

Hydrogeophysical Investigation of Groundwater Potential in Ugbowo Area of Edo State Using Electrical Resistivity Method

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ABSTRACT

A hydrogeophysical investigation of groundwater potential was conducted in the Ugbowo area of Edo State, Nigeria, using Electrical Resistivity Method to characterize the subsurface lithology and evaluate groundwater potential. A Global Positioning System (GPS) receiver was used to obtain the geodetic coordinates of the VES station, which is located at latitude 6° 28' 48.36" N and longitude 5° 35' 17.16" E. The geology of the study area is predominantly composed of the Benin Formation, which underlies approximately 95% of the region. Vertical Electrical Sounding (VES) was performed at one station using the SAS 300C ABEM Terrameter with the Schlumberger array configuration and a maximum electrode spacing of 147 m. The acquired data were processed and interpreted using the IPI2WIN software. The resulting geoelectric model revealed six subsurface layers with apparent resistivity values ranging from 391.51 Ωm to 5836.9 Ωm and depths extending from 1.41 m to 85.23 m. The lithologic units identified include lateritic topsoil, clay, gravel, cemented sandstones, and fine- to coarse-grained sands of varying thicknesses. The aquifer units were predominantly confined and showed good correspondence with lithologic logs from existing boreholes within the study area. A high resistivity lateritic layer was found to dominate the upper subsurface. The Vertical Electrical Sounding (VES) results indicate the presence of an aquifer with a resistivity of 783.37 Ωm , located directly below the fifth layer in the study area. This potential aquifer suggests that the area may be suitable for groundwater development. Based on these findings, it is recommended that drilling contractors consider this information before borehole construction to enhance the efficiency and success of groundwater exploration.

Keywords:

Hydrogeophysical, Investigation, Groundwater, Resistivity, Vertical Electrical Sounding (VES).

INTRODUCTION

Water is an essential resource for the sustenance of life, and its availability directly influences human survival, socioeconomic development, and environmental stability (Odigwe et al., 2025). Groundwater refers to water stored beneath the Earth's surface within soil pores, sediment layers, and fractured rock formations. It serves as a critical alternative source of potable water, especially in regions where surface water is limited or unreliable, a condition increasingly common in many parts of Nigeria. Globally, groundwater scarcity underscores the need for its careful exploitation and sustainable management to support human populations and maintain social stability (Kasidi, 2017). The challenge is particularly acute in developing countries, where an estimated 67% of rural

inhabitants lack access to safe drinking water (Layade et al., 2017).

Nigeria possesses abundant groundwater reserves, along with other natural resources such as hydrocarbons and solid minerals. Access to potable water remains a fundamental necessity for public health and national development (Alile and Abraham, 2015). Surface water, comprising rivers, streams, lakes, and wetlands, is often concentrated in areas highly utilized by humans and animals (Bello and Makinde, 2007).

However, its availability fluctuates seasonally and is vulnerable to pollution, making groundwater exploration increasingly important. The characterization of groundwater systems relies on measurable hydrogeological parameters that can be investigated

using geophysical methods such as electrical resistivity, seismic surveys, and gravity techniques (Alile and Ehigiator, 2011). Among these, the electrical resistivity method is widely recognized for its effectiveness in delineating aquifer zones and assessing groundwater quality (Ismail Mohamaden, 2005; Asfahani, 2006; Bello and Makinde, 2007). Resistivity contrasts often reveal significant differences between competent bedrock and fractured or water-saturated zones (Leroux et al., 2007). Traditional resistivity techniques have often been limited in their ability to resolve lateral variations in subsurface resistivity. As a result, effective groundwater exploration in such complex geological settings necessitates an integrated geological and geophysical framework to improve the delineation of hydrogeologic units and strengthen the accuracy of aquifer characterization. Electrical resistivity methods remain widely applied globally for imaging shallow subsurface structures with the potential to host groundwater (Salami and Babafemi, 2020). These techniques provide accurate subsurface information at relatively low cost, making them valuable for preliminary hydrogeological assessments (El-Kaliouby and Abdalla, 2015). Despite previous drilling activities within the study area, multiple boreholes failed to yield productive water supplies, indicating the need for a more detailed geoelectrical investigation.

Therefore, this study aims to evaluate the groundwater potential of the Ugbowo area in Ovia North-East Local Government Area of Edo State using electrical resistivity methods. Specifically, the research seeks to characterize the subsurface geoelectric layers, interpret the lithological units associated with groundwater occurrence, and propose suitable drilling depths in relation to the delineated aquifer system.

MATERIALS AND METHODS

The equipment and materials utilized for this investigation included a measuring tape, stainless-steel electrodes, and reels of insulated cables, a hammer, a 12-V power battery, and a field-recording sheet. The primary geophysical instrument employed was the ABEM Signal Averaging System (SAS) 300C Terrameter, used for measuring electrical resistivity values. Additionally, a handheld Global Positioning System (GPS) device was used to obtain the geographic coordinates of the survey locations.

Study Location

The study was conducted in Ugbowo, a district within Benin City, located in the Ovia North-East Local Government Area (LGA) of Edo State, Nigeria. The survey site lies at latitude $6^{\circ} 28' 48.36''$ N and longitude $5^{\circ} 35' 17.16''$ E. Ovia North-East LGA is one of the eighteen administrative divisions of Edo State and was established in 1976 following the restructuring of district councils under the Local Government Law. Its

administrative headquarters is situated in Okada. The LGA covers an area of approximately 2,301 km² and recorded a population of 153,849 during the 2006 national census. The region experiences a favorable tropical climate, possesses fertile soils, and supports extensive agricultural activities. Geologically, the study area is underlain predominantly by the Benin Formation, which constitutes approximately 95% of the subsurface sequence. The Benin Formation is characterized by lateritic sand, gravel, cemented sandstone, sandy clay and fine-grained wet as its major lithologic units. The upper portion of this formation consists of reddish-to-reddish-brown lateritic materials, including massive indurated clay and sand. This lateritic horizon overlies a more friable sequence of pinkish to yellowish-white sands that are often gravelly or pebbly and interbedded with clayey layers. The thickness of the Benin Formation is estimated to be about 800 m beneath Benin City, increasing to as much as 1,830 m toward the coastal areas. Exposures of these units are visible in erosion-prone zones, quarry sites, and road cuttings within the region. Lignite streaks and wood fragments are also common within the sequence (Alile et al., 2011).

Field Data Acquisition

Field data acquisition was carried out within the University of Benin main campus, Ugbowo, using the ABEM Terrameter SAS 300C resistivity system and its standard field accessories. A Schlumberger electrode configuration was employed to collect Vertical Electrical Sounding (VES) data at a single sounding station. The survey was executed with a maximum electrode separation of 147 m along the designated VES traverse. The acquired VES data were processed and iteratively modeled to obtain the geoelectric parameters layer resistivity and thickness representing the subsurface stratification. These parameters were subsequently interpreted to infer lithological variations and delineate the aquifer units. Data processing and modeling were performed using Microsoft Excel and the IPI2WIN Resistivity Sounding Interpretation software. To enhance data quality, a signal averaging protocol was applied where necessary during field measurements. This approach enabled the terrameter to automatically acquire multiple consecutive readings and average them in real time, thereby minimizing ambient noise and improving the signal-to-noise ratio (Salami and Babafemi, 2020).

Data Processing

All acquired field data were first subjected to preliminary manual checks before being processed using advanced computer-based interpretation techniques. The apparent resistivity values recorded along each survey traverse were carefully organized and formatted to ensure full compatibility with the IPI2WIN resistivity sounding interpretation software. Interpretation of the Vertical

Electrical Sounding (VES) data was carried out using an inversion approach, in which an initial subsurface resistivity model is progressively adjusted to minimize the discrepancy between the measured field curve and the theoretical response. This iterative refinement process continues until an optimal model is achieved that satisfactorily satisfies both geophysical expectations and mathematical constraints (Loke et al., 2013). The Schlumberger electrode configuration was adopted for the VES survey. Field measurements of resistance (R) were obtained using the ABEM Terrameter SAS 300C, from which the apparent resistivity (ρ_a) was computed using the standard relation:

$$\rho_a = K \times R \tag{1}$$

Where:

K= Constant

K represents the geometric factor corresponding to the electrode spacing employed

R = Resistance in Ohms

$$K = \frac{((AB/2)^2 - (MN/2)^2)\pi}{2\left(\frac{MN}{2}\right)} \tag{2}$$

$$(1 + x)^n = 1 + \frac{nx}{1!} + \frac{n(n-1)x^2}{2!} + \dots \tag{3}$$

AB = Current electrode spacing in meters

MN = Potential electrode spacing in meters

The following sounding curve was acquired from the inversion process for vertical electrical sounding location as shown in Figure 1:

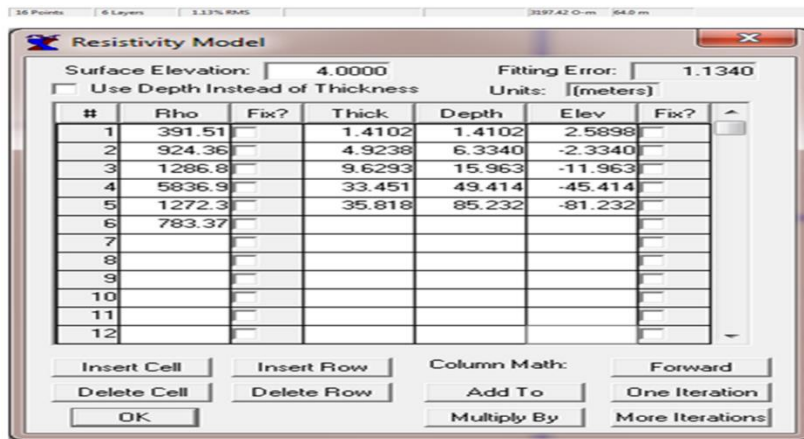


Figure 1: Interpretation of Vertical Electrical Sounding (VES)

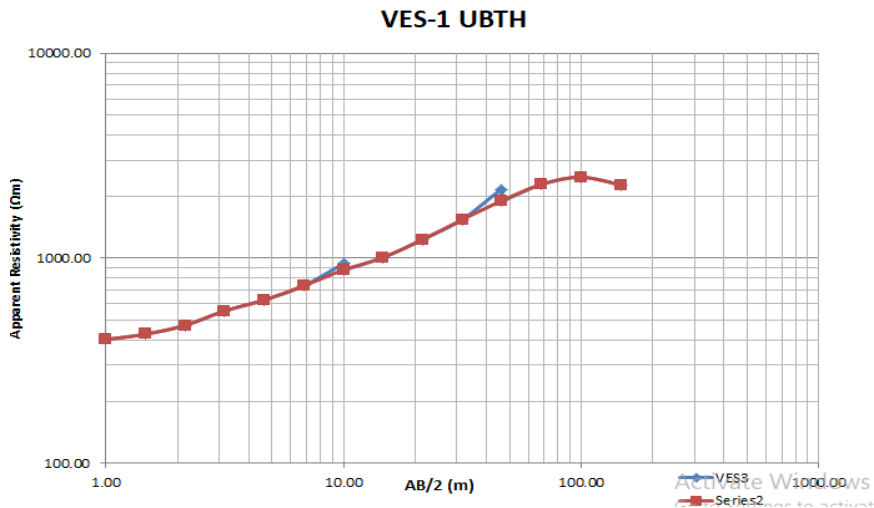


Figure 2: Interpretation of Vertical Electrical Sounding Curve

Borehole/Drillers Log of Ugbowo

The lithology is made up of laterite, different kinds of sand, gravel clay, etc.

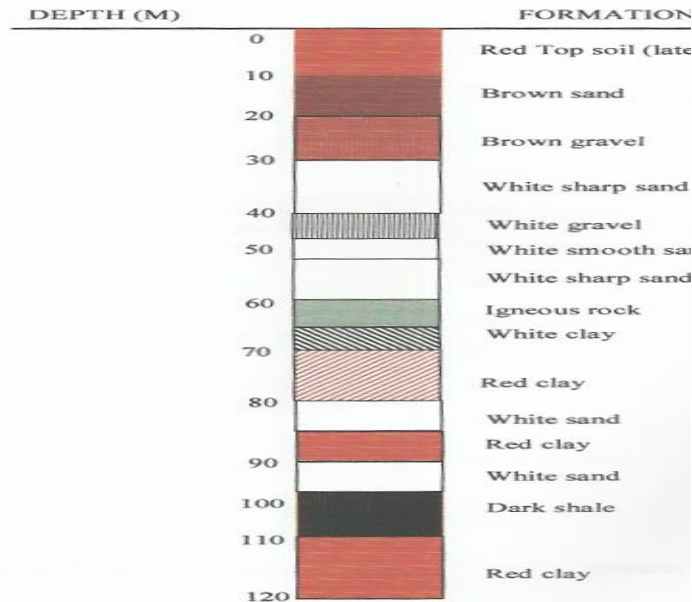


Figure 3: Edo State Urban Water Board (2012)

Table 1: Interpreted VES Results with Model Parameters and Lithology

VES	Layers	Resistivity(Ωm)	Thickness(m)	Depth (m)	Lithology
1	1	391.51	1.4102	1.4102	Lateritic /Wet Sand
	2	924.36	4.9238	6.3340	Dry Sand or Gravel
	3	1286.8	9.6293	15.963	Dry Sand or Gravel
	4	5836.9	33.451	49.414	Cemented sandstone or Gravel
	5	1272.3	35.818	85.232	Cemented sandstone or Gravel
	6	783.37	Undefined	Undefined	Potential Aquifer

RESULTS AND DISCUSSION

The interpreted Vertical Electrical Sounding (VES) curves were synthesized into a geoelectric section (Figure 1) and correlated with an existing borehole driller’s log from the study area. This integration revealed six distinct subsurface layers. The delineated lithologic units comprise lateritic, topsoil, cemented sandstone, dry sand, clay, and fine-to-coarse-grained sand bodies of varying thicknesses. The resistivity model indicates that the near-surface unit is a relatively high-resistivity layer, interpreted as lateritic overburden. The first layer of geoelectric section is at a depth of 1.4102m of thickness 1.4102m, has resistivity value of 391.51 Ωm . The formation lithology is interpreted as lateritic/wet sand, suggesting saturated overburden. The second layer is at a depth of 6.3340m of thickness 4.9238m, has resistivity value of 924.36 Ωm . The formation lithology is interpreted as dry sand or gravel, suggesting coarse sand. The third layer is at a depth of 15.963m of thickness 9.6293m, has resistivity value of 1286.8 Ωm . Lithology of the formation is interpreted as dry sand or gravel, which corresponds to unsaturated or coarse dry sand. The fourth layer is at a depth of 49.414m of thickness 33.451m, and has resistivity value of 5836.9 Ωm . Lithology of the formation is interpreted as cemented

sandstone or gravel, suggesting consolidated sand. The fifth layer is at a depth of 85.232m of thickness 35.818m, and has resistivity value of 1272.3 Ωm . Lithology of the formation is interpreted as cemented sandstone or gravel, suggesting consolidated sand. The sixth formation, which is undefined and has an undefined sand thickness, has a resistivity value of 783.37 Ωm , suggesting prospective water formation (aquiferous zone).

The results of this report are consistent with earlier investigations carried out in the area. For example, the uppermost layer, with an estimated resistivity of about 391 Ωm and interpreted as lateritic or wet sand, is consistent with the findings of Nwozor et al. (2025). Their studies characterize the surficial unit of the Benin Formation as a lateritic or ferruginized sandy overburden, typically exhibiting resistivity values in the range of 300–800 Ωm . This alignment reinforces the presence of comparable shallow, high-resistivity materials across the formation. The second and third layers, with resistivity values ranging from approximately 924 to 1286 Ωm and interpreted as dry coarse sand, are in agreement with reported resistivity ranges for unsaturated, moderately consolidated sands of the Benin Formation. Recent studies (Nwankwo et al., 2023) indicate that unsaturated sand layers typically exhibit resistivities between 800 and

2500 Ωm , which is consistent with this interpretation. The sixth layer, with a resistivity of approximately 783 Ωm , aligns with values characteristic of saturated, coarse-grained aquifer units within the Benin Formation. Recent hydrogeophysical studies (Ojeaga and Osauzou, 2025) report aquiferous hydrogeological units within the Benin formation exhibited resistivities from 516 Ωm to 2603 Ωm , supporting the interpretation of this layer as the main aquifer zone. Their analysis highlights significant heterogeneity in the geological composition, a finding that is consistent with the results of our study shown in Table 1.

CONCLUSION

The geoelectric investigation identified six distinct subsurface layers, including lateritic overburden, clay, gravel, sand units, and cemented sandstone. A deep aquifer was delineated at a resistivity of 783.37 Ωm at the vertical electrical sounding (VES) location, confirming a viable groundwater zone. The depth of this aquifer indicates that groundwater extraction is feasible, but only through deep boreholes rather than shallow wells. Overall, the study area demonstrates significant potential for sustainable groundwater development at greater depths. Based on these findings, it is recommended that drilling contractors utilize the results of this study prior to borehole installation to optimize groundwater exploration. Wider survey spreads are advised to allow geophysicists and geologists to investigate additional subsurface features, creating a comprehensive reference for buried structures in the area. The integration of multiple geophysical methods is encouraged to improve interpretation accuracy. Additionally, care should be taken when deploying cables from reels, and power sources should be fully charged with backup batteries available to ensure uninterrupted vertical electrical sounding operations.

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