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Groundwater Investigation Using Electrical Resistivity Method at the Edati Hill, Northern Bida Basin, Nigeria

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ABSTRACT: *Electrical resistivity investigation was conducted using the Wenner-α and Schlumberger configuration around the Edati hill of the northern Bida Basin to understand the groundwater potential and electrical characteristics of the subsurface lithology. Eight electrical resistivity tomography (ERT) lines and thirty-one electrical resistivity sounding (VES) points were occupied in the study. The ERT inversion results revealed two to three layers within the studied depth, as follows; (a) a clayey to silty layer with varying resistivity (49.1Ωm to 11035Ωm) and thickness, representing the top soil; (b) a very thick claystone layer with resistivity between 383 Ωm and 3261 Ωm, corresponding to non-porous, non-aquiferous ferruginized claystone and sandstone layer, except in the northwest where the sand is non-ferruginized and aquiferous; (c) an intermediate to high resistivity (104 Ωm to 5999 Ωm) layer which forms the main aquifer in the northwest with thickness between 15 and 40 meters. The result of the VES revealed four to five geoelectrical layers; a variable resistivity dry surface layer; increasingly high resistivity second to fifth ferruginized clay layer, with very thin aquifer at depth beyond 150 meters. The second and third layers in the northwest are low resistivity aquiferous sandstones. Sustainable borehole drilling has been determined to be in the northwest of the study area at depth of 70 meters.*

KEYWORDS: Bida Basin, Electrical resistivity, Groundwater, Aquifer, ERT

INTRODUCTION

About 60% of sub-Saharan Africa's population, who are considered the poor and vulnerable living in rural settlements, lack access to clean water. This group rely on water from rivers and streams which are usually of poor quality and low sustainability. As public water works are rarely available in these areas, groundwater is the most reliable alternative for resolving the water supply challenge faced by inhabitants (MacDonald *et al.*, 2008). Water supply developed from groundwater has a long-term high benefit to cost, has low susceptibility to contamination and its installation components can be easily managed by low skilled community technicians. The development of groundwater resources is however complicated because of variability in geological and hydrogeological conditions making its management a bit difficult.

Electrical resistivity method is increasingly being employed in groundwater exploration because of its simplicity in field application, varying adjustable depth of investigation giving useful information about layers being investigated including their level of saturation (El-Sayed *et al.*, 2023), availability of robust 1D, 2D, and 3D interpretation software (Wahab *et al.*, 2021). It has wide application in hydrogeological studies which include estimation of aquifer depth and thickness, detecting contaminant plume, determination of aquifer hydraulic properties, aquifer recharge monitoring and characterization of saline intrusion in coastal aquifers (Wahab *et al.*, 2021) and has been used successfully in various groundwater exploration campaign (El-Sayed *et al.*, 2023; Wahab *et al.*, 2021).

Inhabitants rely heavily on rain harvesting for their domestic water needs during the raining season, with such storage only lasting for a few days. Residents have to travel several kilometres most of the times to the few available borehole water points when there is no rainfall. Although there are no available data on the boreholes drill information, 90% of available boreholes here are non-productive. Previous studies on the groundwater potentials (Aweda *et al.*, 2023; Idris-Nda *et al.*, 2013) have been focused on adjoining areas which have different physiography and water challenge from the study area. The study is aimed at understanding the subsurface distribution of the aquifer in the area, its depth, thickness and resistivity, using electrical resistivity methods with the objective of upgrading or upscaling drilling success rate in future.

Study Area

The study area (Edati Hill) is located about 10km east of Kutigi and 8km east of Enagi, which is part of the northern Bida Basin of central Nigeria situated between 9'02'N – 9°10'N and 5°36'E – 5°44'E (Figure 1). It is home to over 1000 agrarians with heavy reliance on groundwater as source of fresh water supply for processing of farm produce and domestic utilities. It lies within the southern Guinea Savannah climate zone having two marked seasons; a raining season between April and October; and a dry season between November and March, with total mean annual rainfall rarely exceeding 127mm and mean temperature of 35°C (Suleiman, 2014). The area has a hilly topography with elevation between 202 m and 277 m above sea level having a high surface runoff of rainwater with no streams or rivers present.

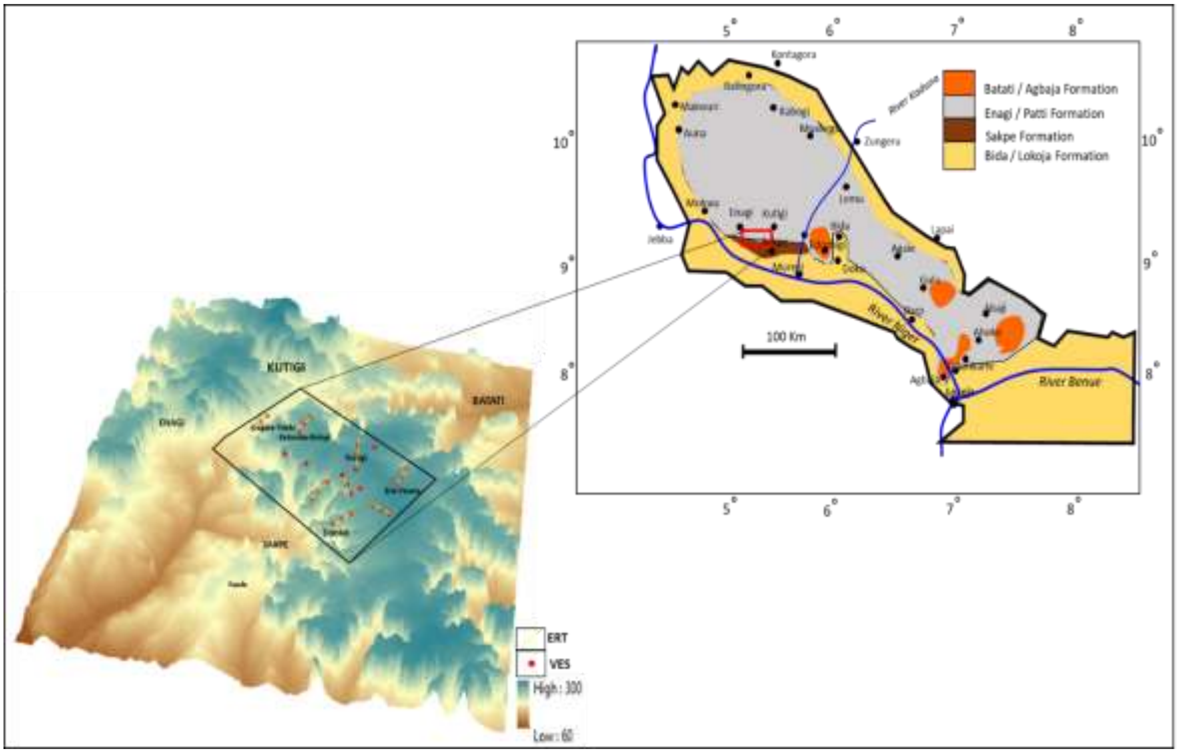

Figure 1. The Study Area (Modified from Obaje *et al.,* 2019)

Geology and Hydrogeology

Regionally, the four major litho-stratigraphic components that constitutes the Cretaceous northern Bida Basin are; the basal Bida Formation, the Sakpe Formation, the Enagi Formation and the Batati Formation. The Basin is an intracratonic basin with a NW-SE trend whose lithic fill are deposited during opening of the South Atlantic Ocean in the Cretaceous, resulting from block faulting, basement fragmentation, subsidence, rifting and drifting (Obaje, 2009). The basin stretching from the Niger-Benue confluence at Lokoja northwards to the basement complex which separates it from the Sokoto Basin in the north. Locally, the area sits directly on the Campanian Sakpe Formation which is composed of bands of pisolitic and oolitic ironstone, intercalated with siltstone and mudstone units with concretions (Figure 1). The formation forms sharp contact with the underlying Bida Formation which is a cyclic fining upwards grey to whitish sandstone unit, with kaolinitic clay intercalations (Rahaman *et al.*, 2019) and a conglomeritic base.

The study area is characterized by low to moderate groundwater which is a property of the Lower Niger Hydrological Basin where the area is situated (Offodile, 2013). Records of groundwater development are rarely available, but potentially good aquifers are believed to be the sandstone units of the Bida and Enagi Formation, as well as the alluvial deposits around the River Niger

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flood plain (Offodile, 2013). Aquifer yield from the Bida Sandstone is reported to be between 1.365m^3/day and 393m^3/d and transmissivity range of 0.9m^3/hr and 136.5m^3/hr (Olabode *et al.*, 2012).

METHODOLOGY AND DATA ACQUISITION

Electrical resistivity tomography (ERT) and vertical electrical sounding (VES) were systematically integrated to understand the vertical and lateral variation in resistivity within the study areas and relate them to possible groundwater occurrence as water content and distribution affects the electrical properties of host rocks. Resistivity has an inverse relationship with rock porosity and clay content, degree of saturation and salinity of water (Mohamaden & Ehab, 2017). In the resistivity method, current is injected into the subsurface using a pair of electrodes while the potential difference is measured using another pair of electrodes placed in between the first pair (El-Sayed *et al.*, 2023). For the ERT, Wenner array with electrode spacing of 10 meters was used and each electrode line was 300 meters. The survey was conducted in eight (8) lines manually using the Campus Ohmega resistivity meter (model 143) manufactured by Allied Associates. Greater depth of penetration was achieved by increasing the inter electrode spacing after data was collected for each level of measurement. The obtained resistivity value for each data point was converted to apparent resistivity by multiplying it with the geometric factor $K=(2\pi a)$, where a is the electrode spacing, and the data stored in .DAT computer format prior to interpretation.

Vertical electrical sounding was conducted along the ERT profiles where moderate resistivity anomalies were interpreted. Other VES stations were located in selected areas where ERT lines could not be deployed due to poor accessibility. Schlumberger array was employed with maximum current electrode spread (AB) of 200 m. A total of thirty-one (31) VES soundings were sounded. The obtained ERT data was process, inverted and interpreted using the Res2Dinv software (Loke & Barker, 1996) while WinResist was used for the VES data.

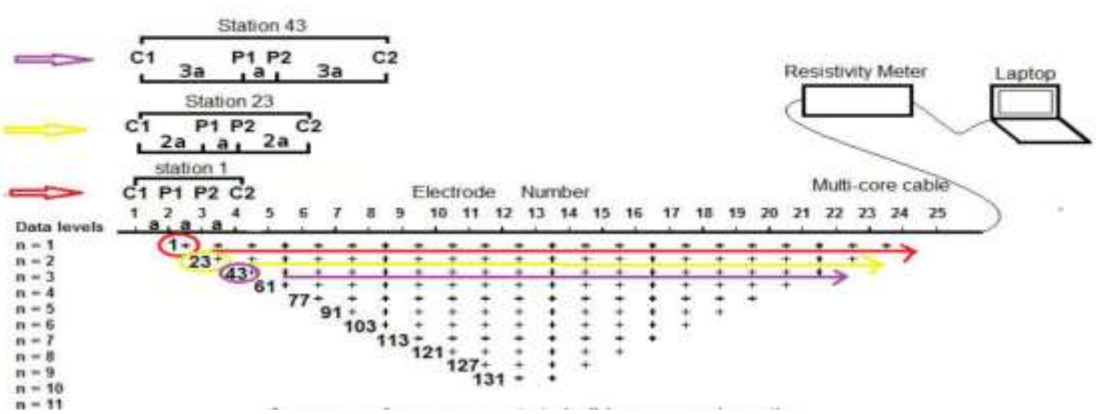

Figure 2. Sequence of ERT Data Measurement (After Sikah *et al.*, 2016)

RESULT AND DISCUSSION

Interpretation of ERT data is easy when the resistivity data is inverted to produce pseudo-sections, which gives a visual illustration of the raw apparent resistivity data (Wahab *et al.*, 2021). Comparison of the raw data with the inverted section is useful in identifying anomalies observed in pseudo-sections. Unusually high or low apparent resistivity measurement which represent less than 1% of the data set, were exterminated during pre-processing. Root Mean Square (RMS) Error of between 2.0 and 7.3% was obtained as the difference between the observed and calculated apparent resistivity data during iteration, which is an indication that the data is of good quality. Figure 3 presents the pseudo-sections for one of the data locations. This section displays the measured and calculated apparent resistivity after iteration. The inverted resistivity model, which shows the model lithology section is shown in Figure 4.

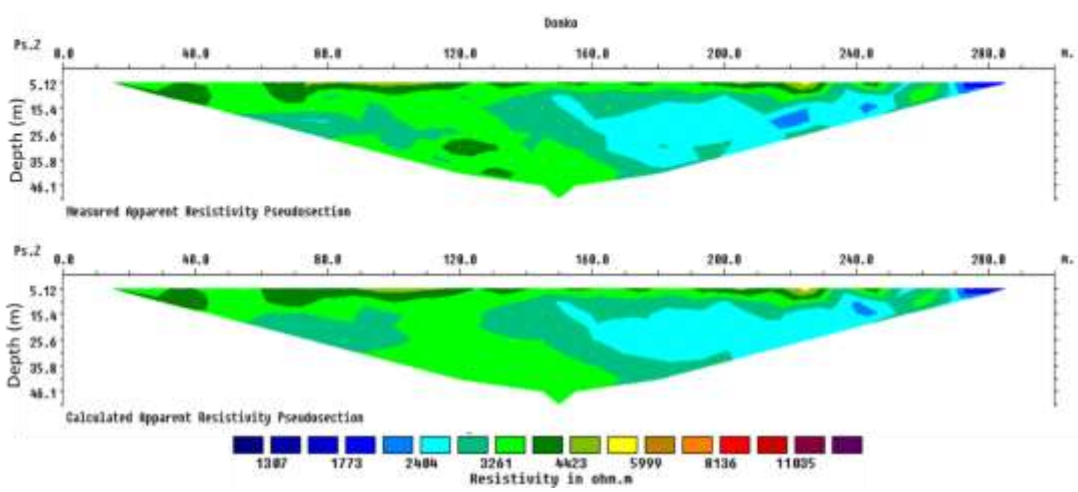

Figure 3. Example of a Pseudo-section for One of the Locations

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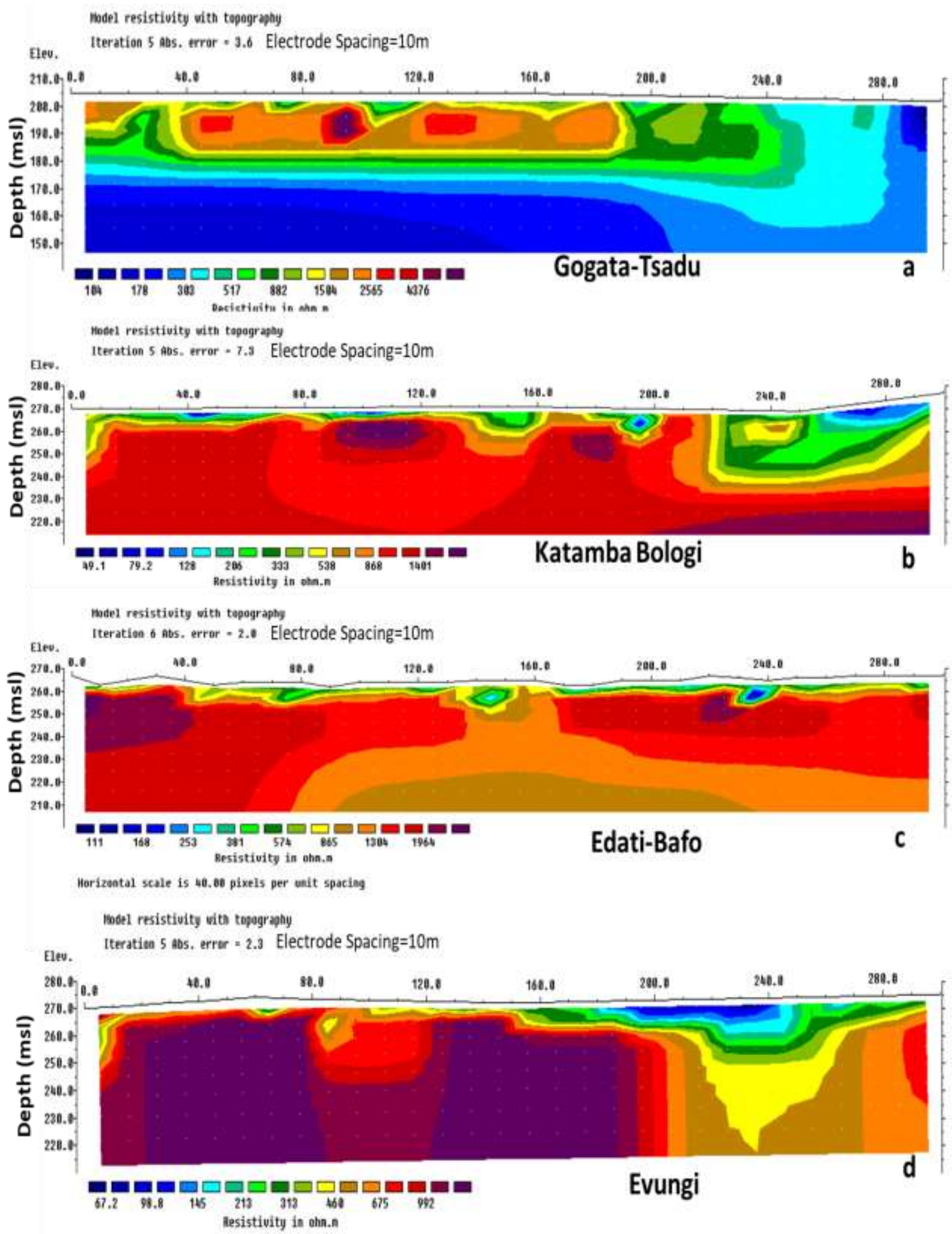

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Figure 4 (a-d). Inverted Section of Data from the Study Area

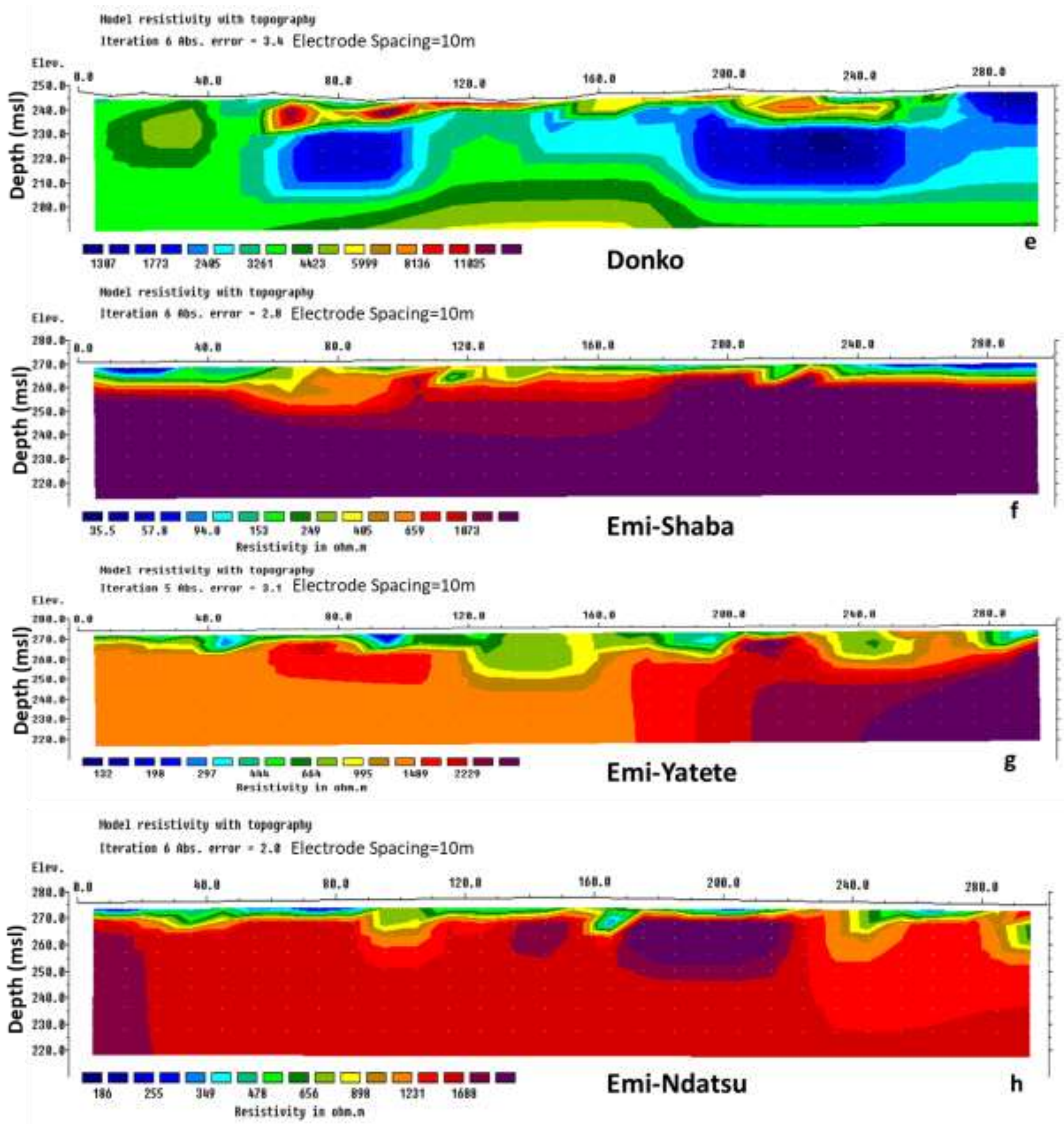

Figure 4 (e-h). Inverted Section of Data from the Study Area

The ERT result revealed the presence of three major resistivity zones having a wide range in the apparent resistivity reading between 35.5Ωm and 10200Ωm across two to three zones. The first zone consists of a low to very high resistivity values between 49.1Ωm and 11035Ωm; the second zone has resistivity of 383 Ωm to 3261 Ωm; while the third zone's resistivity is between 104Ωm and 5999Ωm.

Resistivity of the top layer can be placed into two groups: the first group have low resistivity (<115 Ωm) and are mainly clayey to silty sediments with thickness between 1 and 10 m. This group is dominant especially in the central and south-eastern regions of the area. The second group has high resistivity (115 -11035Ωm) which represents indurated sediments with presence of ferruginized claystone noodles. This layer is more present around the fringes of the study area and has thickness between 5 and 15 m.

The second layer, which forms the intermediate layer in most parts, has a high resistivity (383 – 3261Ωm) and great thickness across the entire study area, except around the northwest fringe (Gogata-Tsadu) where the resistivity decreased (383 - 517Ωm) which corresponds to the shallow confined sandstone aquifers intercalated with ferruginized sandstones at intervals. This layer in other places correspond to non-porous ferruginized claystone and sandstone in other areas which are non aquiferous.

The deeper layer is absent in some of the areas has intermediate to high resistivity values between 104 Ωm in the northwest fringe, to 5999Ωm in the southeast fringe. This layer is mainly ferruginized sandstone and claystone except in the northwest edge where it is medium to fine sand of thickness between 15 and 40m, and is the main aquifer in the area.

Anomalous resistivity points along the ERT profiles were probed deeper using Schlumberger's VES (Figure 5) since the ERT could not be deployed to investigate deeper than 50 meters below the surface. The resistivity curve types interpreted consists of simple three-layer curves as well as other more complex four to five-layer curves. The A-type curve is the most dominates over 35% of the study area which represents increasing resistivity with depth with very low groundwater content (Table 1). This curve, together with the AA-type curves are more around the southeast and central areas and the curves gradually becomes H, HH, HA and HKH northwards and finally HK curve at the northwest boundary of the study area. This signifies an increase in moisture in the thick clay layer and the deep aquifers within the central areas. The HK curves represents a shallow high resistivity clay layer which serves as the confining layer for the dipper lower resistivity aquifer layer whose saturation increases with depth.

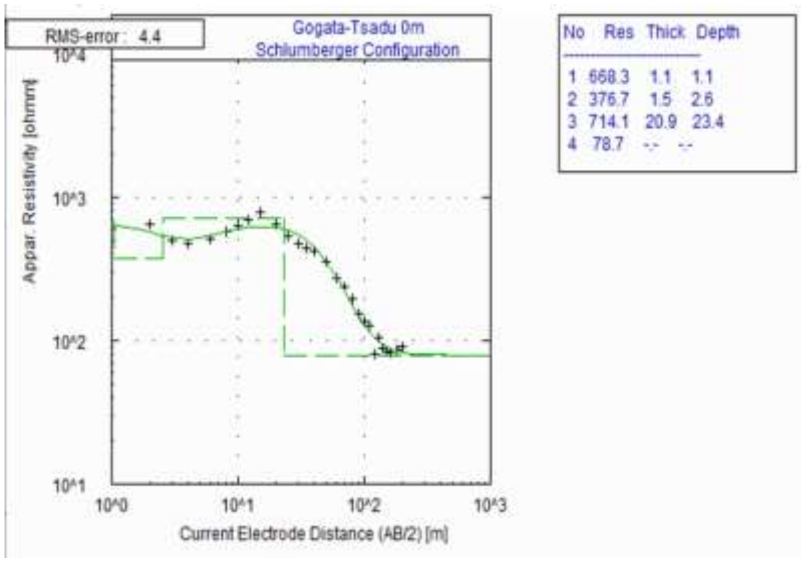

Figure 5. Example VES Curve for One of the Sounding Locations

Table 1. Summary Resistivity Type-Curves from the Study Area

Dominant Curve Type	Frequency	Percentage (%)	Dominant Locations
HK	4	12.9	Northwest
A	11	35.5	Southeast, Central
AA	4	12.9	Southwest, Central
K	3	9.7	West, Central
HH	2	6.5	Southeast
H	3	9.7	Northwest

Iso-resistivity maps are useful in understanding lateral change in electrical resistivity. Resistivity change with depth is easier studied when iso-resistivity maps are generated and compared for different depth (El-Sayed *et al.*, 2023). The iso-resistivity map 6, 30, 50, 100, 150 and 200 m depth is presented in Figure 6. The maps showed significant variation in resistivity of the subsurface lithologic formations in the study area signifying its high heterogeneity. The resistivity generally increases southwest wards across all depths which is caused by the higher ferruginization of the claystone and sandstone in these areas. The adjoining areas with lower resistivity, especially the northern parts where resistivity continues to decrease with depth, is as a result of the presence less ferruginized, more saturated sandstone and clay units where aquifers are present.

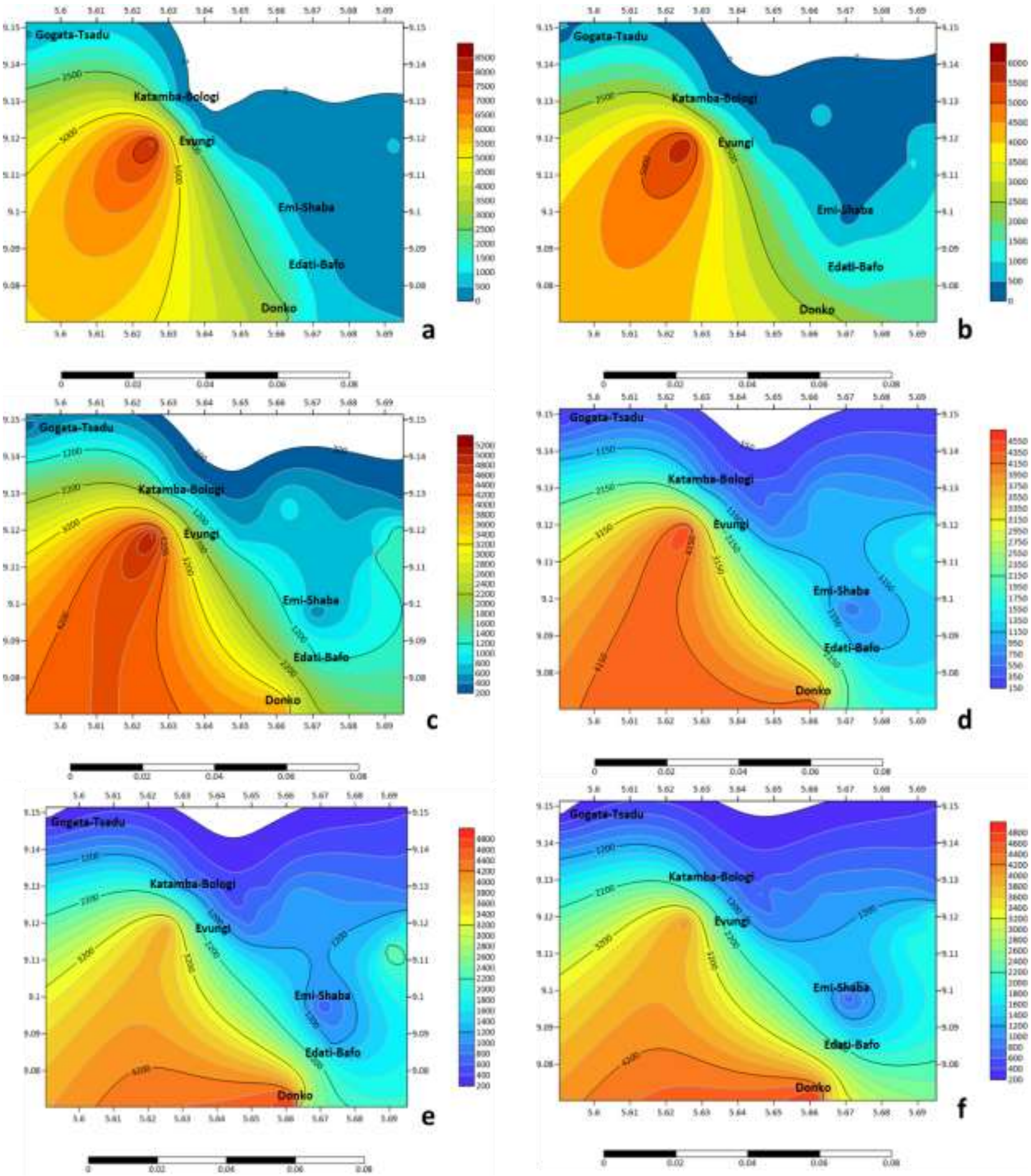
Gogata-Tsadu
Katamba-Bologi
Evungi
Emi-Shaba
Edati-Bafo
Donko
a
b
c
d
e
f

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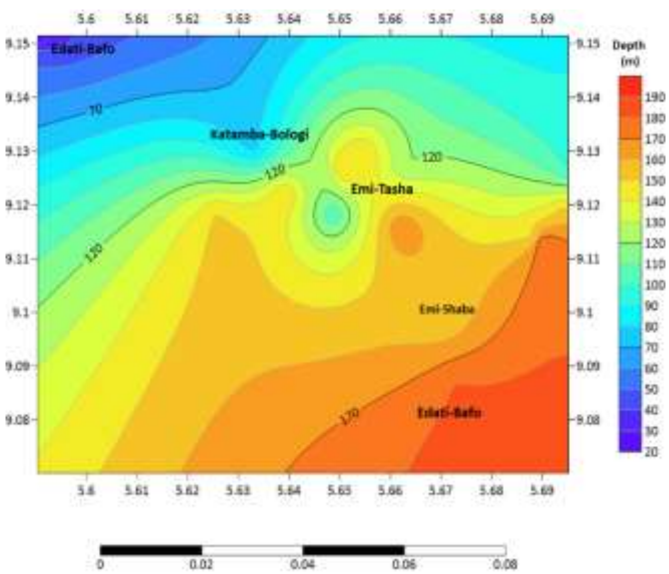
Figure 6. Iso-resistivity Map at (a) 6 m; (b) 30 m; (c) 50 m; (d) 100 m (e) 150 m; and (f) 200 m

Figure 7a. presents the depth to aquifer contour map of the area. The aquifer is shallower (20 to 80m) towards the northwest and is deepest in the southeast where it is between 160 and 180 m. The aquifer resistivity (Figure 7b) is also lowest around the northwest which represents the presence of clay intercalations within the aquifer units here.



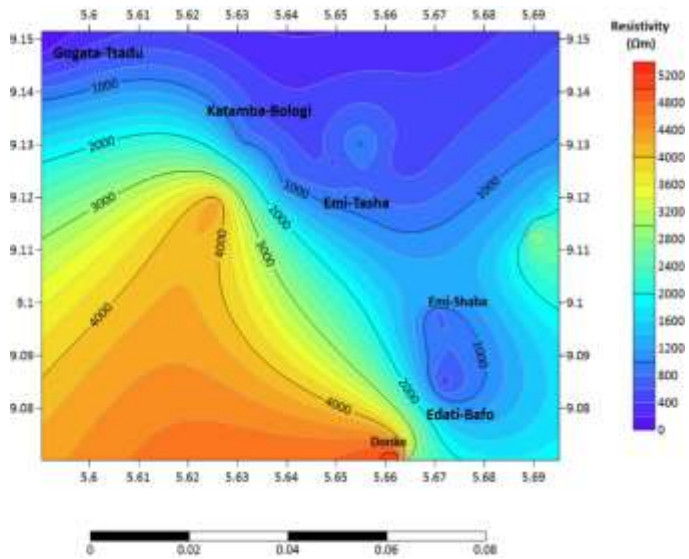


Figure 7. Maps Showing (a) Depth to Aquifer; and (b) Aquifer Resistivity

CONCLUSION AND RECOMMENDATION

Geoelectrical resistivity investigation was conducted within settlements on the Edati hill using the ERT and symmetrical VES configuration in order to determine the groundwater prospects within the area. Results from the ERT inversion obtained from the Wenner (alpha) resistivity array delineated two to three geoelectrical resistivity layer: (1) a shallow very low to high (49.1 Ωm and 11035 Ωm) resistivity top soil layer; (2) a moderate to high (383 Ωm to 3261 Ωm) resistivity layer which is mainly ferruginized claystone; (3) a low to very high (104Ωm and 5999Ωm) resistivity layer which constitutes the aquifer especially within the north region. The VES resistivity curve types indicate the dominance of A-type curve which signifies increasing resistivity with depth. The northern area shows lower resistivity relative to other areas, especially the southwest which has the highest resistivity. The depth the aquifer map revealed that the aquifer is shallower and thicker in the north while it gets deeper and thinner southwards. The aquifer resistivity also increases southwards with highest value around the southwest.

The study recommends that groundwater drilling and development should be more concentrated in the northern part of the study area, especially around Gogata-Tsadu and Katamba-Bologi. The depth to aquifer is shallower here (<70 m) and the aquifer is thicker. The aquifer is thinner and deeper (>150 m) in other areas making development and sustainability more expensive. The result is important in guiding future groundwater development campaign in the study area and locating promising areas for borehole drilling. This type of investigation is further recommended for any hydrogeological studies as it will minimize the time, cost and uncertainty that may be associated with water well construction.

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