Application of Vertical Electrical Sounding for Subsurface Geophysical Characterization in Geidam Town, Geidam Local Government Area, Yobe State.

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Abstract

The study utilizes the Vertical Electrical Sounding (VES) technique aimed at exploring the subsurface lithology and hydrogeological framework of Geidam Local Government Area, Yobe State, Nigeria. The study forms part of the Chad Basin, a large inland sedimentary basin composed mainly of Quaternary and Tertiary deposits such as alluvial sands, clays, silts, Bima Sandstone, Gongila Formation, and the Chad Formation. Field data were collected with the aid Schlumberger array with electrode separations (AB/2) between 1 m and 140 m. The computed apparent resistivity values decreased progressively from 24 Ωm at shallow depths to around 2 Ωm at greater depths. The VES curves predominantly show an H-type response, which reflects a resistive surface horizon underlain by conductive strata. Interpretation identifies three principal layers: a resistive sandy topsoil (20–30 Ωm, 3–6 m thick), an intermediate clayey sand unit (8–15 Ωm, 15–30 m thick), and a conductive saturated clay aquifer (2–5 Ωm) extending below the depth of exploration. Quantitative modelling indicates that the Chad Formation is dominant at depth, which corresponds with regional geology. The low resistivity of deeper layers indicate that the groundwater in this locality is likely saline or mineralized, a common feature of Chad Basin aquifers. The study highlights the usefulness of VES in subsurface characterization with relevance to groundwater assessment, geotechnical analysis, and environmental studies. The findings serve as useful guide for groundwater development and sustainable water management in the semi-arid northeastern region of Nigeria.

Keywords: *Vertical Electrical Sounding (VES); Apparent Resistivity; Geoelectric Layers; Subsurface Characterization; Chad Basin; Groundwater Potential; Geidam; Yobe State; Nigeria*.

Introduction

Water exists naturally in various forms – in the atmosphere as vapor, on the surface as rivers, lakes, oceans, and springs, and underground as groundwater (Okafor, 2011). In many regions, surface water is unreliable due to limited quantity and poor quality, making it unsuitable for both domestic and industrial purposes.

Across the globe, nearly two billion people rely directly on groundwater for drinking, while nearly 40% of food production comes from irrigation that depends largely on aquifers. As population growth and economic activities expand, dependence on aquifers will remain crucial for reliable domestic and agricultural water supply (Morris *et* al., 2003).

The study area experiences water shortages, as residential supplies are inadequate, taps are frequently dry, and many boreholes fail, especially during dry periods. To address such challenges, Nigeria's Water Resources Law (Decree 101 of 1993) serves as the primary legal framework for water management and planning (Kana *et* al., 2014).

The Vertical Electrical Sounding (VES) technique has proven to be efficient and cost-effective in locating groundwater (Anomoharan, 2013). It has also served to determine bedrock depth, delineate clay aquifers, detect saltwater intrusion, monitor groundwater contamination, and define soil characteristics (Gabir *et* al., 2012). This method has been extensively used across Nigeria and globally for subsurface exploration (Anomoharan, 2015).

Aim

The study aims to conduct Vertical Electrical Sounding in Geidam Town, Yobe State, to investigate groundwater prospects. The outcome is expected to provide guidance for borehole siting and serve as a reference database for future studies.

Objectives

The objective of this research is to;

i. Delineate the subsurface geoelectric layers within the study area.
ii. Estimate the resistivity values and the depth of the subsurface layers.
iii. Evaluate the groundwater availability within the study area.
iv. Recommend suitable sites for borehole drilling.
v. Identify reasons behind the frequent failure of existing boreholes, particularly during dry seasons.

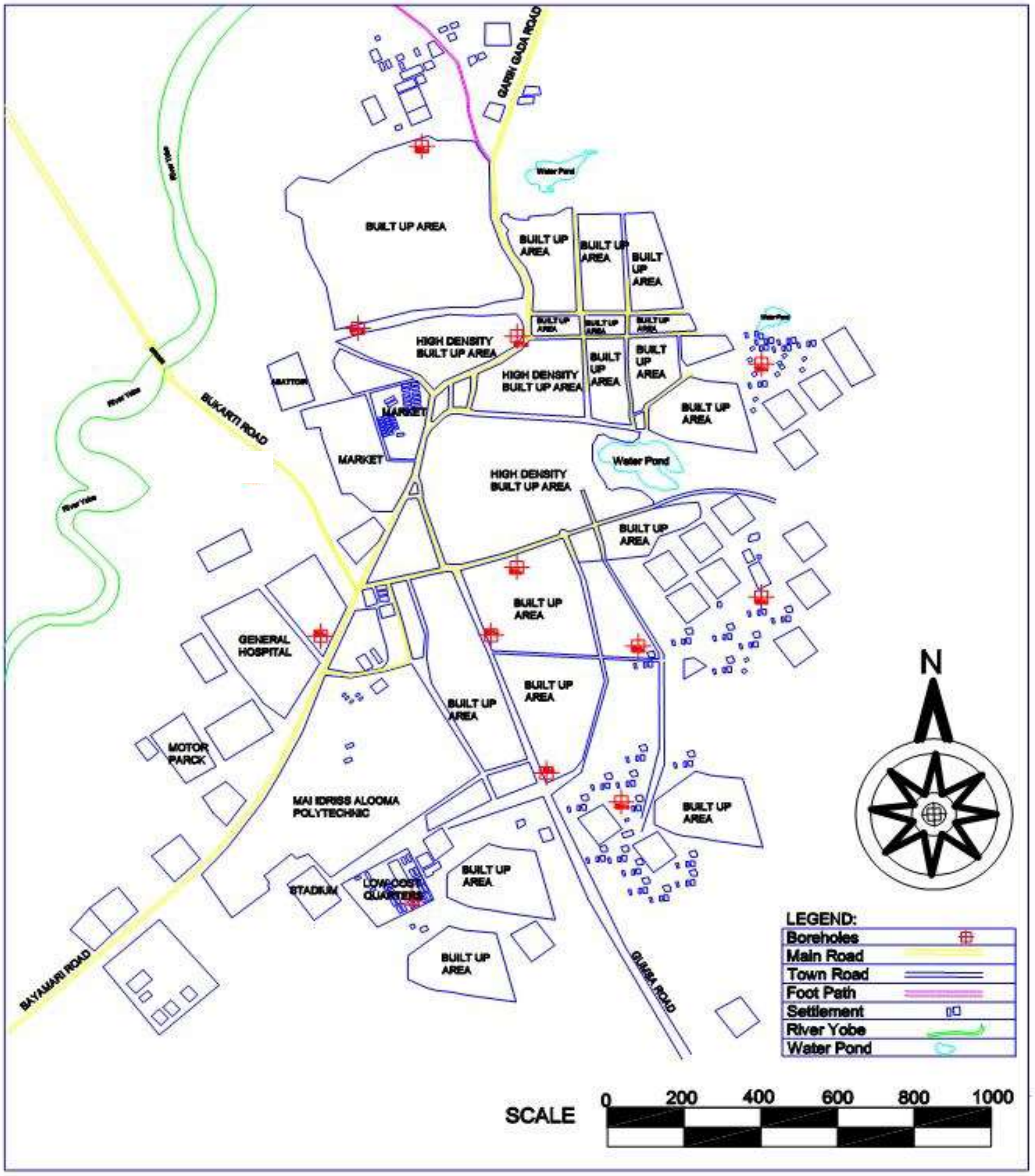

Figure 1 Map of the Study Area (Abdulkarim *et* al., 2021)

Research Method

The research employed electrical resistivity surveying to investigate subsurface characteristics. This geophysical approach involves measuring the resistivity of underground materials from the surface (Abdel-Azim et al., 1996). Among the commonly used configurations, the Wenner and Schlumberger arrays are most suitable for Vertical Electrical Sounding (Sharma, 1997). In this study, the Schlumberger array was adopted, with the maximum current electrode separation (AB/2) extended to 140 m. The apparent resistivity values (ρa) were computed using the relationship between resistance, electrode geometry, and measured current and potential differences.

Study Area

Location of the Study Area

Geidam Local Government Area is located in northeastern Yobe State, Nigeria, within the semi-arid Sahel zone, bordering the Republic of Niger. The town lies about 180 km northeast of Damaturu, the state capital, and is connected by major roads to Gashua, Damaturu, and Maiduguri. Geographically, it falls between latitudes 12°40′N and 13°30′N and longitudes 11°45′E and 12°30′E. The climate is characterized by prolonged dry seasons, short wet seasons, and sparse vegetation dominated by grasses and scattered shrubs.

Geology of the Study Area

The area belongs to the Nigerian sector of the Chad Basin, whose origin is linked to Cretaceous rifting events. It consists of sediments that include sands, sandstones, and alternating clay/shale layers. The Chad Formation, which dips concentrically toward Lake Chad at about 1.5 m/km, is the most dominant sequence in the area. It shows rapid lateral and vertical variations and contains aquifers generally classified into upper, middle, and lower zones (Dawoud and Raouf, 2009). Towards Maiduguri, the formation thickens, while it thins out in the Potiskum axis where the Kerri-Kerri Formation emerges. Surface soils are predominantly sandy with silty admixtures, though clay occurs in some locations. The Kerri-Kerri Formation, part of the Tertiary sequence, underlies the Chad Formation and consists mainly of basal sands. and gravels with greenish clays above, the later containing some minor bands of sands (Dawoud and Raouf, 2009)

Theory of Resistivity Survey

This technique adopts the standardised media which constitute an electric field E around the current source. The current density J and electric field E are associated through ohm's law

$$J = \delta E \tag{1}$$

Where E is the electric field (V/m) and also the potential gradient, δ is the conductivity (the reciprocal of Resistivity ρ) and is measured in Siemens per meter (s/m). Considering the flow of current I. Equation 1.0 gives

$$E = \rho J = -\nabla V = -\frac{dv}{dr} \tag{2}$$

Where J is the current density and is equal to current, I divided by the surface area, which is $2\pi r^2$ for hemisphere of radius r formed around each electrode. Therefore, then potential at any point in the medium or on the boundary is given by

$$v = \frac{I\rho}{2\pi r} \tag{3}$$

Where r is the distance between the electrodes, for an electrode pair with current I at electrode A, and $-I$ at electrode B, the potential at a point is given by the algebraic sum of the individual contributions

$$v = \frac{I\rho}{2\pi r_A} - \frac{I\rho}{2\pi r_B} = \frac{I\rho}{2\pi}\left[\frac{1}{r_A} - \frac{1}{r_B}\right] \tag{4}$$

Where r_A and r_B are distances from the point to electrodes A and B. In addition to electrodes A and B, figure 3.1 shows a pair of electrodes M and N, which carry no current, but between which the potential difference V may be measured.

$$\Delta V = V_m - V_n = \frac{I\rho}{2\pi}\left[\frac{1}{AM} - \frac{1}{BM} + \frac{1}{BN} - \frac{1}{AN}\right] \tag{5}$$

Where V_m and V_n are potentials at M and N respectively. AM, BM, BN and AN are distances between electrodes A and M, B and M, B and N, A and N respectively. Equation (5.0) can be written in terms of the resistivity ρ as

$$\rho = \frac{\Delta V}{I}\left[\frac{2\pi}{\frac{1}{Am} - \frac{1}{BM} + \frac{1}{BN} - \frac{1}{AN}}\right] = K\frac{\Delta V}{I} \qquad (6)$$

Where K is geometric factor from the bracket in equation (10) above,

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} + \frac{1}{BN} - \frac{1}{AN}} = \pi\left(\frac{AB^2}{MN} - \frac{MN}{4}\right)$$

Equation (6) represent the resistivity of uniform or homogeneous earth surface measurement. Whenever these measurements are taken over a real heterogeneous earth surface, equation (6) represents apparent

Therefore, ρa = KR

Where: ρa= Apparent resistivity, K = geometric factor, R = measured resistance, AB = current electrode spacing in meter, MN = potential electrode spacing in meter, V = potential difference in volts and I = electric current in Amperes The resistivity method measures how subsurface materials oppose the flow of electrical current. When current flows through a homogeneous medium, it generates an electric field (E), which is related to current density (J) by Ohm's law (E = ρJ, where ρ is resistivity). For a current introduced at the earth's surface, the potential at any point is influenced by the electrode configuration. In practice, four electrodes are used: two for current injection (A and B) and two for potential measurement (M and N).

The apparent resistivity (ρa) is computed from the measured resistance (R) and a geometric factor (K) that depends on electrode spacing: ρa = KR, where R = V/I. Here, V is the potential difference, I is the applied current, AB is the current electrode spacing, and MN is the potential electrode spacing. The Schlumberger configuration was employed with ABEM Terrameter SAS 300, metal electrodes, cables, GPS receiver, and other field tools. A total of 20 VES stations were surveyed, each extending to AB/2 = 140 m. Data were processed and interpreted using WinResist version 1.0 (Vander Velpen, 2004), while maps were generated using Golden Surfer 12 software.

Results and Discussion

The field results obtained from the twenty (20) sounding is shown in table 1.

Table 1: VES Field Data

S/N	AB/2 (m)	MN/2 (m)	Current I (mA)	Potential DV (mV)	Apparent Resistivity (Ωm)
1.0	1.0	0.5	20.0	24.0	24.0
2.0	3.0	0.5	20.0	22.0	22.0
3.0	5.0	2.0	20.0	20.0	20.0
4.0	9.0	3.0	20.0	18.0	18.0
5.0	13.0	4.0	20.0	16.0	16.0
6.0	19.0	4.5	20.0	14.0	14.0
7.0	27.0	5.0	20.0	12.0	12.0
8.0	33.0	5.0	20.0	10.0	10.0

9.0	41.0	5.5	20.0	9.0	9.0
10.0	50.0	6.0	20.0	8.0	8.0
11.0	60.0	7.0	20.0	7.0	7.0
12.0	69.0	8.0	20.0	6.0	6.0
13.0	77.0	8.5	20.0	5.0	5.0
14.0	89.0	9.0	20.0	4.0	4.0
15.0	100.0	10.0	20.0	3.0	3.0
16.0	110.0	11.0	20.0	2.8	2.8
17.0	121.0	12.0	20.0	2.6	2.6
18.0	130.0	13.0	20.0	2.4	2.4
19.0	135.0	13.5	20.0	2.2	2.2
20.0	140.0	15.0	20.0	2.0	2.0

VES Plots

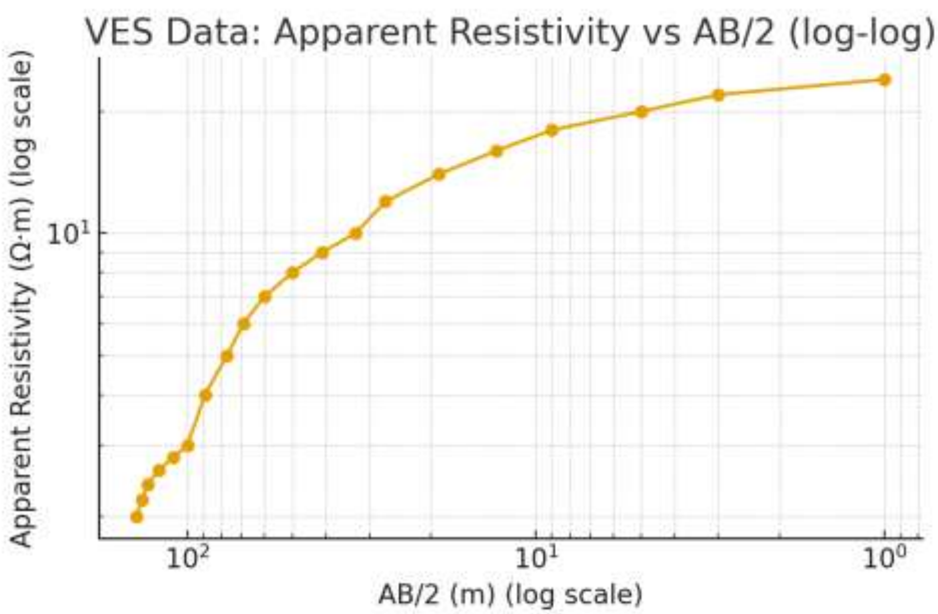

Figure 2: Log-Log Plot of Apparent Resistivity vs AB/2.

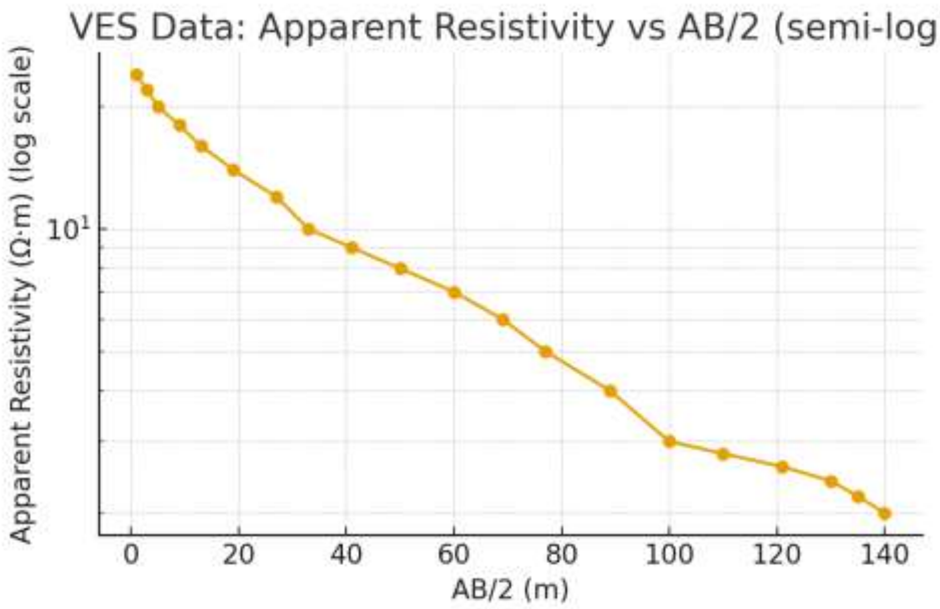

Figure 2: Semi-Log Plot of Apparent Resistivity vs AB/2.

The apparent resistivity values were plotted against the half-current electrode spacing (AB/2) on log-log and semi-log scales to produce the VES curves. Data from twenty (20) sounding stations were modelled to develop geoelectric sections along profiles. The resulting curves correspond to three- and four-layer models, with common types including H curves.

A consistent decrease in resistivity with increasing electrode spacing was observed, suggesting that deeper layers are more conductive. The dominant H-type curves indicate a resistive surface layer overlying more conductive stratum.

The interpreted subsurface sequence consists of three main geoelectric layers:
1. Topsoil/Alluvium: thickness 3–6 m, resistivity 20–30 Ωm.
2. Clayey Sand: thickness 15–30 m, resistivity 8–15 Ωm.
3. Saturated Clay/Chad Formation: extending beyond 30 m, resistivity 2–5 Ωm.

The hydrogeological implication of these findings is that the deep, low-resistivity units represent aquiferous zones of the Chad Formation. However, the very low values suggest the likelihood of saline or mineralized groundwater. Thus, water quality tests are necessary before domestic or agricultural use.

Qualitatively, the decreasing resistivity with depth reflects stratification of sandy topsoil, clayey sands, and saturated clay horizons. Quantitative modelling confirmed this, yielding the following geoelectric parameters:
- Layer 1: Resistivity 20–30Ωm, Thickness 3–6m (Topsoil/Alluvium).
- Layer 2: Resistivity 8–15Ωm, Thickness 15–30m (Clayey Sand).
- Layer 3: Resistivity 2–5 Ωm, indefinite thickness (Saturated Clay/Chad Formation aquifer).

Conclusion

This study applied the Vertical Electrical Sounding (VES) method to characterize the subsurface lithology and hydrogeological conditions of Geidam in Yobe State. The results revealed three principal layers: a resistive sandy topsoil, an intermediate clayey sand unit, and a deeper saturated clay aquifer associated with the Chad Formation. The low resistivity values of the aquifer zones suggest saline or mineralized groundwater, which may limit suitability for domestic use. Nonetheless, the findings are vital for borehole siting, groundwater exploration, and water resource management in this semi-arid environment. Further hydrochemical analyses are advised to assess the quality of the water.

Recommendation

Based on the findings of this study, the following recommendations are made:

i. Boreholes should be sited in areas where geoelectric data show thick and conductive aquifer layers.
ii. Hydrochemical testing of groundwater should be conducted to confirm suitability for domestic and agricultural use.
iii. Regular monitoring of groundwater quality and levels is necessary to ensure sustainability.
iv. Future research should integrate VES with other geophysical and geochemical methods for improved accuracy.
v. Community awareness programs should be promoted to encourage sustainable groundwater utilization practices.

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