

Research Article

Characteristic variation of soil resistivity using Vertical Electrical Sounding (VES) in a tropical zone: A case study of IGEM city, Alakia–Adegbayi, Ibadan, southwestern Nigeria

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Abstract

This study investigates the characteristic variation of soil resistivity in a tropical environment using the Vertical Electrical Sounding (VES) method. The study focuses on IGEM City, Alakia–Adegbayi, Ibadan. Electrical resistivity methods are widely used in groundwater exploration, engineering site characterization, and environmental investigations. The work discusses the geological setting, theoretical background, field procedures, interpretation techniques, and implications for groundwater development and foundation design. The results indicate that variations in resistivity are controlled by lithology, moisture content, porosity, clay content, and weathering intensity. Thick weathered and fractured zones constitute potential aquifer units while highly resistive basement rocks represent competent engineering materials. This investigates the variation of soil resistivity in a tropical environment using the Vertical Electrical Sounding (VES) method. The study focuses on IGEM City, Alakia–Adegbayi, Ibadan. Electrical resistivity methods are widely used in groundwater exploration, engineering site characterization, and environmental investigations. The work discusses the geological setting, theoretical background, field procedures, interpretation techniques, and implications for groundwater development and foundation design. The results indicate that variations in resistivity are controlled by lithology, moisture content, porosity, clay content, and weathering intensity. Thick weathered and fractured zones constitute potential aquifer units while highly resistive basement rocks represent competent engineering materials.

Keywords: Groudwater potential, Soil Resistivity, Vertical Electrical Sounding, Tropical Zone, and subsurface soil

1. Introduction

Water is one of the most important natural resources supporting human existence, agriculture, industry and environmental sustainability. Groundwater serves as a dependable source of potable water in many parts of Nigeria, particularly within crystalline basement terrains where surface water may be seasonal. The occurrence and movement of groundwater are controlled by geological and hydrogeological factors such as weathering, fracturing, porosity and permeability (Shiklomanov & Rodda, 2003).

In the last decade, the involvement of geophysical and geotechnical methods in civil engineering has become a promising approach. (Adepelumi, & Olorunfemi, 2000).

Geophysical methods in cooperation with geotechnical investigations are able to provide answers to those problems, and will even disclose several types of structures that typical use of geotechnical methods, like drills, or field investigation, might fail to detect (Soupios, et al 2007).

Electrical resistivity methods have become important tools in groundwater exploration because subsurface

materials exhibit different electrical properties. Vertical Electrical Sounding (VES) is commonly employed to determine the variation of resistivity with depth. In tropical environments, intense weathering produces complex subsurface conditions that require detailed geophysical characterization. Understanding soil resistivity variation is therefore essential for groundwater development, engineering construction and environmental management.

Several researchers have applied resistivity methods in basement complex terrains.

Telford et al. (1990) described resistivity surveying as one of the most effective methods for subsurface investigation. Reynolds, (2011) emphasized the usefulness of electrical methods in hydrogeological studies. Olorunfemi and Fasuyi, (1993) demonstrated that weathered and fractured basement zones often constitute productive aquifers in southwestern Nigeria. Kearey et al. (2002) noted that resistivity contrasts provide valuable information about lithological boundaries and groundwater occurrence.

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In tropical regions, prolonged weathering results in the formation of lateritic soils, clay horizons and weathered bedrock. These materials display contrasting resistivity values. Clay-rich materials generally exhibit low resistivity while fresh crystalline rocks possess high resistivity values. Consequently, resistivity surveys are capable of identifying favorable groundwater targets and competent foundation horizons. [10.5281/zenodo.22162605](https://doi.org/10.5281/zenodo.22162605)

The present study investigates the characteristics variation of subsurface soil resistivity using vertical electrical sounding (VES) technique in order to characterize the geoelectric layers and assess their implication for engineering and groundwater development at International Gosple Evangelical Mission (IGEM) City, Alakia-Adegayi, Ibadan, Southwestern Nigeria study with the aim of evaluating and investigating subsurface competence for engineering development. The study seeks to determine the geoelectric characteristics of subsurface soil formation, evaluate resistivity characteristics variation, identify competent foundation zones, and assess their engineering implication.

2. Location of the Study Area

IGEM City is located within the Alakia–Adegbayi area of Ibadan, Oyo State, Southwestern Nigeria. The area lies within the Nigerian Basement Complex composed mainly of migmatite-gneiss, quartzite, schist and granitic rocks. Climatic conditions are tropical with alternating wet and dry seasons. Weathering processes have produced significant overburden materials comprising laterite, sandy clay, clayey sand and weathered bedrock. The geology of the area exerts strong control on groundwater occurrence. Productive aquifers are commonly associated with weathered and fractured basement zones. The topography is generally undulating with local drainage channels influencing groundwater recharge.

Geological and Hydrogeological Setting of the study area

The Basement Complex terrain is characterized by low primary porosity. Groundwater storage therefore depends largely on secondary structures such as fractures, joints and weathered zones. Hydrogeological investigations in southwestern Nigeria have demonstrated that thick weathered layers overlying fractured bedrock are favorable targets for borehole development.

The weathering profile typically consists of topsoil, lateritic horizon, clayey weathered layer, partially weathered basement and fresh basement. Each layer exhibits distinct electrical properties which can be mapped using VES techniques.

3. Materials and Methods

3.1. Methods

Four VES stations were occupied using the Schlumberger array configuration. Current electrodes were progressively expanded while potential electrodes remained relatively close to the survey center. Apparent resistivity values were calculated from measured resistance and geometric factors.

Field data were plotted on log-log graphs and interpreted through partial curve matching and computer-assisted inversion. Layer resistivities and thicknesses were estimated from the interpreted curves. Geoelectric sections were subsequently developed to describe subsurface conditions. Electrical resistivity represents the resistance of earth materials to the flow of electrical current. Ohm's law provides the basis for resistivity measurements. The apparent resistivity obtained during field measurements depends on the geometry of the electrode array and the resistivity distribution of subsurface materials. Low resistivity values are often associated with clay-rich formations and water-saturated materials. Moderate resistivity values may indicate weathered formations capable of storing groundwater. High resistivity values generally correspond to fresh basement rocks or dry competent materials.

3.2. Geophysical Investigation

The geophysical investigation was carried out using surface electrical resistivity method Using ABM Tera-metre.

Schlumberger Configuration: In this, the current and potential pairs of electrodes have a common mid-point but the distance between adjacent electrodes differs. This is shown in Figure 1

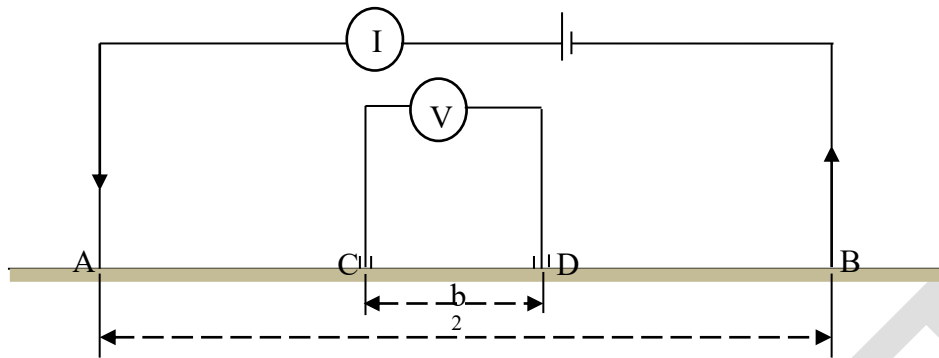


Figure 1. A typical Schlumberger electrode configuration.

From Figure 1, $CD \leq AB / 5$

Substitution of this condition into Equation (1) yields;

$$\rho = \frac{\Delta V}{I} \left[\frac{2\pi}{\left(\frac{1}{r_{AC}} - \frac{1}{r_{CB}}\right) - \left(\frac{1}{r_{AD}} - \frac{1}{r_{DB}}\right)} \right] \quad (1)$$

Hence,

$$\rho_a = \pi \frac{V}{I} \frac{[4a^2 - b^2]}{4b} \quad (2)$$

$$G = \pi \frac{[4a^2 - b^2]}{4b} \quad (3)$$

The techniques employed in order to meet the objectives of the investigation were:

- (1) Horizontal Profiling (HP) using Wenner electrode configuration and
- (2) The Vertical Electrical Sounding (VES) using the Half Schlumberger {Hummel} electrode configuration. For the VES, the Schlumberger electrode configuration was adopted. An ABM Tera-metre was used to carry-out field measurement of resistance (R) from which apparent resistivity (ρ_a) was calculated by the relation.

3.3. Electrical Resistivity Theory

The resistivity of a material is defined as the resistance in ohms between the opposite faces of a unit cube of the material. For a conducting cylinder, the resistance R of the material with length dL and cross-sectional area dA is given by,

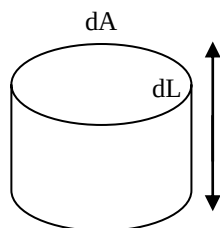


Figure 2. Cyclical conductivity of ER

$$R \propto \frac{L}{A} \quad (4)$$

$$dR = \rho \frac{dL}{dA}$$

ρ is the resistivity of the material in ohm-m. The inverse of resistivity is termed conductivity [unit is Siemens(S) per metre; $1\text{Sm}^{-1} = 1\text{ohm}^{-1}\text{m}^{-1}$].

Electric current passes through a material by one of the three different modes.

$P_a = KR$ Where R= Resistance in ohms

$$K = \rho \frac{(AB/2)^2 - (MN/2)^2}{2MN} \quad (4)$$

And AB= Current electrode spacing in meters.

MN=potential electrode spacing in meters

K= inverse of electrical resistivity (apparent resistivity)

$\pi = 3.142$

4. Results

Interpretation of VES data reveals multiple geoelectric layers. The topsoil exhibits variable resistivity due to differences in soil composition and moisture conditions. The weathered layer generally displays moderate resistivity values and constitutes the principal aquifer horizon. Beneath this layer lies a partially weathered or fractured basement zone that may significantly enhance groundwater productivity.

All VES data plotted on a logarithmic graph with current electrode separation, AB/2 on the abscissa and the apparent resistivity, ρ_a , on the ordinate. Interpretation of the VES curve was carried out using the methods stated below.

(i) Visual curve Inspection.

(ii) Partial survey marching using master curve for VES over layered structure.

(iii) Comparison with previous works of one point that was isolated for VES through HP, one of those points appears most probable to meet the requirement for which the investigation was conducted at the site.

The electrical sound curves below have shown that the study area is underlain by three distinct layers in all parts while Table: 1 gives the summary of the geoelectric parameters and the geologic interpretation.

Figure 3. VES 1

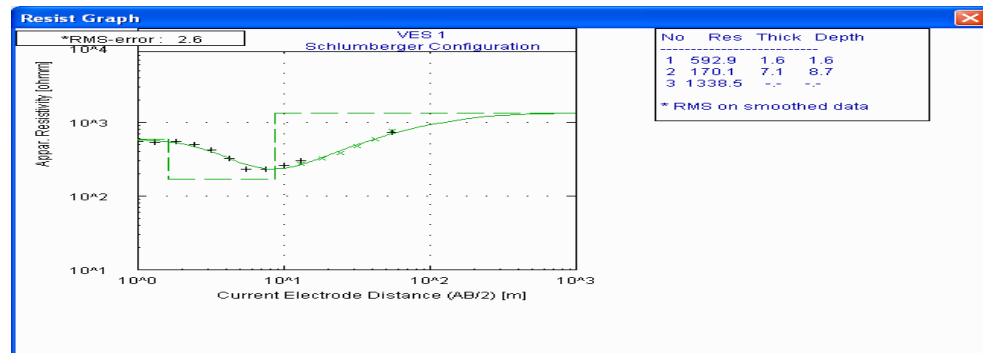


Figure 3. Vertical electrical sounding (VES) 1. Profile obtained using the Schlumberger electrode configuration, showing the variation of apparent resistivity with current-electrode spacing ($AB/2$) and the interpreted three-layer subsurface model.

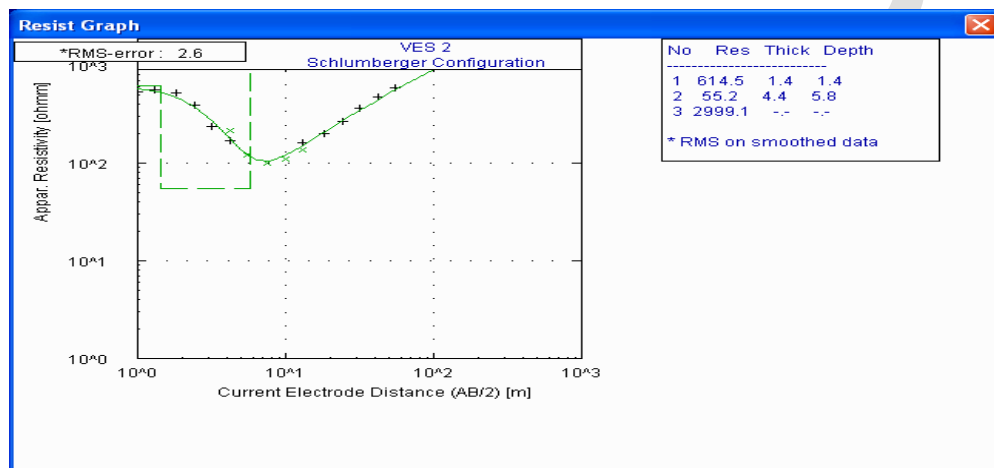


Figure 4. Vertical electrical sounding (VES) 2. Profile obtained using the Schlumberger electrode configuration, showing the variation of apparent resistivity with current-electrode spacing ($AB/2$) and the interpreted three-layer subsurface model.

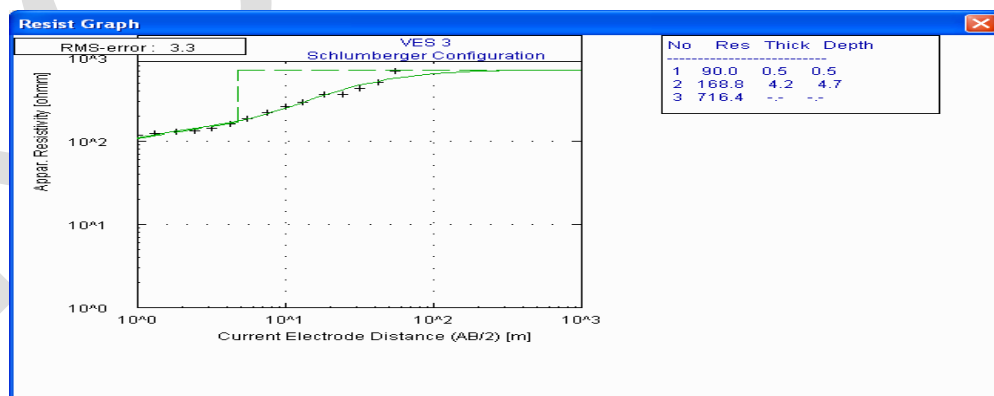


Figure 5. Vertical electrical sounding (VES) 3. Profile obtained using the Schlumberger electrode configuration, showing the variation of apparent resistivity with current-electrode spacing ($AB/2$) and the interpreted three-layer subsurface model.

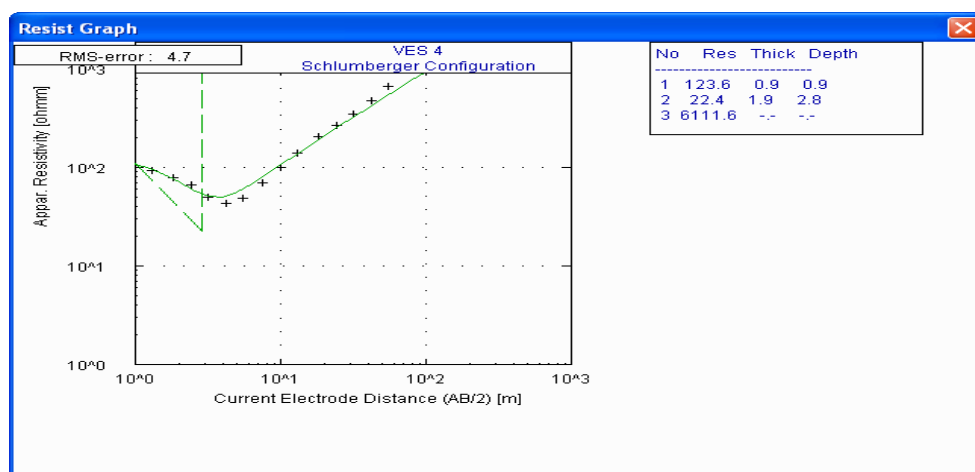


Figure 6. Vertical electrical sounding (VES) 4. Profile obtained using the Schlumberger Electrode configuration, showing the variation of apparent resistivity with current-electrode spacing (AB/2) and the interpreted three-layer subsurface model.

Table 1: Model Interpretation of Layers for the sounding data.

VES Station	Layers	Resistivity (Ohm-m)	Thickness (m)	Depth to Bedrock (m)	Curve type	Probable Lithology
1	1	593	1.6	8.7	H	Topsoil
	2	170	7.1			Weathered
	3	1339	-			Basement
2	1	615	1.4	5.8	H	Fresh
	2	55	4.4			Basement
	3	2999	-			Topsoil
3	1	90	0.5	4.7	A	Weathered
	2	168	4.2			Basement
	3	719	-			Fresh
4	1	124	0.9	2.8	H	Basement
	2	23	1.9			Topsoil
	3	6111	-			Weathered
						Basement
						Fresh
						Basement

Fresh basement rocks are characterized by high resistivity values. Spatial variation in resistivity reflects changes in lithology, weathering intensity, groundwater saturation and structural conditions. The interpreted results indicate that zones containing thick weathered and fractured layers possess higher groundwater potential than areas dominated by shallow basement rocks.

Interpretation of VES data reveals multiple geoelectric layers. The topsoil exhibits variable resistivity due to differences in soil composition and moisture conditions. The

weathered layer generally displays moderate resistivity values and constitutes the principal aquifer horizon. Beneath this layer lies a partially weathered or fractured basement zone that may significantly enhance groundwater productivity.

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layers possess higher groundwater potential than areas dominated by shallow basement rocks. The Spatial Variation of Soil Resistivity Within IGEM City

The apparent resistivity values obtained from the four Vertical Electrical Sounding Stations indicates significant lateral and Vertical variations within the study area. These variations reflect differences in lithology moisture content, clay fraction, weathering intensity and structural characteristics of the underlying basement rocks.

VES 01 recorded H-type curve relatively high resistivity value at shallow depths followed by a progressive decrease with increasing electrode spacing. This response suggests the presence of resistive topsoil overlying a weathering layer capable of groundwater accumulation. The gradual decline in resistivity indicates increasing moisture content within the subsurface layers. Such a geoelectric sequence is characteristic of basement complex terrains where groundwater accumulation occurs within the weathered horizon (Olorunfemi & Olorunniwo, 1985).

VES 02 exhibit a classical H- type geoelectric curve characterized by a conductive intermediate layer bounded by resistive horizons. Such a geoelectric configuration is widely recognized as hydrogeological condition in basement complex terrains because groundwater storage commonly occurs within the weathered horizon (Olorunfemi & Olorunniwo, 1985). Groundwater-bearing horizon depending on its thickness and the degree of saturation (Reynolds, 2011).

VES 03 displayed A-type curve comparatively high resistivity values throughout much of the sounding depth, suggesting the dominance of lateritic materials and shallow basement rock. This variation are consistent with previous investigation conducted within the Nigeria Basement Complex terrain where groundwater occurrence is primarily controlled by weathered and fractured zone ((Reynolds, 1990., (Olorunfemi & Olorunniwo, 1985). The relatively limited development of conductive weathered materials implies lower groundwater potential than that observed at VES 01 and VES 02.

VES 04 H- type curve, revealed a decrease in apparent resistivity followed by a substantial increase at greater depth. This behavior indicates the presence of a conductive weathered layer overlying competent basement rock. The interpreted sequence is typical of tropical weathered profile developed over crystalline rocks.

4. Discussion

The observed resistivity variations are consistent with previous studies conducted within tropical basement terrains of Nigeria. The relationship between resistivity and hydrogeological conditions highlights the effectiveness of VES as a reconnaissance tool for groundwater exploration. Resistivity contrasts allow the differentiation of lithological units and provide insight into aquifer geometry the interpreted VES result characteristics revealed multilayered of subsurface conditions typical of Basement complex terrains in Southwestern Nigeria (Reynolds, 2011). the geoelectric sections generally indicate the presence of Topsoil, Weathered layer, partially Weathered or fracture Basement, and Fresh Basement rock.

The results further demonstrate that weathering processes play a critical role in determining subsurface electrical characteristics. Tropical weathering produces heterogeneous materials whose resistivity values vary significantly over short distances. Such variations underscore the importance of detailed geophysical surveys during site investigations. The topsoil layer exhibits varying resistivity values resulting from differences in soil composition, moisture content, and degree of compaction. according to Reynolds (2011), topsoil resistivity is strongly influenced by seasonal moisture variation and clay content.

The observed resistivity variations are consistent with previous studies conducted within tropical basement terrains of Nigeria. The relationship between resistivity and hydrogeological conditions highlights the effectiveness of VES as a reconnaissance tool for groundwater exploration. Resistivity contrasts allow the differentiation of lithological units and provide insight into aquifer geometry. The weathered layer demonstrates significant resistivity variation across the study area, hence, Olorunfemi et al. (1999) reported that low-resistivity Weathered zones are commonly associated with clay-rich materials, whereas moderate resistivity values often indicate sandy clay and lateritic formations with better engineering competence.

The results further demonstrate that weathering processes play a critical role in determining subsurface electrical characteristics. Tropical weathering produces heterogeneous materials whose resistivity values vary significantly over short distances. Such variations underscore the importance of detailed geophysical surveys during site investigations. The fractured and partially weathered basement units display intermediate resistivity values, similar observation have been reported in foundation investigation within the Nigerian Basement Complex terrain (Olorunfemi & Olorunniwo 1985).

Fresh basement rock is generally characterized by high resistivity values due to its compact nature and low porosity (Telford et al., 1990).

5. Conclusion

The study demonstrates the usefulness of Vertical Electrical Sounding in evaluating soil resistivity variation within tropical environments. The study identified Variations in resistivity associated with topsoil, weathered layers, fracture basement, and fresh basement formations. The observed resistivity contrasts reflect differences in lithology, moisture content, weathered intensity, clay concentration, and groundwater occurrence. Weathering and Thick weathered and fractured zones represent favorable groundwater targets, whereas highly resistive basement rocks are suitable for engineering foundations.

The findings provide valuable information for groundwater development, urban planning and infrastructure design within IGEM City and surrounding areas.

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Abbreviations

VES Vertical Eletctrical Sounding

IGEM International Gospel Evangelical Ministry

Author Contributions

Sheu Isiaq Owoyemi: Conceptualization, Investigations, Validation, Writing- Original Draft, Review & Editing

Conflicts of Interest

The author(s) declare that they have no known competing financial interests, professional affiliations or personal relationships that could have appeared to influence the work reported in this paper.

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