 m and 680.0 Ωm VES 15 (Ugbe-Enu) (RMS: 1.8%), 191.6 m and 9069.0 Ωm VES 16 (Urum) (RMS: 2.4%), 221.6 m and 3810.3 Ωm VES 17(Urum) (RMS: 4.2). The study proves that the depth to prolific aquifer in the study area ranged 221.6 – 16.4 m with resistivity range of 52738.1 Ωm – 177.0 Ωm respectively. The lithological descriptions of the study show predomantly shale and shaly sand with its sandstone composition. Structurally the competency of the layers to infrastructural development is moderately favorable.

Keywords: Infrastructural Development, Groundwater Exploration, Vertical Electrical Sounding, Geoelectrical Sounding, Win-Resistivity Plots and Aquifer Depth.

1. INTRODUCTION

Recently the world has grown into civilization. Urbanization and industrialization has influenced the population rate. Awka North faces a serious water supply challenges driven by rapid increase in population. There is need to improved source of basic resources like safe drinking water. Easy access to good road and civil structures promote sustainable cities and communities (SDGs 11). There are several water storage units geologically known as aquifer, aquiclude and aquitard but the interest of every geoscientist in groundwater exploration is the aquifer. Aquifer is water bearing rock that is saturated and characterized with permeability and porosity. However, vertical electrical sounding method were employed in the research to investigate water saturated depth and the subsurface layer for engineering structures. Vertical electrical sounding (VES) is a geoelectrical method that has been reliable and widely applied techniques in groundwater, environmental and geotechnical investigations for mapping complex geological structures as it can delineate the resistivity distribution of such structures (Odoh, Ben. I., Onwuemesi, A.G., Okoro E.I and Ajaegwu, N.E 2007).

2. LOCATION AND GEOLOGICAL SETTING THE STUDY AREA

The study area covered nine (8) towns of Awka North; Ebenebe, Achalla, Isu Aniocha, Urum, Amansea, Amanuke, Mgbakwu and Ugbenu (Fig. 1). Awka North is located within the latitudes 6°00′N and 6°25′N and longitudes 6°45′E and 7°00′E (Akujieze et al., 2007). Awka North has it's headquarter situated at Achalla. Awka North Local Government Area lies. Awka North is underlain by Imo shale predominantly. Awka North LGA is characterized by undulating topography which reveals a significant role in shaping various aspects of the local environment, including water drainage, soil formation, and vegetation distribution. The drainage pattern in Awka North LGA can be described as dendritic, which is typical of regions with relatively homogeneous rock types and a moderate to high degree of relief. This pattern is characterized by randomly branching streams and tributaries, resembling the shape of a tree (Summerfield, 1991). Major rivers in the area include the Idemili River and its tributaries, which eventually drain into the larger Niger River Basin.

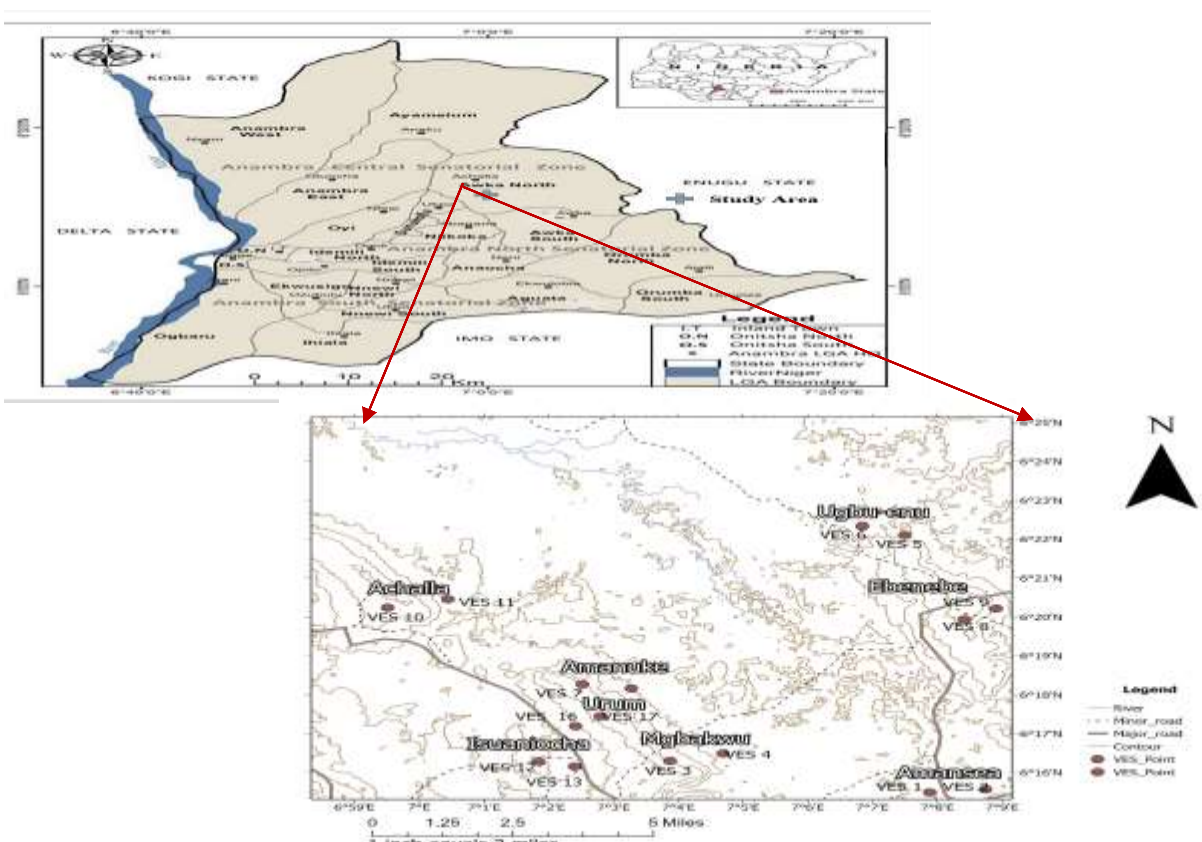

Fig. 1: Map of Anambra State and Topographic Map showing the study area and VES locations modelled with ArcGIS Software

3. METHODOLOGY

Geophysical data obtained from the field were aimed at determining the physical properties on the plane delineated by injecting current along spaced paths and measuring the resulting voltage. The resistivity readings were used to for computing the apparent resistivities. During the field process, two current electrodes are usually separated outwards starting from the lowest arbitrary number while the potential electrode remains at stationary. Potential electrodes kept being adjusted except when 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. This technique is practically easy using Schlumberger array. Schlumberger array used in the field work helped to determine the vertical variations of resistivity within the ground as shown in fig. 2. Schlumberger Array is faster, more accurate and has a slightly greater depth of investigation.

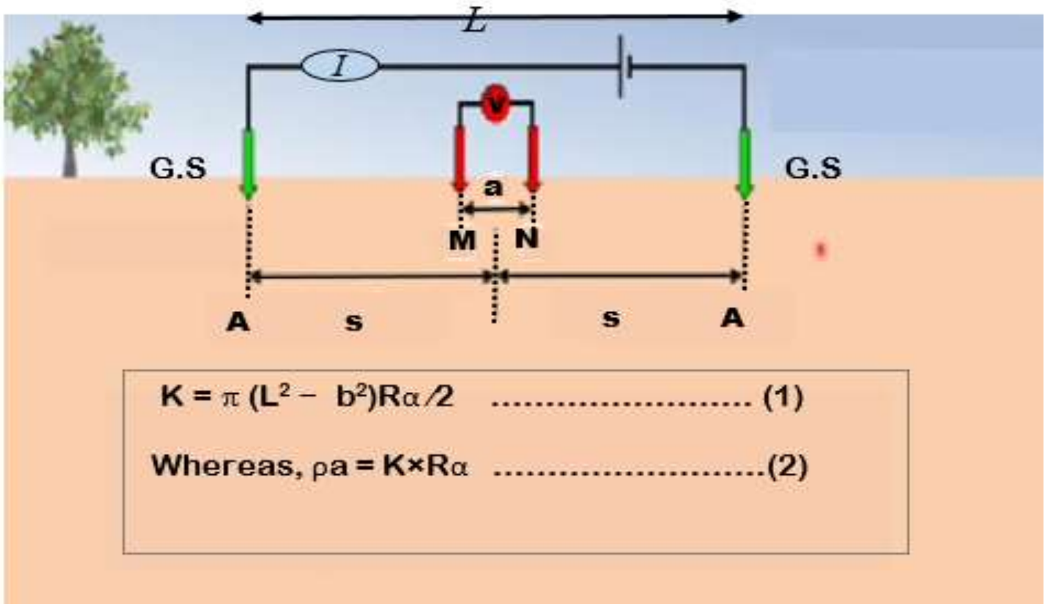

Fig. 2: Electrode configurations in Schlumberger Array (Mines, 2003)

3.1 Integrated Interpretation of VES 1 – 17 Data locations of Awka North L.G.A for Aquifer Delineation and Infrastructural Development.

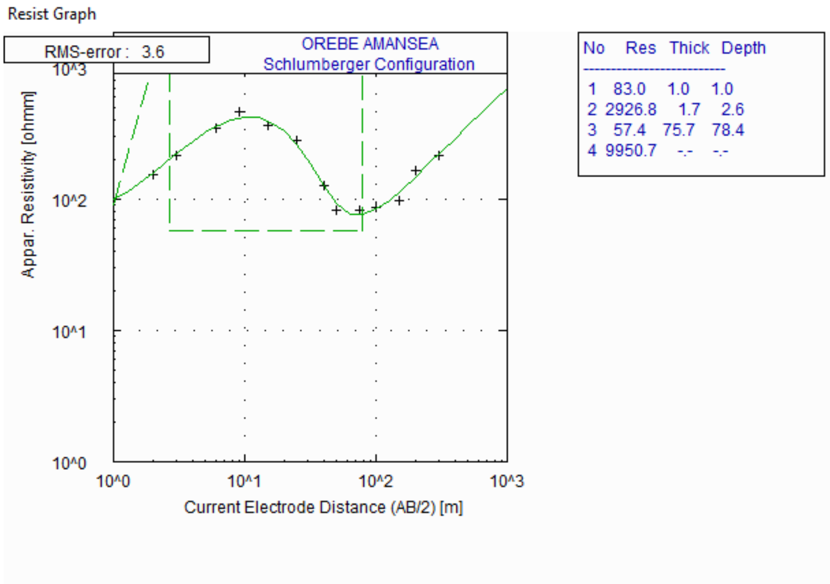

Fig. 3: Winresistivity plots of VES I Location in Awka North LGA

The Vertical Electrical Sounding (VES) data gathered from Station ID "VES 1" at OREBE AMANSEA (Fig.3) reveals a four-tiered aquiferous system and engineering geological configuration, characterized as follows:

Surface Layer: Top layer/Laterite (83.0 Ωm, 1.0 m thick), Upper Intermediate Layer: Sandstone (2926.0 Ωm, 1.7 m thick), Lower Intermediate Layer: Shale (57.4 Ωm, 75.7 m thick) and Deepest Formation: Water-Saturated Sand (9950.7 Ωm, undetermined thickness). The deepest formation, classified as water-saturated sand, indicates the presence of a potential aquifer within the local aquiferous framework. Positioned at a depth of 78.4 meters and extending beyond 154.1 meters, this layer offers significant prospects for sustainable groundwater exploration and exploitation within the region.

Each aquiferous unit's properties necessitate meticulous evaluation in engineering geological design:

Surface Layer (Top layer/Laterite): The shallow lateritic formation provides a stable foundation for lightweight infrastructure but may require additional engineering geological assessment for more substantial construction projects.

Upper Intermediate Layer (Sandstone): The sandstone layer demands thorough aquiferous examination during the planning phase of engineering projects, considering potential complexities concerning aquifer connectivity, groundwater flow, and water quality, impacting the overall structural integrity of engineering initiatives.

Lower Intermediate Layer (Shale): The shale formation warrants comprehensive engineering geological appraisal in civil engineering design, addressing possible challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Deepest Formation (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand necessitates exhaustive aquiferous assessment in engineering geological planning, managing potential hurdles related to aquifer connectivity, groundwater movement, and geomechanical stability.

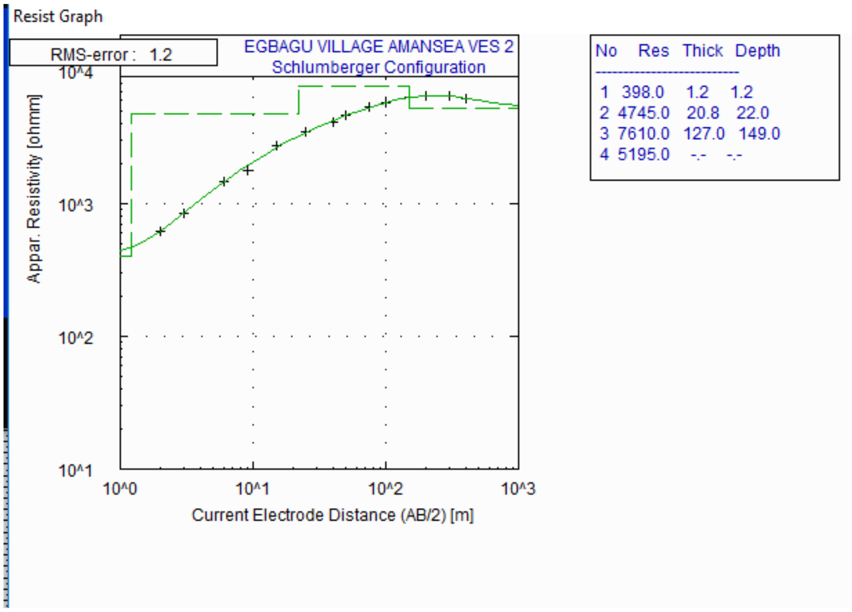

Fig. 4: Winresistivity plots of VES 2 Location in Awka North LGA

Stratigraphic Analysis and Aquifer Identification from VES 2 Data at EGBAGU VILLAGE AMANSEA (Fig.4)

The Vertical Electrical Sounding (VES) data acquired from Station ID "VES 2" at EGBAGU VILLAGE AMANSEA reveals a stratigraphic sequence comprising four layers and a potential aquifer. The geological configuration is characterized as follows:

Surface Layer: Top layer/Laterite (398.0 Ωm, 1.2 m thick), Intermediate Layer 1: Shalysand (4745.0 Ωm, 20.8 m thick), Intermediate Layer 2: Water-Saturated Sand (7610.0 Ωm, 127.0 m thick) and Deepest Formation: Sandstone (5195.0 Ωm, undetermined thickness). The third layer, categorized as water-saturated sand, indicates the existence of a potential aquifer within the local geological framework. Located at a depth of 22.0 meters and extending beyond 149.0 meters, this layer holds significant promise for sustainable groundwater exploration and utilization within the region.

Each layer's properties necessitate meticulous evaluation in geological engineering design:

Surface Layer (Top layer/Laterite): The shallow lateritic formation provides a stable foundation for lightweight infrastructure but may require additional geological assessment for larger construction projects.

Intermediate Layer 1 (Shalysand): The shalysand layer demands thorough geological examination during the planning phase of engineering projects, considering potential complexities concerning aquifer connectivity, groundwater flow, and water quality, impacting the overall structural integrity of engineering initiatives.

Intermediate Layer 2 (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand warrants exhaustive geological assessment in engineering planning, managing potential challenges related to aquifer connectivity, groundwater movement, and geomechanical stability.

Deepest Formation (Sandstone): The sandstone formation necessitates comprehensive geological appraisal in civil engineering design, addressing possible challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

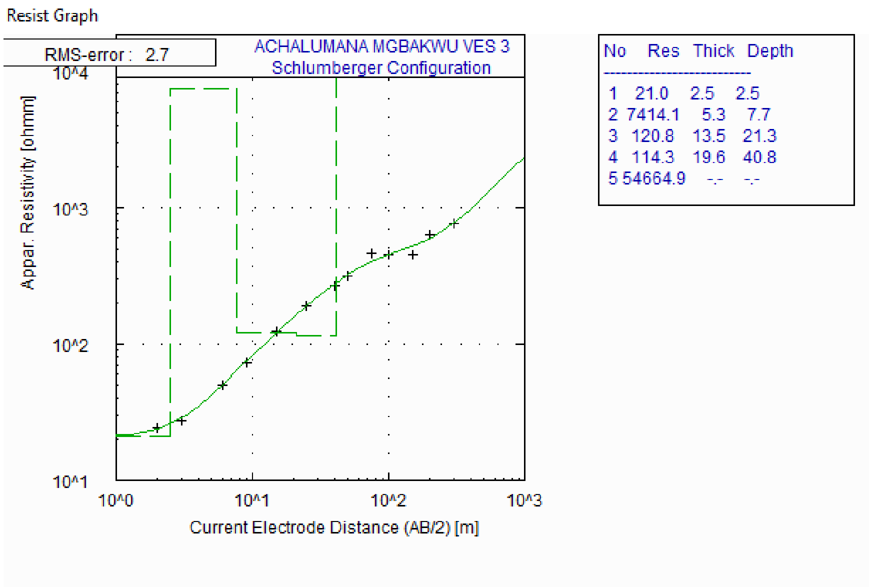

Fig. 5: Winresistivity plots of VES 3 Location in Awka North LGA

Stratigraphic Configuration and Aquifer Assessment of VES 3 Data from AKWA (Fig.5).
The Vertical Electrical Sounding (VES) data obtained from Station ID "VES 3" at ACHALUMANA MGBAKWU exposes a stratigraphic configuration comprising five distinct layers and a potential aquifer. The geological sequence can be described as follows:
Surface Stratum: Top layer/Laterite (21.0 Ωm, 0.8 m thick), Upper Intermediate Stratum: Sandstone (7414.0 Ωm, 1.6 m thick), Middle Intermediate Stratum: Shalysand (120.8 Ωm, 40.1 m thick), Lower Intermediate Stratum: Sandshale (114.3 Ωm, 25.9 m thick) and Deepest **Aquiferous Formation: Water-**Saturated Sand (50664.9 Ωm, 40.7 m thick). The fifth layer, classified as water-saturated sand, signifies a prospective aquifer within the local aquiferous framework. Positioned at a depth of 42.5 meters and extending up to 109.0 meters, this layer holds significant potential for sustainable groundwater exploration and exploitation in the region.

Each stratigraphic unit's attributes necessitate detailed evaluation in geological engineering design:

Surface Stratum (Top layer/Laterite): The shallow lateritic formation provides a stable base for lightweight infrastructure but may require further geological assessment for larger construction projects.

Upper Intermediate Stratum (Sandstone): The sandstone layer demands comprehensive geological examination during the planning phase of engineering projects, considering potential complexities regarding aquifer connectivity, groundwater flow, and water quality, impacting the overall structural integrity of engineering endeavors.

Middle Intermediate Stratum (Shalysand): The shalysand layer warrants exhaustive geological appraisal in engineering planning, addressing possible challenges related to aquifer connectivity, groundwater movement, and geomechanical stability.

Lower Intermediate Stratum (Sandshale): The sandshale formation necessitates extensive geological evaluation in civil engineering design, addressing probable challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Deepest Aquiferous Formation (Water-Saturated Sand): As a potential aquifer layer, the water-saturated sand mandates rigorous geological assessment in engineering geological planning, managing potential issues concerning aquifer connectivity, groundwater movement, and geomechanical stability.

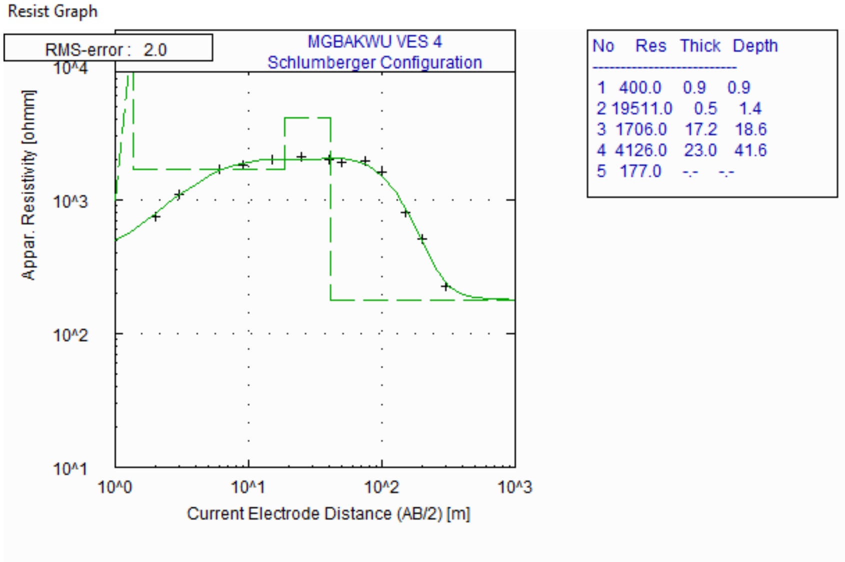

Fig. 6: Winresistivity plots of VES 4 Location in Awka North LGA

Geoelectrical Stratigraphy and Aquifer Potentiality of VES 4 Data from MGBAKWU.
The Vertical Electrical Sounding (VES) data gathered from Station ID "VES 4" at MGBAKWU reveals a stratigraphic succession comprising five distinct layers and a potential aquifer (Fig.6). The geoelectrical configuration can be described as follows:
Surface Formation: Top layer/Laterite (400.0 Ωm, 0.9 m thick), Upper Intermediate Formation: Sandstone (19511.0 Ωm, 0.5 m thick), Middle Intermediate Formation: Shalysand (1706.0 Ωm, 17.2 m thick) and Lower Intermediate Formation: Sandstone (4126.0 Ωm, 23.0 m thick)
Deepest Aquiferous Formation: Water-Saturated Sand (177.0 Ωm, undetermined thickness)
The fifth layer, identified as water-saturated sand, represents a potential aquifer within the local aquiferous framework. Situated at a depth of 18.6 meters and extending beyond 64.6 meters, this layer offers promising opportunities for sustainable groundwater exploration and exploitation in the region.
Each geoelectrical unit's properties demand thorough examination in geological engineering design:
Surface Formation (Top layer/Laterite): The shallow lateritic formation offers a stable foundation for lightweight infrastructure but may require additional geological assessment for larger construction projects.
Upper Intermediate Formation (Sandstone): The sandstone layer necessitates comprehensive geological examination during the planning phase of engineering projects, considering possible complexities regarding aquifer connectivity, groundwater flow, and water quality, affecting the overall structural integrity of engineering endeavors.
Middle Intermediate Formation (Shalysand): The shalysand layer warrants rigorous geological appraisal in engineering planning, addressing potential challenges related to aquifer connectivity, groundwater movement, and geomechanical stability.
Lower Intermediate Formation (Sandstone): The sandstone formation requires meticulous geological evaluation in civil engineering design, tackling probable challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Deepest Aquiferous Formation (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand compels rigorous geological assessment in engineering geological planning, managing potential issues concerning aquifer connectivity, groundwater movement, and geomechanical stability.

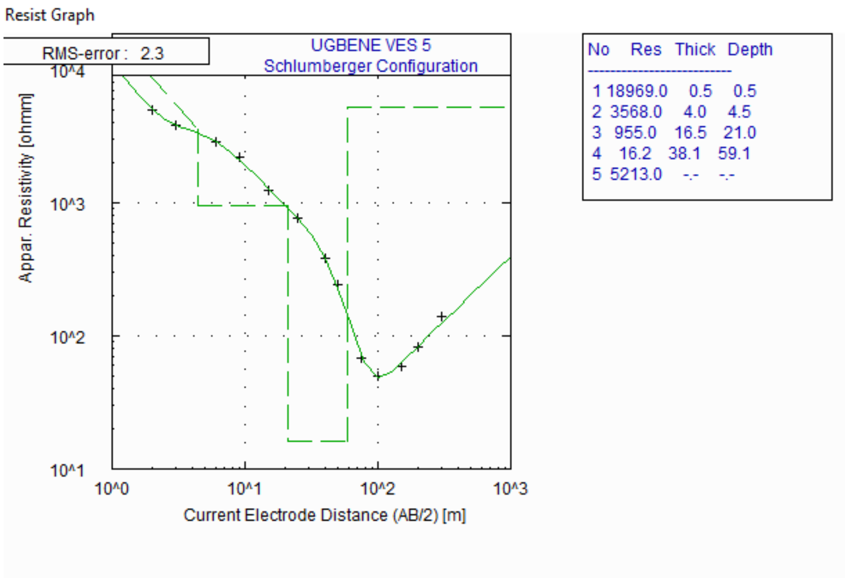

Fig. 7: Winresistivity plots of VES 5 Location in Awka North LGA

Geoelectric Layering and Aquifer Potential of VES 5 Data from UGBENE

The Vertical Electrical Sounding (VES) data acquired from Station ID "VES 5" at UGBENE unveils a geoelectric layering consisting of five unique layers and a prospective aquifer (Fig.7). The stratigraphic sequence is characterized as follows:

Surface Formation: Top layer/Laterite (18969.0 Ωm, 0.5 m thick, Upper Intermediate Formation: Sandstone (3568.0 Ωm, 4.0 m thick), Middle Intermediate Formation: Shalysand (955.0 Ωm, 16.5 m thick) and Lower Intermediate Formation: Shale (16.2 Ωm, 38.1 m thick)

Deepest Aquiferous Formation: Water-Saturated Sand (5213.0 Ωm, undetermined thickness)

The fifth layer, categorized as water-saturated sand, signifies the presence of a potential aquifer within the local aquiferous framework. Located at a depth of 21.0 meters and extending beyond 97.2 meters, this layer offers substantial prospects for sustainable groundwater exploration and utilization within the region.

Each geoelectric unit's properties demand meticulous examination in geological engineering design:

Surface Formation (Top layer/Laterite): The shallow lateritic formation provides a stable foundation for lightweight infrastructure but may require additional geological assessment for larger construction projects.

Upper Intermediate Formation (Sandstone): The sandstone layer necessitates detailed geological analysis during the planning phase of engineering projects, considering potential complexities concerning aquifer connectivity, groundwater flow, and water quality, impacting the overall structural integrity of engineering projects.

Middle Intermediate Formation (Shalysand): The shalysand layer warrants in-depth geological appraisal in engineering planning, addressing probable challenges related to aquifer connectivity, groundwater movement, and geomechanical stability.

Lower Intermediate Formation (Shale): The shale formation requires meticulous geological evaluation in civil engineering design, tackling possible challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Deepest Aquiferous Formation (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand compels detailed geological assessment in engineering geological planning, managing potential concerns regarding aquifer connectivity, groundwater movement, and geomechanical stability.

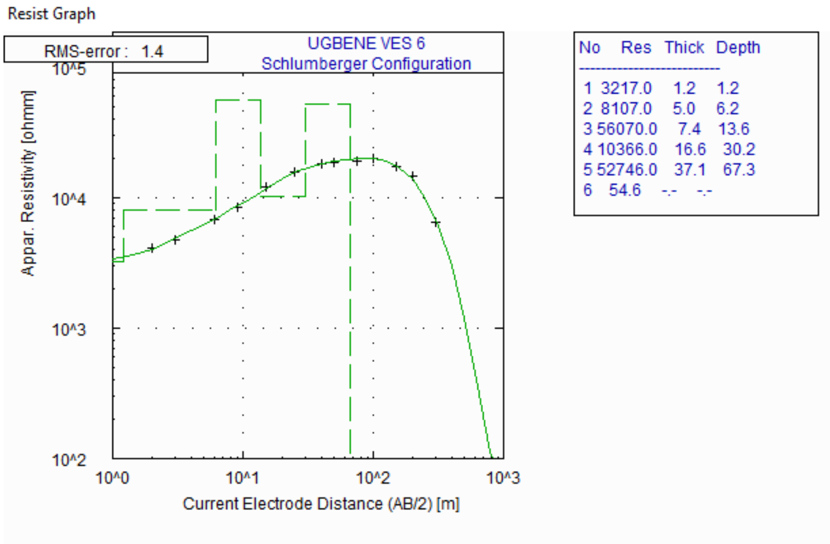

Fig. 8: Winresitivity plots of VES 6 Location in Awka North LGA

Stratigraphic Sequence and Aquifer Prospects from VES 6 Data in UGBENE

The Vertical Electrical Sounding (VES) data collected from Station ID "VES 6" in UGBENE divulges a stratigraphic sequence encompassing six unique layers and a prospective aquifer (Fig.8). The geological succession is characterized as follows:

Surface Formation: Top layer/Laterite (3217.0 Ωm, 1.2 m thick), Upper Intermediate Formation: Shalysand (8107.0 Ωm, 5.0 m thick), Middle Intermediate Formation: Sandstone (56070.0 Ωm, 7.4 m thick), Lower Intermediate Formation 1: Water-Saturated Sand (10366.0 Ωm, 16.6 m thick) Lower Intermediate Formation 2: Sandstone (52746.0 Ωm, 37.1 m thick) and Deepest Formation: Shale (54.6 Ωm, undetermined thickness). The fourth layer, classified as water-saturated sand, signifies the presence of a potential aquifer within the local aquiferous framework. Positioned at a depth of 6.2 meters and extending up to 30.2 meters, this layer presents substantial prospects for sustainable groundwater exploration and exploitation within the region.

Each geological unit's properties necessitate comprehensive examination in geological engineering design:

Surface Formation (Top layer/Laterite): The shallow lateritic formation offers a stable foundation for lightweight infrastructure but may require further geological assessment for larger construction projects.

Upper Intermediate Formation (Shalysand): The shalysand layer demands rigorous geological evaluation during the planning phase of engineering projects, considering potential complexities concerning aquifer connectivity, groundwater flow, and water quality, impacting the overall structural integrity of engineering ventures.

Middle Intermediate Formation (Sandstone): The sandstone formation warrants in-depth geological appraisal in engineering planning, addressing probable challenges related to aquifer connectivity, groundwater movement, and geomechanical stability.

Lower Intermediate Formation 1 (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand compels meticulous geological evaluation in civil engineering design, tackling possible challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Lower Intermediate Formation 2 (Sandstone): The sandstone layer necessitates thorough geological assessment in engineering geological planning, managing potential issues concerning aquifer connectivity, groundwater movement, and geomechanical stability.

Deepest Formation (Shale): The shale formation requires comprehensive geological examination in infrastructure development, addressing potential challenges related to aquifer connectivity, groundwater flow, and water quality.

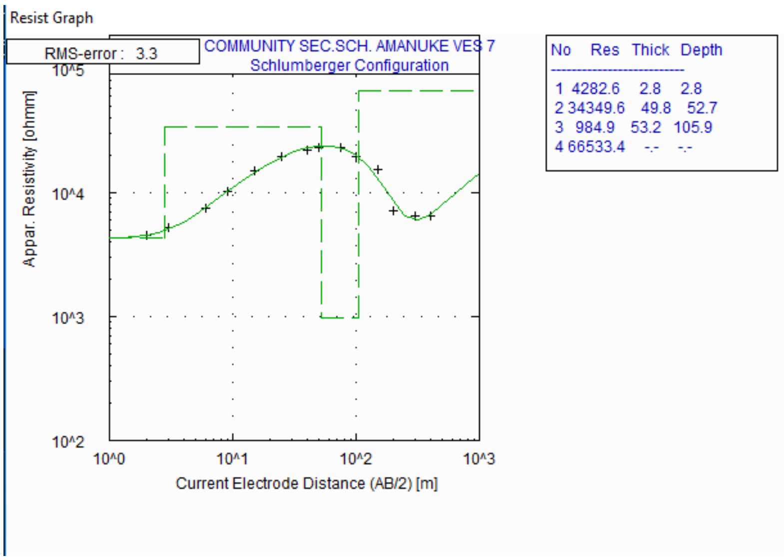

Fig. 9: Winresistivity plots of VES 7 Location in Awka North LGA

Geoelectrical Configuration and Aquifer Assessment from VES 7 Data at COMMUNITY SEC.SCH.AMANUKE

The Vertical Electrical Sounding (VES) data obtained from Station ID "VES 7" at COMMUNITY SEC.SCH.AMANUKE discloses a geoelectrical configuration consisting of four distinct layers and a potential aquifer (Fig.9). The stratigraphic sequence can be described as follows:

Surface Layer: Top layer/Laterite (4282.6 Ωm, 2.8 m thick), Upper Intermediate Layer: Sandstone (34349.6 Ωm, 49.8 m thick)

Lower Intermediate Layer (Aquiferous Formation): Water-Saturated Sand (984.9 Ωm, 53.2 m thick).

Deepest Formation: Sandstone (66533.4 Ωm, undetermined thickness)

The third layer, classified as water-saturated sand, indicates the presence of a potential aquifer within the local hydrogeological framework. Located at a depth of 52.7 meters and extending beyond 105.9 meters, this layer presents substantial prospects for sustainable groundwater exploration and exploitation within the region.

Each geoelectrical unit's characteristics necessitate detailed examination in geological engineering design:

Surface Layer (Top layer/Laterite): The shallow lateritic formation provides a stable foundation for lightweight infrastructure but may require additional geological evaluation for larger construction projects.

Upper Intermediate Layer (Sandstone): The sandstone layer demands comprehensive geological examination during the planning phase of engineering projects, considering potential complexities regarding aquifer connectivity, groundwater flow, and water quality, impacting the overall structural integrity of engineering endeavors.

Lower Intermediate Layer (Aquiferous Formation - Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand compels rigorous geological assessment in civil engineering design, tackling possible challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Deepest Formation (Sandstone): The sandstone formation necessitates thorough geological evaluation in engineering geological planning, addressing probable challenges related to aquifer connectivity, groundwater movement, and geomechanical stability.

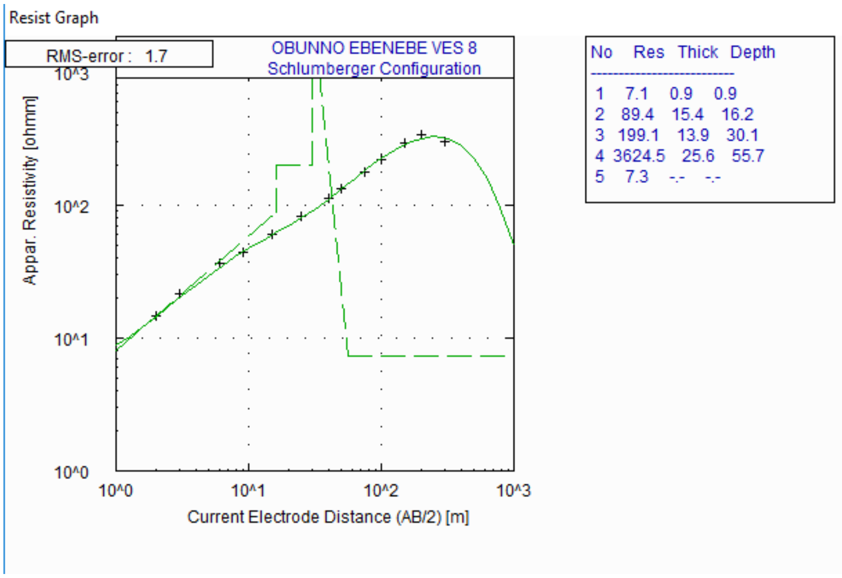

Fig. 10: Winresistivity plots of VES 8 Location in Awka North LGA

Stratigraphic Arrangement and Aquifer Prospects from VES 8 Data at OBUNNO EBENEBE

The Vertical Electrical Sounding (VES) data retrieved from Station ID "VES 8" at OBUNNO EBENEBE uncovers a stratigraphic arrangement consisting of five distinct layers and a potential aquifer (Fig.10). The geological sequence is characterized as follows:

Surface Stratum: Top layer/Laterite (7.1 Ωm, 0.9 m thick), Upper Intermediate Stratum: Sandyshale (89.4 Ωm, 15.4 m thick), Middle Intermediate Stratum: Shalysand (199.1 Ωm, 13.9 m thick).

Lower Intermediate Stratum (Aquiferous Formation): Water-Saturated Sand (3624.5 Ωm, 25.6 m thick).

Deepest Stratum: Shale (7.3 Ωm, undetermined thickness)

The fourth layer, categorized as water-saturated sand, signifies the existence of a potential aquifer within the local hydrogeological framework. Positioned at a depth of 16.2 meters and extending up to 55.7 meters, this layer presents substantial prospects for sustainable groundwater exploration and utilization within the region.

Each stratigraphic unit's properties require comprehensive examination in geological engineering design:

Surface Stratum (Top layer/Laterite): The shallow lateritic formation provides a stable foundation for lightweight infrastructure but may necessitate additional geological assessment for larger construction projects.

Upper Intermediate Stratum (Sandyshale): The sandyshale layer demands in-depth geological evaluation during the planning phase of engineering projects, considering potential complexities regarding aquifer connectivity, groundwater flow, and geomechanical stability.

Middle Intermediate Stratum (Shalysand): The shalysand formation warrants meticulous geological appraisal in engineering planning, addressing probable challenges related to aquifer connectivity, groundwater movement, and geomechanical stability.
Lower Intermediate Stratum (Aquiferous Formation - Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand necessitates rigorous geological assessment in civil engineering design, tackling potential challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.
Deepest Stratum (Shale): The shale stratum requires thorough geological examination in engineering geological planning, managing potential issues concerning aquifer connectivity, groundwater flow, and geomechanical stability.

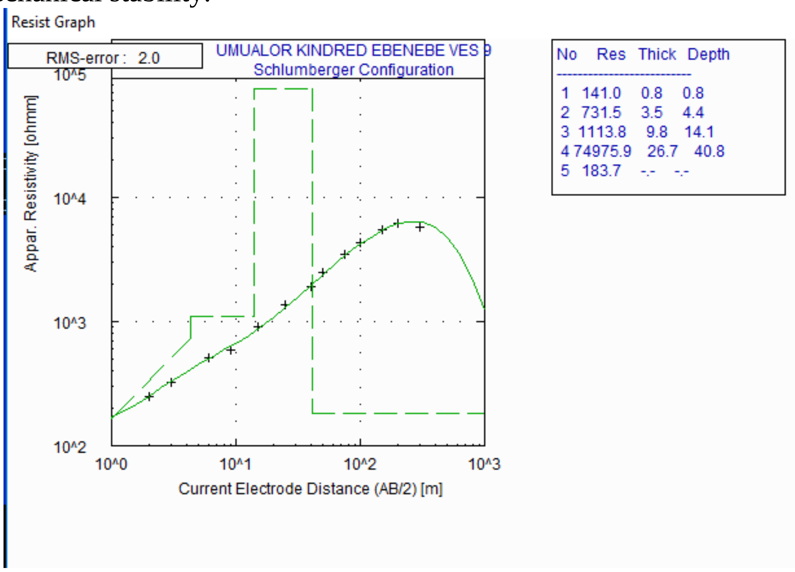

Fig. 11: Winresistivity plots of VES 9 Location in Awka North LGA

Stratigraphic Profile and Aquifer Prospects from VES 9 Data at UMUALOR KINDRED EBENEBE
The Vertical Electrical Sounding (VES) data gathered from Station ID "VES 9" at UMUALOR KINDRED EBENEBE reveals a stratigraphic profile comprising five distinct layers and a potential aquifer (Fig.11). The geological succession is characterized as follows:
Surface Stratum: Top layer/Laterite (141.0 Ωm, 0.8 m thick), Upper Intermediate Stratum: Sandyshale (731.5 Ωm, 3.5 m thick), Middle Intermediate Stratum: Shalysand (1113.8 Ωm, 9.8 m thick), Lower Intermediate Stratum: Sandstone (74975.9 Ωm, 26.7 m thick), Deepest **Aquiferous Stratum: Water-Saturated Sand (183.7 Ωm, undetermined thickness)**
The fifth layer, categorized as water-saturated sand, indicates the presence of a potential aquifer within the local hydrogeological framework. Located at a depth of 4.4 meters and extending beyond 68.3 meters, this layer presents substantial prospects for sustainable groundwater exploration and exploitation within the region.
Each stratigraphic unit's characteristics demand meticulous examination in geological engineering design:
Surface Stratum (Top layer/Laterite): The shallow lateritic formation provides a stable foundation for lightweight infrastructure but may necessitate further geological evaluation for larger construction projects.
Upper Intermediate Stratum (Sandyshale): The sandyshale layer necessitates comprehensive geological examination during the planning phase of engineering projects, considering potential complexities concerning aquifer connectivity, groundwater flow, and geomechanical stability.

Middle Intermediate Stratum (Shalysand): The shalysand formation warrants detailed geological assessment in engineering planning, addressing probable challenges related to aquifer connectivity, groundwater movement, and geomechanical stability.
Lower Intermediate Stratum (Sandstone): The sandstone stratum requires thorough geological analysis in civil engineering design, tackling potential challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.
Deepest Aquiferous Stratum (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand demands rigorous geological evaluation in engineering geological planning, managing potential issues concerning aquifer connectivity, groundwater movement, and geomechanical stability.

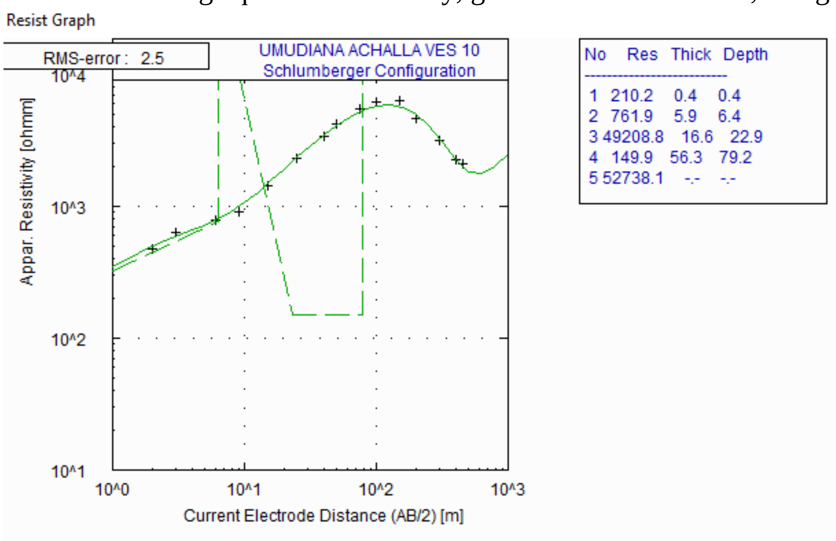

Fig. 12: Winresistivity plots of VES I0 Location in Awka North LGA

Geoelectric Sequence and Aquifer Potentiality from VES 10 Data in UMUDIANA ACHALLA

The Vertical Electrical Sounding (VES) data acquired from Station ID "VES 10" in UMUDIANA ACHALLA exposes a geoelectric sequence comprising five unique layers and a prospective aquifer (Fig.12). The geologic succession is described as follows:
Surface Stratum: Top layer/Laterite (210.2 Ωm, 0.4 m thick), Upper Intermediate Stratum: Shalysand (761.9 Ωm, 5.9 m thick), Middle Intermediate Stratum: Sandstone (49208.8 Ωm, 16.6 m thick), Lower Intermediate Stratum: Sandyshale (149.9 Ωm, 56.3 m thick) and Deepest Aquiferous Stratum: Water-Saturated Sand (52738.1 Ωm, undetermined thickness). The fifth layer, categorized as water-saturated sand, reveals the existence of a potential aquifer within the regional hydrogeological system. Situated at a depth of 6.4 meters and stretching beyond 135.5 meters, this stratum offers considerable prospects for sustainable groundwater exploration and exploitation within the area.

Each geoelectric unit's properties demand thorough examination in geotechnical engineering design:

Surface Stratum (Top layer/Laterite): The shallow lateritic stratum provides a stable substratum for lightweight construction but may necessitate further geological evaluation for larger infrastructure projects.
Upper Intermediate Stratum (Shalysand): The shalysand layer compels comprehensive geological assessment during the engineering planning phase, addressing potential challenges related to aquifer connectivity, groundwater flow, and geomechanical stability.

Middle Intermediate Stratum (Sandstone): The sandstone formation requires exhaustive geological appraisal in geotechnical design, tackling probable challenges concerning groundwater dynamics, slope stability, and sustainable water extraction.

Lower Intermediate Stratum (Sandyshale): The sandyshale formation necessitates rigorous geological analysis in engineering geological planning, managing potential complications associated with aquifer connectivity, groundwater movement, and geomechanical stability.

Deepest Aquiferous Stratum (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand warrants meticulous geological assessment in civil engineering design, confronting possible challenges regarding aquifer connectivity, groundwater circulation, and geomechanical stability.

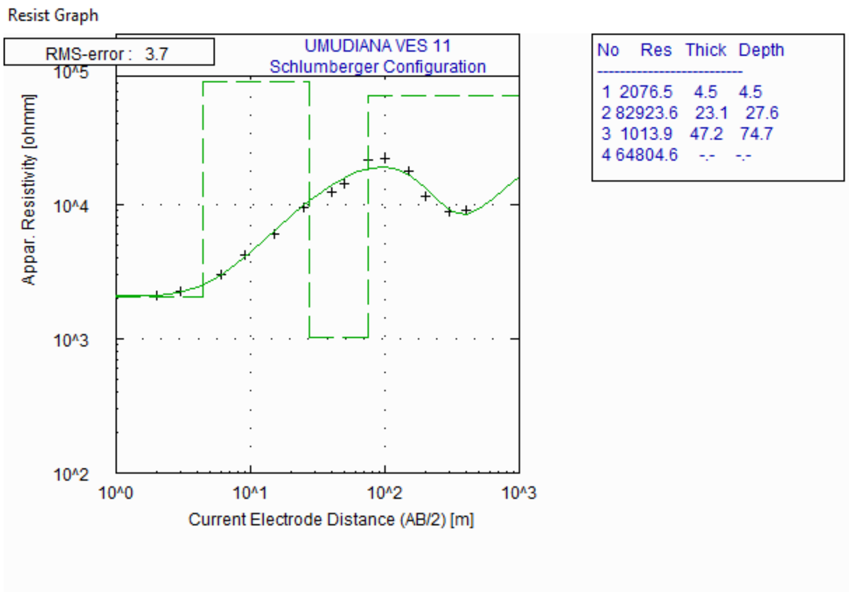

Fig. 13: Winresistivity plots of VES I1 Location in Awka North LGA

Geoelectrical Composition and Aquifer Prospects from VES 11 Data in UMUDIANA

The Vertical Electrical Sounding (VES) data procured from Station ID "VES 11" in UMUDIANA uncovers a geoelectrical composition consisting of four distinct strata and a potential aquifer (Fig.13). The stratigraphic series is described as follows:

Surface Stratum: Top layer/Laterite (2076.5 Ωm, 4.5 m thick), Upper Intermediate Stratum: Sandstone (82923.6 Ωm, 23.1 m thick), **Lower Intermediate Aquiferous Stratum:** Water-Saturated Sand (1013.9 Ωm, 47.2 m thick) and Deepest Stratum: Sandstone (64804.6 Ωm, undetermined thickness)

The third layer, identified as water-saturated sand, indicates the existence of a potential aquifer within the regional hydrogeological system. Located at a depth of 27.6 meters and extending beyond 74.7 meters, this stratum presents substantial prospects for sustainable groundwater exploration and utilization within the area.

Each geoelectrical unit's attributes necessitate meticulous examination in geological engineering design:

Surface Stratum (Top layer/Laterite): The shallow lateritic formation provides a stable foundation for lightweight construction but may necessitate additional geological assessment for larger infrastructure projects.

Upper Intermediate Stratum (Sandstone): The sandstone layer demands exhaustive geological evaluation during the engineering planning phase, addressing potential challenges related to aquifer connectivity, groundwater flow, and geomechanical stability.

Lower Intermediate Aquiferous Stratum (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand requires rigorous geological assessment in geotechnical design, tackling potential challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Deepest Stratum (Sandstone): The sandstone stratum necessitates comprehensive geological appraisal in geological engineering planning, managing probable complications concerning aquifer connectivity, groundwater movement, and geomechanical stability.

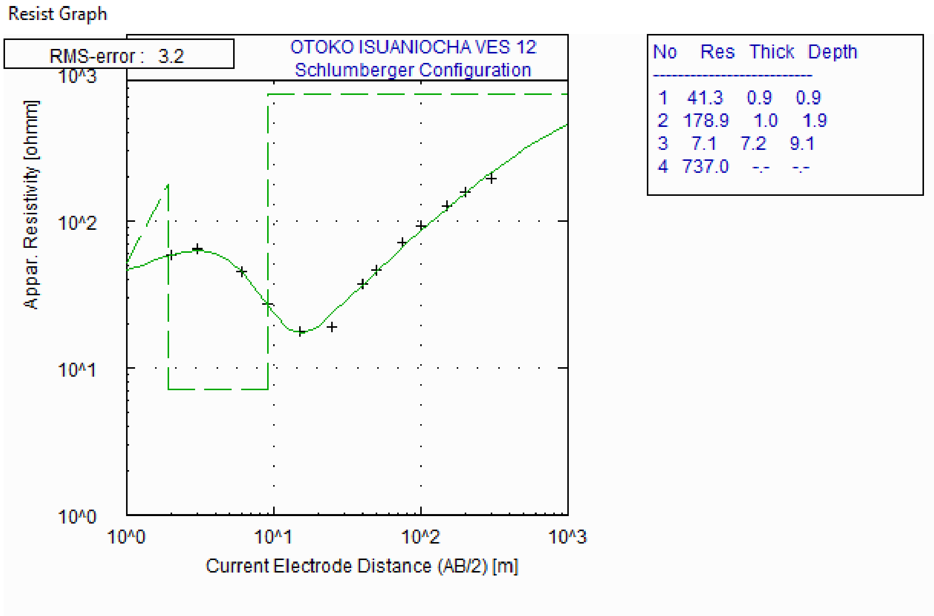

Fig. 14: Winresistivity plots of VES I2 Location in Awka North LGA

Geoelectrical Arrangement and Aquifer Prospects from VES 12 Data at OTOKO ISUANIOCHA

The Vertical Electrical Sounding (VES) data collected from Station ID "VES 12" at OTOKO ISUANIOCHA discloses a geoelectrical arrangement characterized by four unique strata and a prospective aquifer (Fig.14). The geologic sequence can be described as follows:

Surface Stratum: Top layer/Laterite (41.3 Ωm, 0.9 m thick), Upper Intermediate Stratum: Sandyshale (178.9 Ωm, 1.0 m thick), Lower Intermediate Stratum: Shale (7.1 Ωm, 7.2 m thick) and Deepest Aquiferous Stratum: Water-Saturated Sand (737.0 Ωm, undetermined thickness). The fourth layer, identified as water-saturated sand, denotes the existence of a potential aquifer within the local hydrogeological framework. Situated at a depth of 1.9 meters and extending beyond 16.4 meters, this stratum presents significant prospects for sustainable groundwater exploration and exploitation within the region.

Each geoelectrical unit's properties necessitate meticulous examination in geological engineering design:

Surface Stratum (Top layer/Laterite): The shallow lateritic formation provides a stable substratum for lightweight infrastructure but may necessitate additional geological assessment for larger engineering projects.

Upper Intermediate Stratum (Sandyshale): The sandyshale layer demands thorough geological evaluation during the planning phase of engineering endeavors, addressing potential complexities concerning aquifer connectivity, groundwater movement, and geomechanical stability.

Lower Intermediate Stratum (Shale): The shale stratum requires exhaustive geological appraisal in geotechnical design, tackling probable challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Deepest Aquiferous Stratum (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand warrants comprehensive geological assessment in geological engineering planning, managing potential challenges related to aquifer connectivity, groundwater circulation, and geochemical stability.

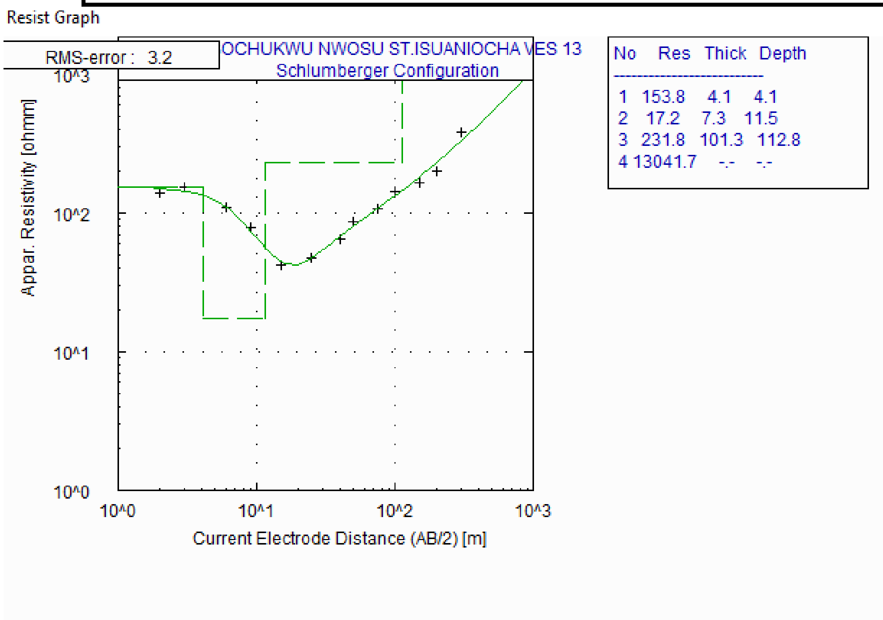

Fig. 15: Winresistivity plots of VES I3 Location in Awka North LGA

Stratigraphic Configuration and Aquifer Potentiality from VES 13 Data at OCHUKWU NWOSU ST. ISUANIOCHA

The Vertical Electrical Sounding (VES) data obtained from Station ID "VES 13" at OCHUKWU NWOSU ST. ISUANIOCHA unveils a stratigraphic configuration consisting of four distinct layers and a prospective aquifer (Fig.15). The geologic sequence is described as follows:

Surface Stratum: Top layer/Laterite (153.8 Ωm, 4.1 m thick), Upper Intermediate Stratum: Shale (17.2 Ωm, 7.3 m thick), Lower Intermediate Stratum: Sandyshale (231.8 Ωm, 101.3 m thick) and Deepest Aquiferous Stratum: Water-Saturated Sand (13041.7 Ωm, undetermined thickness). The fourth stratum, identified as water-saturated sand, signifies the existence of a potential aquifer within the regional hydrogeological framework. Positioned at a depth of 11.5 meters and extending beyond 214.1 meters, this layer offers significant prospects for sustainable groundwater exploration and exploitation within the area.

Each stratigraphic unit's attributes necessitate meticulous examination in geological engineering design:

Surface Stratum (Top layer/Laterite): The shallow lateritic formation provides a stable foundation for lightweight infrastructure but may require further geological evaluation for larger construction projects.

Upper Intermediate Stratum (Shale): The shale layer demands comprehensive geological assessment during the planning phase of engineering endeavors, addressing potential complexities concerning aquifer connectivity and groundwater flow.

Lower Intermediate Stratum (Sandyshale): The sandyshale stratum warrants exhaustive geological appraisal in geotechnical design, tackling probable challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Deepest Aquiferous Stratum (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand necessitates thorough geological assessment in geological engineering planning, managing potential challenges related to aquifer connectivity, groundwater circulation, and geomechanical stability.

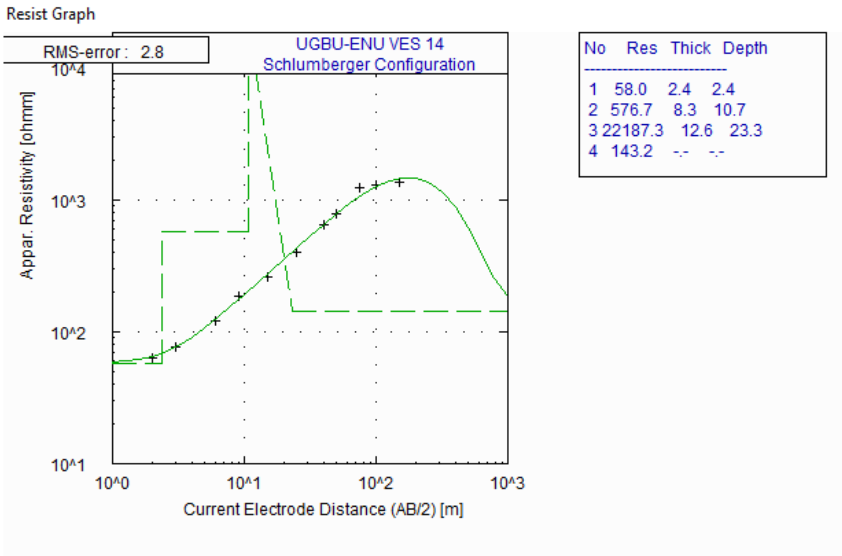

Fig. 16: Winresistivity plots of VES I4 Location in Awka North LGA

Vertical Electrical Sounding (VES) Profile and Aquifer Prospects from VES 14 Data at UGBU-ENU

The Vertical Electrical Sounding (VES) data derived from Station ID "VES 14" at UGBU-ENU divulges a VES profile comprising four distinctive layers and a probable aquifer (Fig.16). The stratigraphic series can be delineated as follows:

Surface Stratum: Top layer/Laterite (58.0 Ωm, 2.4 m thick), Upper Intermediate Stratum: Shalysand (576.7 Ωm, 8.3 m thick), Lower Intermediate Aquiferous Stratum: Water-Saturated Sand (22187.3 Ωm, 12.6 m thick) and Deepest Stratum: Sandyshale (143.2 Ωm, undetermined thickness). The third layer, classified as water-saturated sand, denotes the presence of a prospective aquifer within the local hydrogeological framework. Located at a depth of 10.7 meters and extending beyond 35.9 meters, this stratum offers substantial opportunities for sustainable groundwater exploration and exploitation within the area.

Each VES profile unit's characteristics necessitate thorough examination in geological engineering design:

Surface Stratum (Top layer/Laterite): The shallow lateritic formation provides a stable substratum for lightweight infrastructure but may necessitate additional geological assessment for larger construction projects.

Upper Intermediate Stratum (Shalysand): The shalysand stratum demands comprehensive geological evaluation during the planning phase of engineering endeavors, addressing potential complexities concerning aquifer connectivity, groundwater flow, and geomechanical stability.

Lower Intermediate Aquiferous Stratum (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand warrants meticulous geological assessment in geotechnical design, tackling potential challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Deepest Stratum (Sandyshale): The sandyshale layer requires exhaustive geological appraisal in geological engineering planning, managing probable challenges related to aquifer connectivity, groundwater movement, and geomechanical stability.

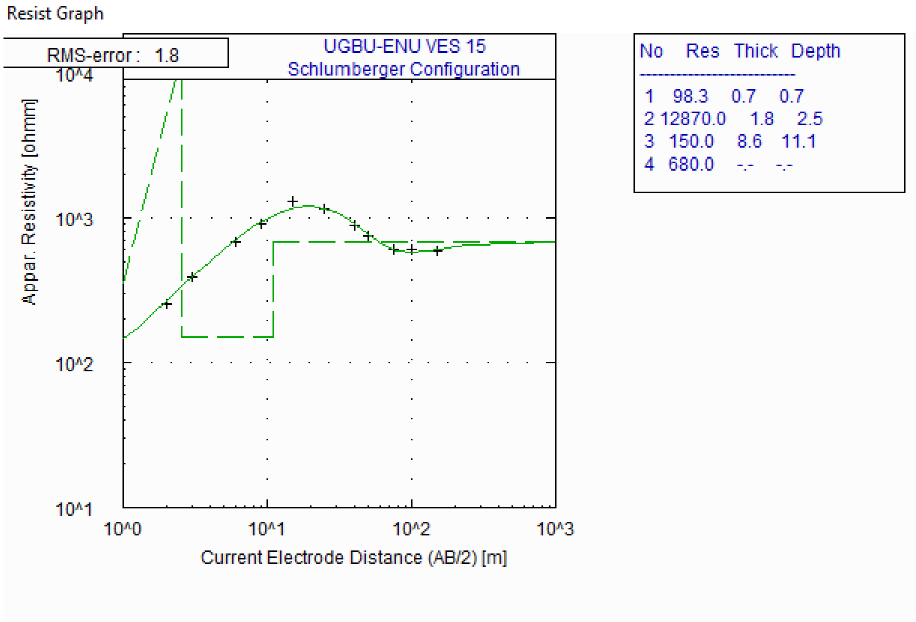

Fig. 17: Winresistivity plots of VES I5 Location in Awka North LGA

Stratigraphic Sequence and Aquifer Prospects from VES 15 Data at UGBE-ENU

The Vertical Electrical Sounding (VES) data acquired from Station ID "VES 15" at UGBE-ENU uncovers a stratigraphic sequence composed of four distinct layers and a prospective aquifer (Fig.17). The geoelectric succession is described as follows:

Surface Stratum: Top layer/Laterite (98.3 Ωm, 0.7 m thick), Upper Intermediate Stratum: Sandstone (12870.0 Ωm, 1.8 m thick), Lower Intermediate Stratum: Sandyshale (150.0 Ωm, 8.6 m thick) and Deepest Aquiferous Stratum: Water-Saturated Sand (680.0 Ωm, undetermined thickness). The fourth layer, identified as water-saturated sand, denotes the existence of a potential aquifer within the regional hydrogeological system. Situated at a depth of 2.5 meters and stretching beyond 19.7 meters, this stratum presents significant prospects for sustainable groundwater exploration and exploitation within the area.

Each stratigraphic unit's properties necessitate meticulous examination in geological engineering design:

Surface Stratum (Top layer/Laterite): The shallow lateritic formation provides a stable substratum for lightweight construction but may necessitate further geological evaluation for larger infrastructure projects.

Upper Intermediate Stratum (Sandstone): The sandstone layer demands comprehensive geological assessment during the planning phase of engineering endeavors, addressing potential complexities related to aquifer connectivity, groundwater flow, and geomechanical stability.

Lower Intermediate Stratum (Sandyshale): The sandyshale formation warrants exhaustive geological appraisal in geotechnical design, tackling probable challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Deepest Aquiferous Stratum (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand necessitates rigorous geological evaluation in geological engineering planning, managing potential challenges concerning aquifer connectivity, groundwater circulation, and geomechanical stability.

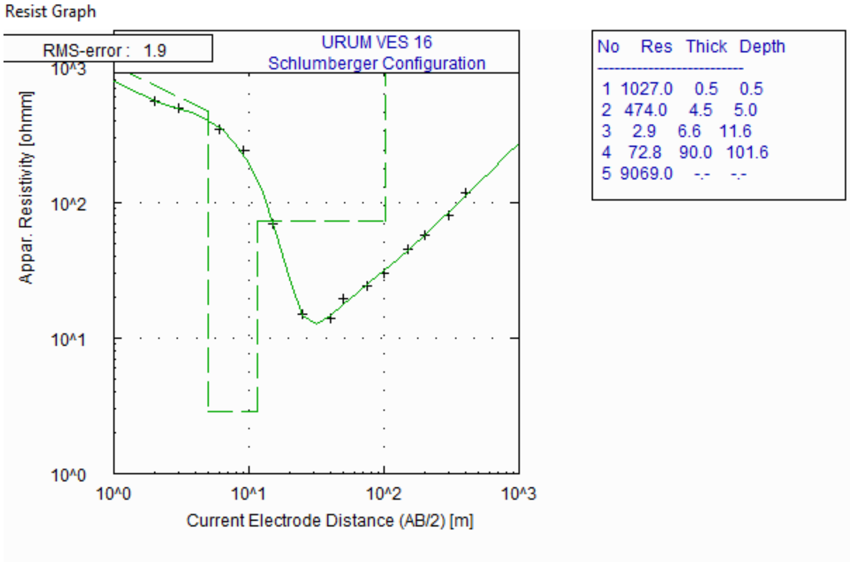

Fig. 18: Winresistivity plots of VES I6 Location in Awka North LGA

Geoelectric Arrangement and Aquifer Prospects from VES 16 Data in URUM

The Vertical Electrical Sounding (VES) data attained from Station ID "VES 16" in URUM reveals a geoelectric arrangement comprising five unique layers and a prospective aquifer (Fig.18). The geoelectric sequence can be outlined as follows:

Surface Stratum: Top layer/Laterite (1027.0 Ωm, 0.5 m thick), Upper Intermediate Stratum: Shalysand (474.5 Ωm, 4.5 m thick), First Lower Intermediate Stratum: Shale (2.9 Ωm, 6.6 m thick), Second Lower Intermediate Stratum: Sandyshale (72.9 Ωm, 90.0 m thick) and Deepest Aquiferous Stratum: Water-Saturated Sand (9069.0 Ωm, undetermined thickness). The fifth layer, classified as water-saturated sand, signifies the presence of a potential aquifer within the regional hydrogeological framework. Positioned at a depth of 5.0 meters and stretching beyond 191.6 meters, this stratum presents considerable prospects for sustainable groundwater exploration and utilization within the area.

Each geoelectric unit's characteristics necessitate meticulous examination in geological engineering design:

Surface Stratum (Top layer/Laterite): The shallow lateritic formation provides a stable substratum for lightweight infrastructure but may require additional geological assessment for larger construction projects.

Upper Intermediate Stratum (Shalysand): The shalysand layer demands comprehensive geological evaluation during the planning phase of engineering endeavors, addressing potential complexities concerning aquifer connectivity, groundwater flow, and geomechanical stability.

First Lower Intermediate Stratum (Shale): The shale stratum warrants exhaustive geological appraisal in geotechnical design, tackling probable challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Second Lower Intermediate Stratum (Sandyshale): The sandyshale formation necessitates thorough geological assessment in geological engineering planning, managing potential challenges related to aquifer connectivity, groundwater movement, and geomechanical stability.

Deepest Aquiferous Stratum (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand requires rigorous geological evaluation in geotechnical design, handling potential challenges concerning aquifer connectivity, groundwater circulation, and geomechanical stability.

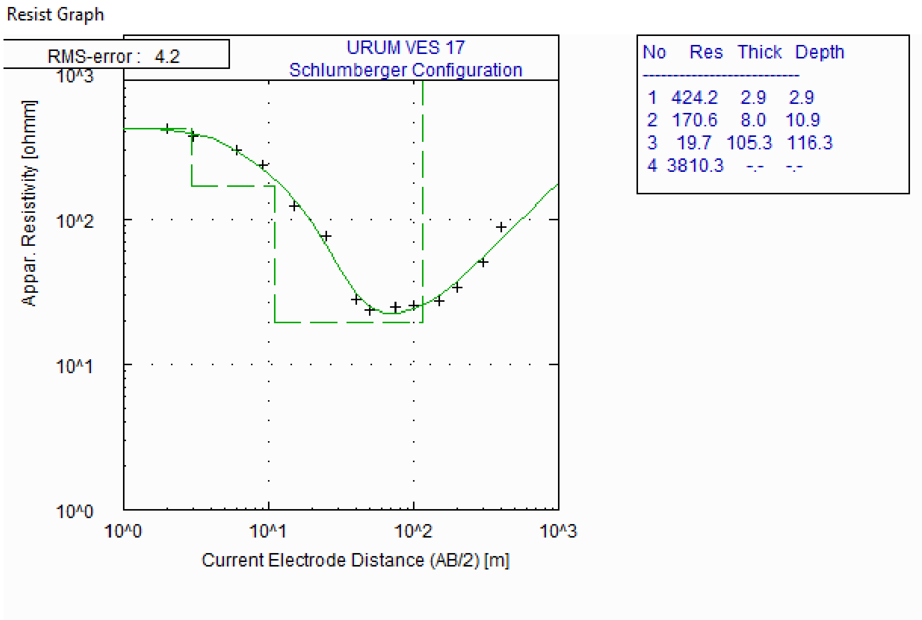

Fig. 19: Winresistivity plots of VES I7 Location in Awka North LGA

Stratigraphic Formation and Aquifer Prospects from VES 17 Data in URUM

The Vertical Electrical Sounding (VES) data acquired from Station ID "VES 17" in URUM uncovers a stratigraphic formation comprised of four distinct layers and a prospective aquifer (Fig. 19). The geoelectric sequence is delineated as follows:

Surface Stratum: Top layer/Laterite (424.2 Ωm, 2.9 m thick), Upper Intermediate Stratum: Sandyshale (170.6 Ωm, 8.0 m thick), Lower Intermediate Stratum: Shale (19.7 Ωm, 105.3 m thick) and Deepest Aquiferous Stratum: Water-Saturated Sand (3810.3 Ωm, undetermined thickness). The fourth layer, identified as water-saturated sand, indicates the presence of a potential aquifer within the local hydrogeological framework. Situated at a depth of 10.9 meters and stretching beyond 221.6 meters, this stratum presents significant prospects for sustainable groundwater exploration and exploitation within the area.

Each stratigraphic unit's attributes necessitate meticulous examination in geological engineering design:

Surface Stratum (Top layer/Laterite): The shallow lateritic formation provides a stable foundation for lightweight infrastructure but may require further geological evaluation for larger construction projects.

Upper Intermediate Stratum (Sandyshale): The sandyshale layer demands comprehensive geological assessment during the planning phase of engineering endeavors, addressing potential complexities related to aquifer connectivity, groundwater flow, and geomechanical stability.

Lower Intermediate Stratum (Shale): The shale stratum warrants exhaustive geological appraisal in geotechnical design, tackling probable challenges associated with groundwater dynamics, slope stability, and sustainable water extraction.

Deepest Aquiferous Stratum (Water-Saturated Sand): As a prospective aquifer layer, the water-saturated sand necessitates thorough geological evaluation in geological engineering planning, managing potential challenges concerning aquifer connectivity, groundwater circulation, and geomechanical stability.

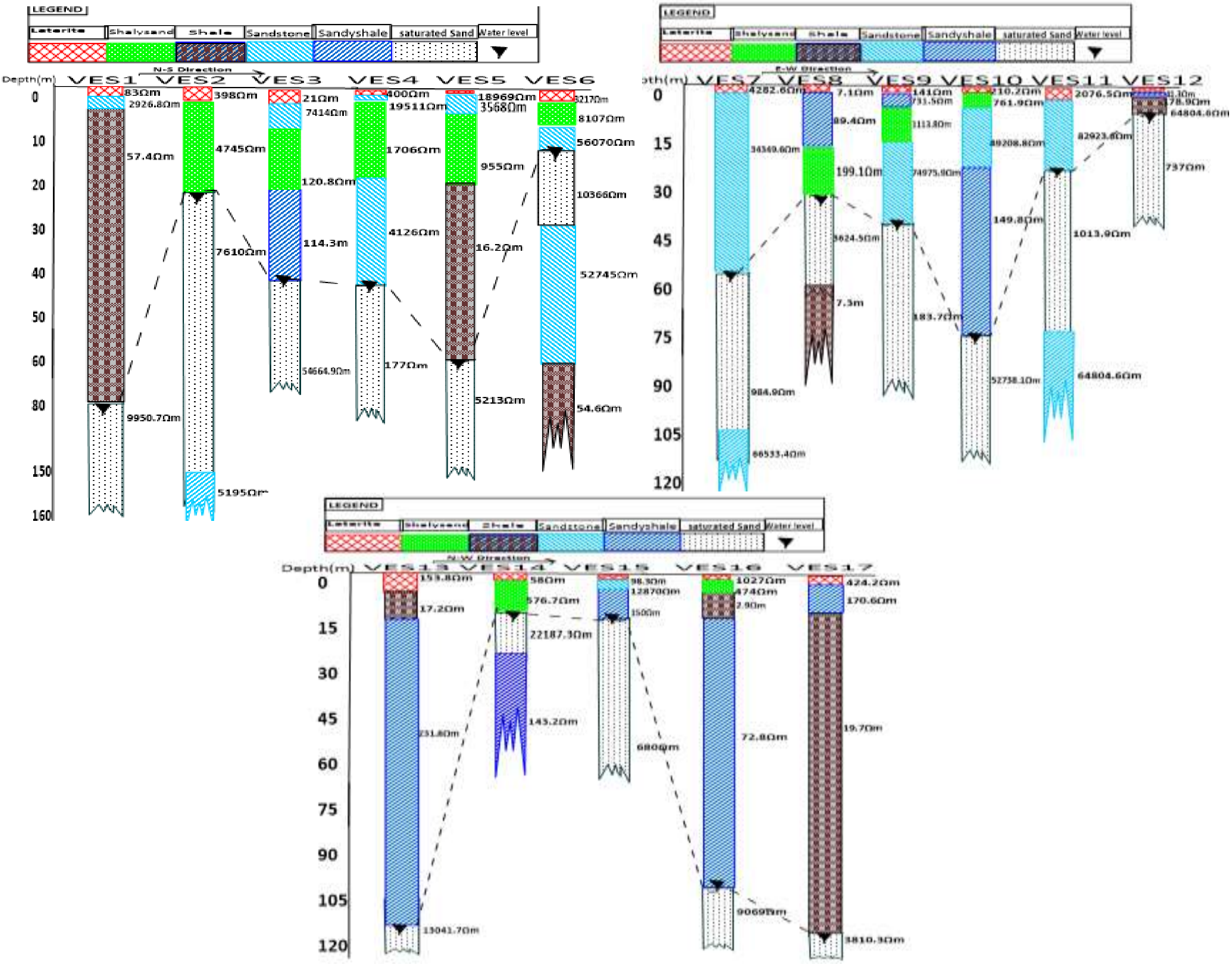

Fig. 20: Lithology plots of VES 1-17 Locations of Awka North LGA

The extensive analysis and interpretation of the Vertical Electrical Sounding (VES) data collected from stations VES 1 to VES 17 (Fig. 20) have revealed insights into the subsurface geological structure and potential aquifers in the study area. Through the examination of resistivity values and curve types, we have identified distinct layers, including laterite, shale, sandstone, sandyshale, and water-saturated sand. Notably, various stations have exhibited layers of prospective aquifers, offering substantial opportunities for sustainable groundwater exploration and utilization. The table 1 and fig.21 below is summary of the geoelectrical sounding results from the modelled win-resistivity profiles.

Table; 1. Station ID/ Layers	App Res (Ωm)	Thickness (m)	Depth (m)	Description
VES 1(OREBE AMANSEA) (RMS: 3.6%)				CURVE TYPE KH(ρ1< ρ2>ρ3< ρ4)
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(ρ1< ρ2< ρ3>ρ4)
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(ρ1< ρ2< ρ3< ρ4>ρ5)
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((ρ1< ρ2< ρ3< ρ4> ρ5)
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((ρ1> ρ2>ρ3< ρ4<ρ5)
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(ρ1< ρ< ρ3>ρ4> ρ5)
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)				CURVE TYPE AH(ρ1<ρ< ρ3<ρ4)

(RMS: 2.8%)				
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**

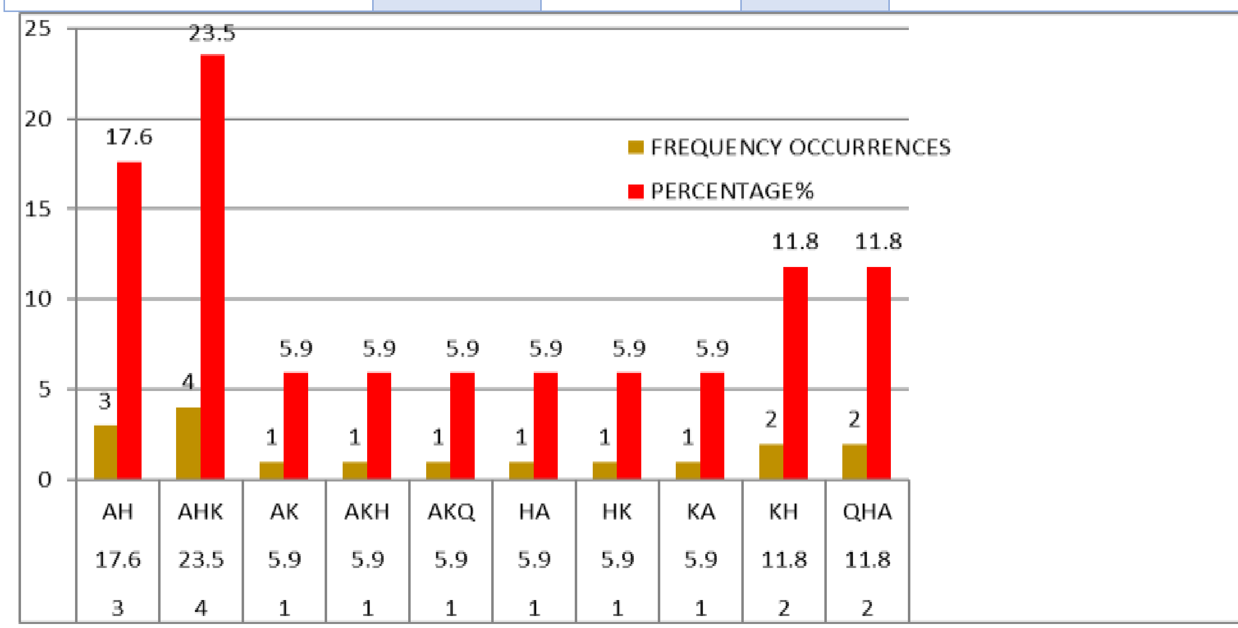

Fig. 21: Curve Type Frequency and Percentage of Surveyed Locations in Awka North

4. RESULTS AND INTERPRETATIONS

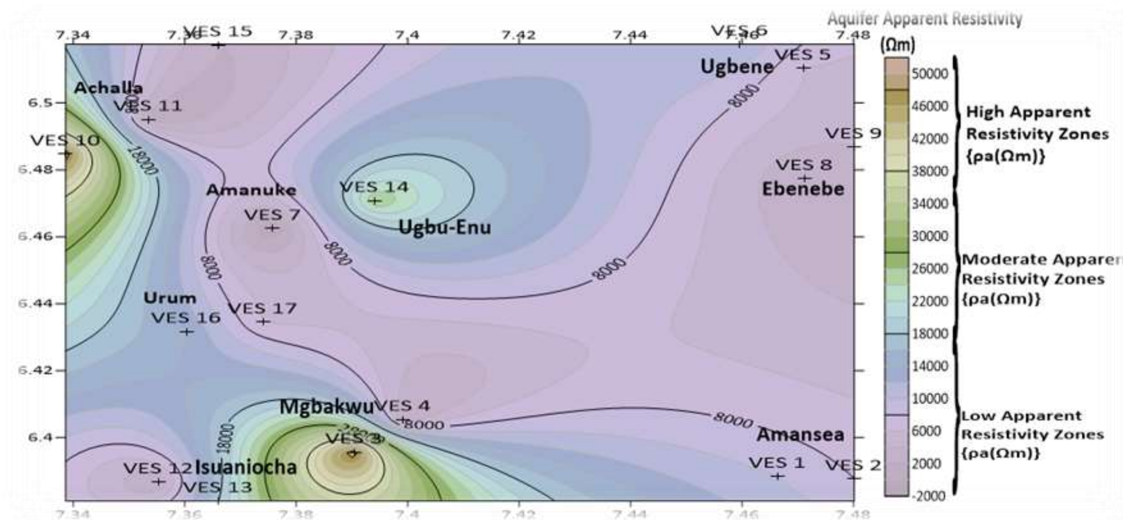

Fig. 22.: Aquifer Apparent Resistivity Map of Awka North Local Government Area

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 resistivity of locations ranged from high resistivity zones (ρa > 30kΩm) - moderate resistivity zones (14kΩm < ρa < 30kΩm and Fig. 22 - low resistivity zones (ρa < 14kΩm. Location VES 3 and 10 (partly Ugbakwu and Achalla) have a significant high electrical resistivity values.

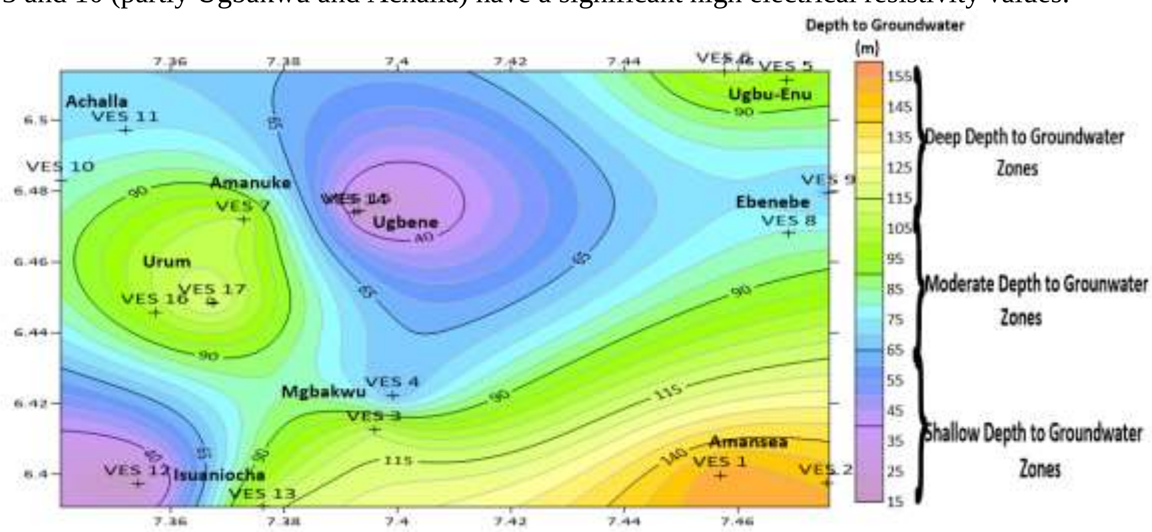

Fig. 23: Depth to Groundwater Map of Awka North Local Government Area

The depth at which groundwater is encountered beneath the Earth's surface is an essential parameter for assessing the suitability of geological formations for infrastructure development.

Fig. 23, Shallow or low Groundwater Zones (10-80 meters): Areas (VES 12) with shallow groundwater depths can present challenges for infrastructure development, such as increased pore water pressure, reduced soil strength, and potential for water-induced damage.

Moderate Groundwater Zones (80-150 meters): These zones (VES 1,3,4,5,6,7,8,9,10,11,13,14 and 15) can offer a mix of advantages and challenges for infrastructure development. While groundwater is not as close to the surface as in shallow zones, construction in these areas may still necessitate careful consideration of groundwater conditions and the potential for geotechnical hazards, such as liquefaction or settlement.

Deep Groundwater Zones (>150meters): Areas (VES 2,16 and 17) with deep groundwater levels can provide a more stable environment for infrastructure development, as they generally experience fewer water-related issues. However, it is essential to consider the potential impacts of limited water availability on construction activities and the overall sustainability of the infrastructure project. The respective zones are partly Amansea and Urum.

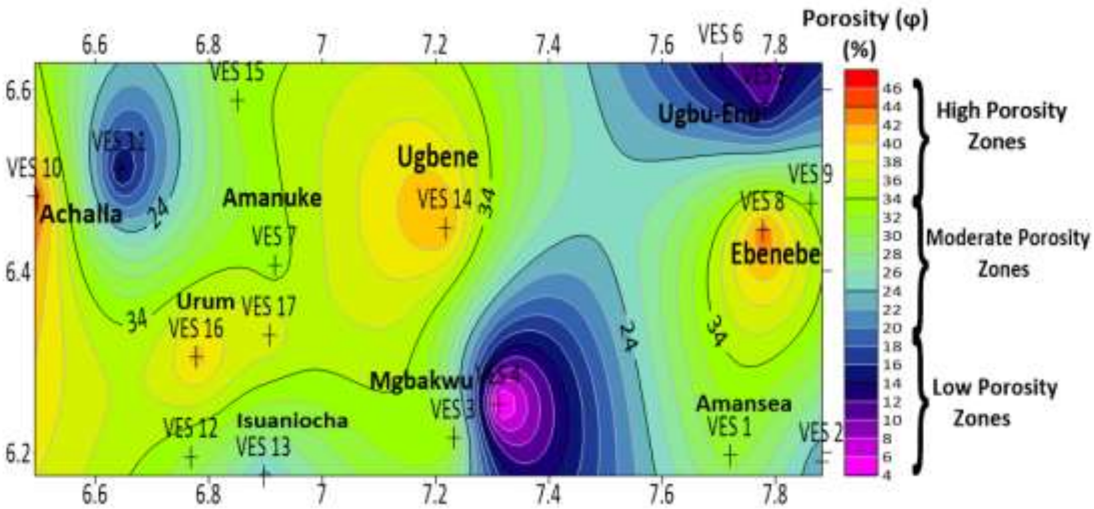

Fig. 24: Porosity Map of Awka North Local Government Area

Subsurface Void Space: Significance for Infrastructure Planning

Porosity, a measure of the void space within subsurface materials, is a critical parameter for assessing the suitability of geological formations for infrastructure development.

Fig. 24, Low Porosity Materials (Porosity < 18%): Subsurface materials with low porosity typically exhibit limited void space, which can impact water storage and flow characteristics in the subsurface. Construction in these zones may require careful consideration of water management practices, such as drainage and erosion control measures, to prevent potential issues related to water accumulation or soil weakening. Zones here are VES 4,5,6 and 11 with respect to their locations partly Mgbakwu, Ugbu-Enu and Partly Achalla.

Moderate Porosity Materials (18% < Porosity < 34%): Materials with moderate porosity offer a balance of benefits and challenges for infrastructure development. While these materials provide some void space for water storage and flow, construction in these zones may necessitate cautious monitoring of water levels and pore water pressure to prevent potential issues such as soil settlement or instability. The following scenario are being displayed on the above topographical map locating various zones (VES 1,2,3,7,9,12,13 and 15 of moderate porous material with their respective locations Amansea, partly Mgbakwu, Amanuke, partly Ebenebe, Isuaniocha and some part of Ugbene.

High Porosity Materials (Porosity > 34%): High porosity materials exhibit substantial void space, enabling significant water storage and flow, but also presenting challenges for infrastructure development. Construction activities in these zones must account for potential impacts on local groundwater resources and the risk of soil instability due to water infiltration and movement. High porosity zones are (VES 8,10,14,16 and 17) at their respective locations partly (Ebenebe, Achalla) and partly Ugbene and Urum.

5. CONCLUSION

The research concludes the following;

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. Locations like (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. The respective locations are Amansea, Partly Mgbakwu, Ugbene, Amanuke, Ebenebe, Achalla, Partly Isuaniocha and Urum.

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 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.

Construction in the zones with low groundwater potentials may require specialized engineering interventions, including dewatering systems, waterproofing techniques, and advanced foundation designs, to ensure structural stability and mitigate potential risks. The location of the VES point is partly Isuaniocha and Ugbene. A comprehensive understanding of the geological characteristics, hydraulic properties, and composition of subsurface materials is crucial for designing suitable foundation systems and construction methodologies. Respective Zones locations are partly Amansea, Mgbakwu, Ugbu-Enu, Amanuke, Ebenebe, Achalla, Partly Isuaniocha and Ugbene.

CONFLICT OF INTEREST

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

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