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Electrical Resistivity Tomography for Subsurface Lithology Mapping in Groundwater Exploration at Mosogar, Delta State, Nigeria

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ABSTRACT: The objective of this paper is to apply electrical resistivity tomography for substrate lithology mapping in groundwater exploration in Mosogar, Delta State, Nigeria with five profiles spreading over 100 meters using appropriate standard techniques. The results revealed distinct resistivity zones corresponding to clay, sand, and gravel layers, with implications for groundwater potential. Geoelectric sections identified reveal a diverse lithological sequence, including clayey soils, sandstones, shale, laterite, and mixed clay-sand units, with resistivity values ranging from < 200 Ωm for clayey soils to > 20,000 Ωm for compact sandstone formations. In profile 1 low values of < than 200 Ωm was observed at distances 10 – 20 m to a depth of about 9.94 m and distances 55 m – 75 m to a depth of about 5.00 m from the top soil, while in profile 2,Distinctive zones with low resistivity values were observed at distance 45 m – 65 m to a depth of about 3.00 m from the surface and distance 10 m – 24 m at a depth between about 6.76 m to 9.94 m, with low resistivity values ranging from 40.5Ωm – 150Ωm. The 2D inversion of profile 4 and 5 has resistivity of moderately high magnitude at the top layer and patches of low resistive rocks can be seen across both profiles. The resistivity values from both profiles indicate the possible presence of clayey soil, laterite, sandstone and patches of clay. The results identified the most promising aquifer zone within the resistivity range of1225–7000 Ωm, corresponding to a lithological composition of laterite, shale, and sandstone, at a depth of 9.94 - 17.3 m. This zone exhibited favorable hydrogeological properties, with sufficient permeability for groundwater storage and transmission. The findings highlight the effectiveness of ERT in resolving subsurface complexities and identifying optimal groundwater-bearing zones in sedimentary environments. This study provides critical insights for borehole placement and sustainable groundwater resource management, offering a valuable framework for similar investigations in the Niger Delta and beyond.

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Groundwater is a critical resource in many regions of the world, particularly in areas where surface water sources are insufficient or unreliable. In Mosogar, a locality situated in the Niger Delta region of Delta State, Nigeria, groundwater is the primary source of water for domestic, agricultural, and industrial use. This is a typical scenario in many parts of the world, especially in developing countries where surface water bodies may be scarce or polluted. However, the effective development and management of groundwater resources rely heavily on understanding the subsurface lithology and identifying aquiferous zones. The properties of groundwater are influenced by the characteristics of the surrounding geological formations (Atapko, 2009; Akankpo andIgbokwe, 2011). The nature of an aquifer is determined by the subsurface geological composition, which significantly affects the movement of water from the

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surface (through infiltration) to subsurface water via recharge processes (Bashir *et al.,* 2014). Traditional methods of subsurface exploration, such as drilling and sampling, are often invasive, expensive, and limited in scope, providing data only at discrete points. In contrast, geophysical techniques like Electrical Resistivity Tomography (ERT) offer a non-invasive and cost-effective approach to investigating subsurface conditions over broader areas. ERT works by measuring the electrical resistivity of subsurface materials, which varies depending on the composition, porosity, saturation, and fluid content of the geological layers. The Wenner-Schlumberger configuration is particularly advantageous for groundwater exploration. It combines the strengths of the Wenner and Schlumberger arrays, offering a balance between sensitivity to vertical variations and lateral resolution. This configuration is well-suited for detecting subsurface lithological changes and mapping aquifer boundaries, making it a reliable choice for hydrogeological studies. The application of geophysical techniques for groundwater exploration and water quality assessment has grown significantly in recent years, driven by advancements in computer software and numerical modeling solutions (Chinwuko *et al.*, 2016). Geophysical methods such as Vertical Electrical Sounding (VES), Electrical Resistivity Tomography (ERT), and the self-potential method are commonly used in these studies. Among these, Electrical Resistivity Tomography (ERT) is increasingly employed for both reconnaissance and confirmatory surveys (Olorunfemi and Oni, 2019; Olorunfemi *et al.*, 2020). The 2D resistivity models obtained from the inversion of 2D resistivity data serve as close approximations of the three-dimensional horizontal layers (Shemang and Chaoka, 2003; Owen *et al.*, 2006). Also, several researchers have deployed the use of Electrical resistivity tomography methods for groundwater assessment and monitoring such as aquifer potential, characterization and contamination (Ofomola *et al.*, 2022; Ofomola *et al.*, 2024; Ofomola *et al.*, 2023). Jegede *et al*. in 2011 carried out a two-dimensional Electrical resistivity imaging survey at the old cemetery and Tsamiya waste disposal sites in Zaria metropolis over a period of ten months with a view to monitoring the migration of leachate plumes within the subsurface.

Osazuwa and Chinedu in 2008 carried out a two-dimensional electrical resistivity survey at the periphery of the impounding reservoir of the Ahmadu Bello University farm dam, Northern Nigeria in order to investigate the subsurface seepage conditions and identify possible weak zone that could serve as seepage paths within the subsurface in the vicinity of the damp. The results show Anomalous low resistivity zones within the bedrock and were interpreted as zones of weakness representing preferential flow pathways for water from the impounding reservoir. Hence, the objective of this paper is to apply electrical resistivity tomography for subsurface lithology mapping in groundwater exploration at Mosogar, Delta State, Nigeria.

MATERIALS AND METHOD

Location and Geology of Survey Area: The study area, located in Mosogar, Ethiope West Local Government Area of Delta State, Nigeria, is positioned at Latitude 5° 55' 5" N and Longitude 5° 46' 29" E (Fig. 1). The region experiences a tropical climate with distinct rainy and dry seasons. The rainy season typically spans from March to September, with a brief break in August, while the dry season dominates the remainder of the year. Annual rainfall ranges from 2,300 mm to 3,000 mm, with an average temperature of 25.5°C and an estimated average wind speed of 13 km/h. The terrain is characterized by a gently sloping flat surface of the Sombreiro-Warri Deltaic Plain Sand, at an elevation of approximately 15 m, and features vegetation typical of freshwater wetlands and rainforest ecosystems. Mosogar is situated within the Niger Delta Basin, which features three primary depositional (sedimentary) environments: marine, mixed, and continental. At the base lies the Akata Formation, predominantly composed of marine shales interspersed with sand beds. Above it is the Agbada Formation, characterized by interbedded sands and shales.

The youngest unit, the Benin Formation, intersects the aquifers throughout the modern Niger Delta. The aquiferous Sombreiro-Warri Deltaic Plain Sand is often indistinguishable from the Benin Formation (Short, 1967). The Benin Formation serves as the principal source of groundwater in the Niger Delta region, underlying Quaternary alluvial deposits of sands, silts, and clays that were transported and deposited during varying hydrological episodes, shaping distinctive geomorphological features. Shale intercalations within the formation act as confining layers for the sand aquifers. The hydrogeology of the area is predominantly influenced by the depositional environment and the succession of sands and clays.

The sand units, which form multi-aquifer systems, vary in grain size from fine to medium to coarse and exhibit sorting ranging from poor to well-sorted. Locally, the geology comprises clay, sand, pebbles, sandstone, gravel, shale, mangrove swamps, lignite, and alluvium (Short, 1967; Ibanga and George, 2016). Optimal sites for borehole drilling are selected based on hydrogeological assessments.

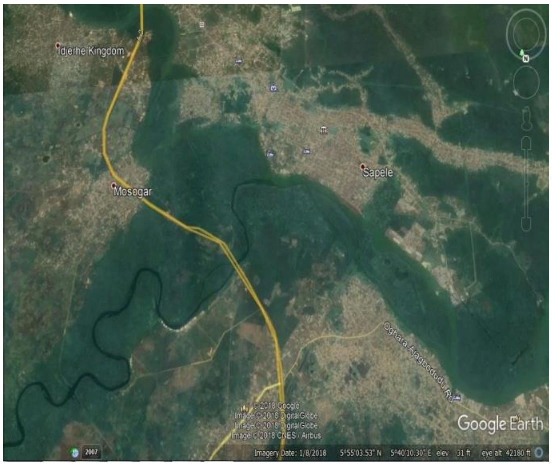

Fig. 1: Google earth map showing the study area

Data Collection Method: The materials applied include Petro - Zenith earth resistivity meter, distance measuring device (tape), hammers, electric cables, electrodes, RES2DINV software, Battery, laptop, Global Positioning System (GPS) etc. 2-D electrical resistivity method. The geophysical investigation method used was the two-dimensional (2D) electrical resistivity imaging applying the Wenner – Schlumberger configuration. A minimum electrode spacing of 5metres (5m) was used for each of the profile with a total length of 100 m surveyed for each profile due to available space and the unavoidable vehicular (traffic) obstructions. A total of five (5) Wenner – Schlumberger lateral lines coverage with length lying within 100 m were established in the study area. The Wenner – Schlumberger array used for this study has a spacing rule which is constant with a factor "n" and the electrodes arranged in the order C_1, P_1, P_2 and C_2, as shown in Figure 2.

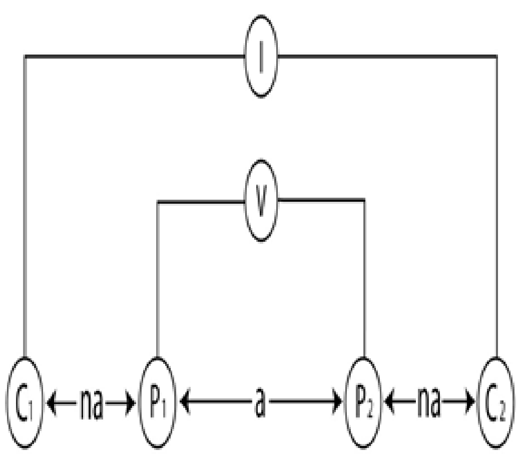

Fig.2: The electrode setting of Wenner - Schlumberger configuration electrode (Ofomola *et al*., 2024)

Initially, a series of measurements was conducted along the profile length using electrodes spaced evenly at intervals of **a** = 5m and the spacing factor **n** = 1. Upon completing this initial sequence, additional measurements were taken following the same pattern and procedure. However, for each subsequent series, the spacing between C1-P_1 and P_2-C_2 was increased to 2**a**, 3**a**, 4**a**, and so on, while the spacing between P_1-P_2 remained constant at **a** = 5m (that is, n = 2 for the 2nd series of measurements, n = 3 for the 3rd series of measurements and so on).

Based on the electrodes, the geometry factor of the Wener Schlumberger configuration becomes

$$K = \pi n(n + 1)a \qquad (1)$$

The apparent resistivity for the wenner Schlumberger configuration is

$$\rho = \pi n(n + 1)a \,\frac{\Delta V}{I} \qquad (2)$$

Where ρ = is apparent resistivity (Ωm), a is electrode spacing (m), I is current (mA) and V is potential difference (mV)The tape as a measuring instrument was used for all length measurements during the investigation. The location (latitude and longitude) of Wenner - Schlumberger points were also obtained with the aid of the GPS from the several measurements taken, it was then possible to generate a series of data which were recorded in a data sheet or writing pad and thereafter inputted into a computer for computerized inversion and processing with the RES2DINV software. The data processing and inversion is done to obtain a pseudo-section/image (Fig. 2-4) of the subsurface under investigation. These 2D resistivity images (pseudo-section) gives an approximate picture of the subsurface characteristics, which then becomes easy interpret. The measurements collected were compiled into a data sheet or log and subsequently entered into a computer for inversion and processing using the RES2DINV software. This process generated pseudo-sections or 2D resistivity images (Figure 2-4) that provided an approximate representation of the subsurface characteristics, enabling easier interpretation.

RESULTS AND DISCUSSIONS

The results of the electrical 2D resistivity maps (inversion) of the sub formation collected from the earth sample sections are shown in Fig. 3-7 with profile length of 100 m each at different depths up to 17.3 m. Low and high resistivity values were delineated in the various sections of the study area in the 2D structure. Fig. 3 denotes the 2-D resistivity image from the known resistivity magnitude (measurement).

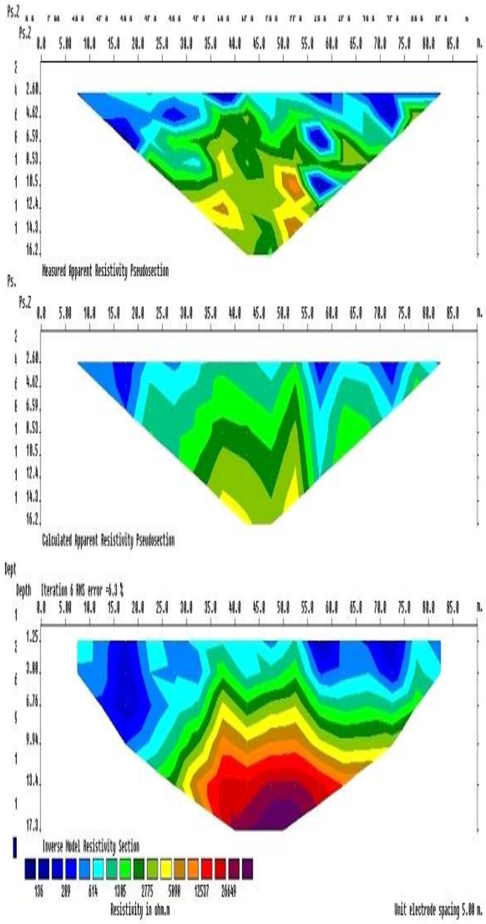

Fig. 3: Pseudo-section plots showing the measured apparent resistivity, Calculated apparent resistivity and Inverse model resistivity section of profile 1

In this profile, a length of 100 m and a depth of 17.3 m were surveyed. Although, this profile shows resistivity of high magnitude at the base, low values of less than 200 Ωm was observed at distances 10 – 20 m to a depth of about 9.94 m and distances 55 m – 75 m to a depth of about 5.00 m from the top soil. Fig. 4 represent the 2-D resistivity map from the obtained apparent resistivity size (magnitude).

In this profile, a length of 100 m and a depth of 17.3 m was surveyed. Distinctive zones with low resistivity values found in this profile were at distance 45 m – 65 m to a depth of about 3.00 m from the surface and distance 10 m – 24 m at a depth between about 6.76 m to 9.94 m, where low resistivity values ranging from 40.5Ωm – 150Ωm was observed. The inverse resistivity model of profiles 1, 2 and 3 as shown in (Fig.3 to 5) show similar results. The low resistivity sections reflect at the top layer of each of the profile.

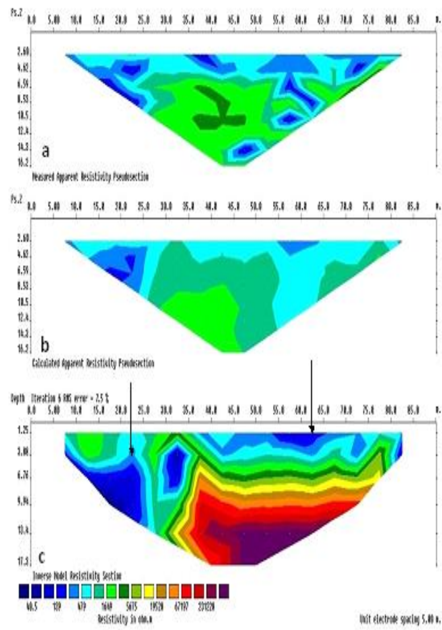

Fig. 4: Pseudo-section plots showing the measured apparent resistivity, calculated apparent resistivity and Inverse model resistivity section of profile 2

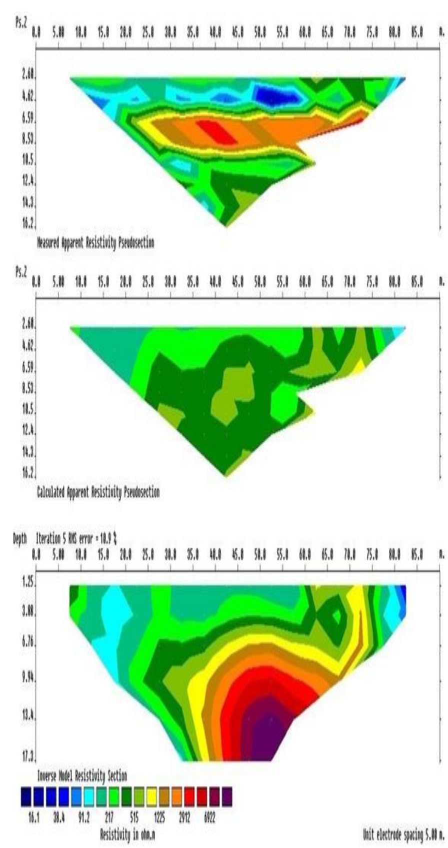

Fig. 5: Pseudo-section plots showing the measured apparent resistivity, calculated apparent resistivity and Inverse model resistivity section of profile 3

Table 1: Apparent resistivity range and lithology variations for distinctive zones across geologic sections using the inverse resistivity section for the various profiles

Profile Number	Location	Resistivity Range(Ωm)	Depth (m)	Length (m)	Inferred Lithology
1	Oki Street Mosogar	< 200	1.25 – 5.00 1.25 – 9.94	15.0 – 35.0 55.0 – 75.0	Clayey Soil
		12537- 30000	12.0 – 17.3	34.0 – 60.0	Sandstone, Shale
2	Oki Street Mosogar	40.5 – 150	1.25 – 3.00 6.76 – 9.94	45.0 – 65.0 10.0 – 24.0	Clay, Water, Silt Sand
		> 20000	9.94 – 17.3	37.0 – 75.0	Sandstone, Shale
3	Okomore Road, Mosogar	< 200	1.25 – 3.88 1.25 – 9.94	30.0 – 60.0 12.0 -25.0	Clay/Sand
		1225 – 7000	9.94 – 17.3	35.0 – 65.0	Laterite, Shale and Sandstone
4	College Road, Mosogar	5.42 – 23.9	5.00 – 9.94 6.76 – 13.4	12.0 – 20.0 60.0 – 75.0	Clayey soil
		465 – 1000	2.00 – 8.00	35.0 – 50.0	Laterite and Sandstone
5	College Road, Mosogar	7.97 – 29.7	3.00 – 9.94 6.76 – 13.4	10.0 – 20.0 45.0 – 75.0	Clay
		414 - 800	3.00 – 9.94	35.0 – 45.0	Laterite

This shows there is a correlation in the lithologic profiles in the area. The tops soil is characterized by possible clay and sandy clay sediment. These are clear indications of geologic structures beneath the surface which usually facilitate road failure occurrence. The High resistive Layer from each of the profiles can be seen clearly to start from a depth of about 10m and below. This shows that the resistive zone comprises of Sandstone and Shale.

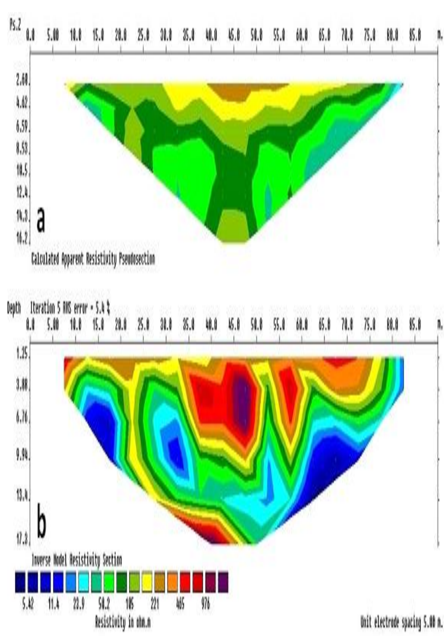

Fig. 6: Pseudo-section plots showing the measured calculated apparent resistivity and Inverse model resistivity section of profile

Fig. 5 show the inverse resistivity model revealing the resistivity sections along this profile. In this profile, a length of 100 m and a depth of 17.3 m was observed. Low resistivity values of less than 200 Ωm was observed at distances 12 m – 25 m to a depth of about 9.94 m and distances 30 – 60 m to a depth of around 3.88 m below the top soil. Fig. 6 depicts the inverse resistivity model revealing the resistivity sections along this profile. Patches of low resistivity values ranging from 5.42 Ωm – 23.9 Ωm were observed in this profile at distances 12 m – 20 m at a depth between about 5.00 m – 9.94 m and 60 m – 75 m at a depth between about 6.76 m – 13.4 m.

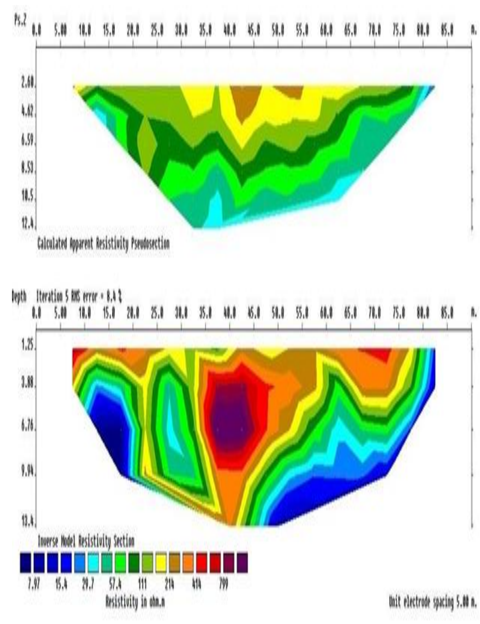

Fig. 7: Pseudo-section plots showing the measured calculated apparent resistivity and Inverse model resistivity section of profile

Fig. 7 shows the inverse resistivity model revealing the resistivity sections along this profile. Particular areas with low resistivity values ranging from 7.97 Ωm –

29.7 Ωm were observed in this profile at distances 10 m – 20 m at a depth between about 3.00 m – 9.94 m and 45 m – 75 m at a depth between about 6.76 m – 13.4 m. Fig. 4 and 5 were taken along the same road parallel to each other and hence, these profiles clearly show correlation to each other. From the 2D inversion of both profiles, resistivity of moderately high magnitude at the top layer and patches of low resistive rocks can be seen across both profiles. The resistivity values from the profiles indicating the possible presence of clayey soil, laterite, sandstone and patches of clay. The results obtained from the geoelectric section identified the most promising aquifer zone within the resistivity range of 1225–7000 Ωm, corresponding to a lithological composition of laterite, shale, and sandstone, at a depth of 9.94–17.3 m. This zone exhibited favorable hydrogeological properties, with sufficient permeability for groundwater storage and transmission.

Conclusion: Geophysical study of Mosogar has been adopted to map Subsurface Lithology along the five Wenner Schlumberger sections. The results from the sections indicate the presence of clayey composition (low resistivity values) and sandstone and shales (high resistivity values). The geoelectric investigations effectively delineated the subsurface lithological variations, revealing a diverse sequence of clayey soils, sandstones, shale, laterite, and mixed clay-sand units. These findings underscore the utility of Electrical Resistivity Tomography (ERT) in resolving subsurface complexities and guiding borehole placement for sustainable groundwater development. The insights gained provide a robust framework for addressing groundwater exploration challenges in the Niger Delta and similar sedimentary environments globally.

Declaration of Conflict of Interest: The authors declare that no known conflict of interest or personal relationships that could have influence the work reported in this paper**.**

Declaration of Data Availability: Data are available upon request from the corresponding author.

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