GEOPHYSICAL STUDIES OF SHONGA FOR THE ASSESSMENT OF GROUNDWATER POTENTIALS

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NATIONAL DIPLOMA (HND),

IN PHYSICS ELECTRONIC

DECLARATION

Hereby declared that:

- This thesis has been prepared by us and that it is a record of our own research efforts carried out under the supervision of Mr. A.M.A Bello;
- To the best of our knowledge, it has neither been carried out nor presented in any other institution of higher learning for a certificate:
- All quotations and or citations and sources of information have been well-acknowledged by means of reference

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DEDICATION

We dedicate our project to Almighty God the giver of knowledge and our parents.

CERTIFICATION

This is to certify that this project work has been written by **SULE MOSES, ENIJUNI JOSEPH OLAWALE , SOLIU OPEYEMI FATIMOH. EKUNDAYO HALEEMAH ANITA**

and has been read and approved as meeting the parts of the requirements for the award of Higher National Diploma (HND) in Science Laboratory technology Department, Institute of Applied Sciences, Kwara State Polytechnic.

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ABSTRACT

This study focuses on the geophysical investigation of Shonga, located in Kwara State, Nigeria, with the primary objective of assessing the groundwater potentials of the area. Given the growing demand for potable water due to increasing population and agricultural activities, the need for sustainable groundwater exploration has become critical. The research employed the Vertical Electrical Sounding (VES) method using the Schlumberger electrode configuration to map subsurface lithological variations and identify aquiferous zones that could support groundwater development.

A total of several VES stations were occupied across the study area. The field data obtained were processed and interpreted using standard curve-matching techniques and computer-assisted modeling to generate geoelectric sections. The interpretation revealed the presence of four distinct geoelectric layers: topsoil, weathered layer, fractured basement, and fresh basement. The topsoil consists mainly of sandy clay and laterite with variable thicknesses. Beneath this layer lies the weathered layer, which, in some locations, is highly saturated and constitutes a significant groundwater-bearing formation. The fractured basement, where present, further enhances the groundwater potential due to its secondary porosity and permeability. The fresh basement is typically resistive and non-water-bearing.

The resistivity values of the weathered and fractured layers ranged between low to moderate, indicating zones of good groundwater potential, especially where the combined thickness of these layers is considerable. Longitudinal conductance values also aided in identifying areas that offer natural protection against contamination, enhancing the reliability of these zones for groundwater exploitation. The study recommends that boreholes should be sited in locations where both the weathered layer and fractured basement are well developed, as these zones present the most promising conditions for sustainable water supply.

In conclusion, the geophysical survey has provided valuable insights into the subsurface structure and groundwater potential of Shonga. The results will serve as a scientific guide for future groundwater development projects and contribute to improved water resource management in the area. This work underscores the importance of geophysical methods in hydrogeological investigations, particularly in basement complex terrains like Shonga.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Motivation

Groundwater remains an indispensable natural resource that underpins the socio-economic development of both urban and rural populations. It serves as a primary source of water for domestic use, agriculture, industry, and public health. This is particularly true in many developing countries like Nigeria, where centralized water supply systems are often insufficient or poorly maintained. In such contexts, groundwater becomes the most accessible and reliable alternative, especially in rural and peri-urban communities that are underserved by conventional infrastructure[1-4].

In Nigeria, the Sustainable Urban and Rural Water Supply, Sanitation and Hygiene (SURWASH) program[1], spearheaded by the Federal Government in partnership with international development partners, is designed to bridge critical gaps in water resource management. The program aims to expand access to safe and sustainable water supply, improve sanitation, and promote hygiene practices in both urban and rural areas. A major emphasis of SURWASH is placed on evidence-based decision-making, where scientific and technological tools are employed to guide the development of resilient water systems.

Within the context of Kwara State, and more specifically the Edu Local Government Area which includes Shonga and Tsaragi**,** the relevance of SURWASH becomes even more pronounced. These areas are experiencing rapid demographic growth, shifting rainfall patterns, and increasing occurrences of seasonal water scarcity. These challenges have compounded the pressure on existing water sources, necessitating the deployment of advanced groundwater exploration strategies to meet rising demand sustainably. SURWASH's holistic approach aligns with these needs by promoting the integration of hydrogeological investigations and geophysical surveys into local water planning and implementation efforts.

Among the most effective geophysical techniques for groundwater investigation under SURWASH is the electrical resistivity method**,** particularly Vertical Electrical Sounding (VES)**.** This method involves injecting electric current into the ground and measuring the resulting potential difference to determine subsurface resistivity. The resistivity values obtained are indicative of the lithological composition and moisture content of subsurface materials. VES is especially valuable for identifying aquifer horizons, estimating their depth and thickness, and evaluating their potential to yield groundwater.

A significant enhancement to the interpretation of VES data is the use of Dar Zarrouk parameters**,** which include longitudinal conductance (S) and transverse resistance (R)**.** These parameters are derived from resistivity and thickness data of individual geoelectric layers. Longitudinal conductance is calculated as the sum of the ratio of layer thickness to resistivity ($S = \sum(h/\rho)$), and it is useful for assessing the protective capacity of the overburden above an aquifer. High conductance values generally imply better protection against surface contamination, particularly from anthropogenic sources. Transverse resistance ($T = \sum(h \times \rho)$), on the other hand, reflects the transmissivity potential of a layer—higher values typically indicate zones that can store and transmit significant quantities of groundwater[5-9].

The application of these parameters within the SURWASH framework offers multiple benefits. Firstly, it enhances the reliability of aquifer delineation by providing quantitative measures of subsurface conditions. Secondly, it supports risk assessments related to groundwater vulnerability and recharge sustainability. Thirdly, it contributes to optimal borehole siting, thereby reducing the incidence of failed or low-yielding wells—an issue that has historically plagued rural water development projects.

Furthermore, the findings of this investigation are intended to serve as a technical reference for stakeholders involved in water resource development. This includes government agencies, non-governmental organizations (NGOs), water resource engineers, hydrogeologists, and community development planners. By embedding geophysical data into the SURWASH implementation process, these actors can make informed decisions that maximize impact and cost-effectiveness[1].

In addition to supporting infrastructure development, this study aligns with the capacity-building goals of SURWASH by demonstrating the utility of scientific methods in addressing water challenges. It underscores the importance of data acquisition, interpretation, and knowledge dissemination in enhancing water governance at the local level. Moreover, it encourages cross-sectoral collaboration, integrating insights from geology, engineering, public health, and environmental science.

Ultimately, the integration of geophysical studies—especially those focused on electrical resistivity—within the SURWASH framework marks a significant step toward sustainable groundwater development in Kwara State. By generating actionable knowledge on subsurface conditions in Shonga, this project contributes directly to the realization of SURWASH objectives, which include universal access to safe water, improved sanitation, and the promotion of hygiene practices that uphold public health and socio-economic resilience.

1.2 Properties of Geophysical Anomalies

Geophysical anomalies are deviations in physical properties of subsurface materials that differ from expected background values. These anomalies often indicate variations in lithology, moisture content, mineralization, or structural features such as faults and fractures.

In resistivity surveys, anomalies arise from the contrasts in electrical resistivity between geological units. For groundwater studies, such contrasts can be used to infer saturated zones, weathered/fractured basement zones, clayey or sandy layers, and the boundaries between aquifers and aquitards. The size, shape, depth, and magnitude of anomalies are interpreted in the context of the subsurface environment.

Resistivity anomalies are influenced by:

- Lithology (e.g., clay vs. sand vs. rock)
- Porosity and permeability
- Degree of water saturation
- Presence of conductive minerals (e.g., iron oxides, sulfides)

Understanding and correctly interpreting these anomalies is crucial in estimating aquifer parameters and determining viable drilling points for boreholes

1.3 Aim and Objectives of the Study

1.3.1 Aim:

The primary aim of this project was to interpret collected VES Data in other to access the Groundwater potentials of Shonga within Edu local Government area of Kwara state Nigeria.

1.3.2 Objectives:

In furtherance of the above stated Aim of this work, the specific objectives were;

1. Acquire VES data using the Schlumberger configuration across selected locations in Shonga;
2. Analyze subsurface resistivity distributions and delineate aquifer zones;
3. Calculate longitudinal conductance and transverse resistance for various layers;
4. Evaluate the protective capacity of overburden layers against contamination;
5. Determine aquifer transmissivity using geoelectric data; and
6. Identify suitable locations for groundwater development control and management.

CHAPTER TWO

LITERATURE REVIEW

2.1 Review of Previous Studies

Over the past few decades, the increasing demand for reliable groundwater resources in Nigeria has led to a growing reliance on geophysical methods—particularly electrical resistivity techniques—as essential tools in groundwater exploration. These techniques offer a non-invasive, cost-effective, and scientifically robust means of investigating the subsurface for water-bearing formations without the need for extensive drilling or excavation. As both urban expansion and rural water scarcity intensify across the country, resistivity-based geophysical surveys have become central to effective borehole siting, aquifer mapping, and hydrogeological assessments (Bello, Ajayi and Makinde, 1997; Bello, Sambo and Makinde 2005).

In geological settings dominated by Basement Complex rocks**,** which characterize a significant portion of Nigeria's terrain, groundwater occurrence is typically confined to weathered and fractured zones. In such terrains, electrical resistivity methods have proven particularly valuable due to their sensitivity to moisture content, fracture density, and lithological variation. The studies by Olorunfemi and Fasuyi (1993) Bello , Makinde and Coker (2010) stands out as a landmark contribution in this domain. Their work, which focused on the interpretation of Vertical Electrical Sounding (VES) data in Basement Complex terrain, demonstrated that low-resistivity zones often correspond to weathered or fractured rock layers**,** which serve as conduits and reservoirs for groundwater. They established that combining geophysical resistivity data with geomorphological and geological information enhances the identification of potential aquifer zones, thus improving the success rate of borehole drilling projects.

Building upon this foundation, Akinlalu et al. **(**2018**)** conducted further research in parts of southwestern Nigeria, employing the Schlumberger array configuration of VES to characterize groundwater potentials in rural settlements. Their study reinforced the notion that integrating electrical resistivity results with borehole lithologs and hydrogeological information not only improves interpretative accuracy but also enhances the reliability of aquifer delineation. They reported that zones with intermediate to low resistivity, typically between 30 and 150 Ω·m**,** were consistently associated with saturated layers of lateritic soils, clayey sands, and weathered bedrock—conditions favorable for sustainable groundwater abstraction. The study concluded that resistivity methods remain an indispensable approach for effective water resource development, particularly in locations where geological heterogeneity complicates direct aquifer detection.

In sedimentary terrains—such as that found in Shonga within Edu Local Government Area, Kwara State—the hydrogeological context differs significantly. Here, the occurrence of groundwater is more closely related to variations in sediment composition, grain size, and saturation levels**.** These settings tend to exhibit broader, more continuous aquifer layers compared to the discrete and localized aquifers of Basement Complex areas. The study by Olayinka and Olorunfemi (1994) is especially relevant to this project, as it focused on the application of electrical resistivity techniques in sedimentary environments. Using a combination of VES and lateral profiling, their research revealed that resistivity contrasts could effectively delineate saturated zones, clay-rich impermeable layers, and stratigraphic discontinuities**.** Their interpretations were validated through borehole logs and hydrogeological ground-truthing, affirming that resistivity anomalies corresponded closely with lithological changes and water-bearing strata.

Bello et al (2005), Olayinka (1996), Oladapo et al (2004) and their team emphasized the importance of multi-parameter analysis**,** recommending the incorporation of Dar Zarrouk parameters such as longitudinal conductance and transverse resistance for more refined interpretations of aquifer characteristics. Their work highlighted that low longitudinal conductance values may signal vulnerability to surface contamination due to insufficient protective overburden, while high transverse resistance values are indicative of aquifers with good transmissivity and storage potential.

(iba, 1998 and Ayoba, 2005, Bayewu and Olorunfemi, 2011) Several other studies across Nigeria have corroborated the utility of the electrical resistivity method in both sedimentary and crystalline environments. For example:

Abiola et al. (2011) conducted VES surveys in north-central Nigeria and demonstrated that combining geoelectric sections with existing geological maps allowed for accurate aquifer zonation.

Ako and Olorunfemi (1989) provided early evidence that resistivity methods could be successfully adapted to rural water supply schemes in challenging terrains, leading to improved water access in underserved areas.

Olayinka and Olorunfemi (1992) developed methodologies for interpreting VES data using computer modeling and curve-matching techniques, which have since been widely adopted in hydrogeophysical studies.

The synthesis of these previous investigations underscores a few central themes:

1. **Electrical resistivity methods are adaptable across diverse geological settings**, from fractured basement to stratified sedimentary basins.
2. **Integration of geophysical data with geological and hydrogeological knowledge** enhances interpretation accuracy.
3. **Resistivity values are diagnostic of groundwater potential**, especially when interpreted through the lens of known aquifer properties, geological context, and structural controls.
4. **Dar Zarrouk parameters offer quantitative insights** into aquifer protection and productivity, and their adoption in modern studies is critical for sustainable groundwater development.

2.2 Concept of Electrical Resistivity in Hydrogeological

Surveys The electrical resistivity technique is predicated on measuring how subsurface materials resist the flow of electrical current. Since geological layers differ in moisture content and composition, each exhibits a unique resistivity response.

In hydrogeological investigations, materials such as saturated sands and gravels exhibit low resistivity due to the presence of conductive groundwater, while dry or compact rocks like granite typically register high resistivity values. Using electrodes to introduce current and measure voltage differences, the resistivity distribution of the underground layers can be mapped.

This method is especially effective in identifying water-bearing formations, with electrode spacing adjustments allowing for modeling of depth, thickness, and extent of aquifers.

2.3 Electrical Resistivity Surveys in Hydrogeological Investigations

The electrical resistivity method is a geophysical technique widely applied in subsurface investigations, particularly in the context of groundwater exploration. It is based on the principle that different earth materials exhibit varying abilities to resist the flow of electric current. This variation, known as resistivity, is influenced by the physical and chemical properties of subsurface formations, including mineral composition, porosity, water content, salinity, saturation level, and degree of compaction.

In practical terms, the method involves introducing an electric current into the ground using a pair of current electrodes and measuring the resulting potential difference across another pair of potential electrodes. The measured values are then used to calculate the apparent resistivity of the subsurface, which is an averaged measure of the electrical properties encountered along the current path. These values are plotted and analyzed to interpret the underlying lithological structure and fluid content, thereby providing insight into the location and extent of aquifer systems.

2.4 Role of Resistivity in Groundwater Identification

From a hydrogeological perspective, the resistivity of a subsurface material is directly correlated with its water-bearing capacity. For example:

Saturated sands, gravels, and weathered/fractured basement rocks usually present low resistivity values (generally less than 100 $\Omega \cdot m$) because water—especially when containing dissolved ions—enhances electrical conductivity.

Dry rocks, crystalline basement, or unfractured bedrock tend to exhibit high resistivity values (often exceeding 1000 $\Omega \cdot m$) due to the absence of fluid pathways and poor conductivity.

Thus, by mapping the spatial distribution of resistivity values, geophysicists can infer the geometry, thickness, and depth of groundwater-bearing formations. Additionally, this method helps detect aquifer boundaries, impermeable clay layers, weathered zones, and structural discontinuities like fractures or faults that may influence groundwater flow.

2.5 Electrode Spacing and Depth of Investigation

- A key advantage of electrical resistivity surveys is the flexibility to adjust electrode spacing. Increasing the distance between current and potential electrodes allows deeper penetration into the ground, enabling the detection of aquifers at various depths. This principle underlies the use of Vertical Electrical Sounding (VES), which is commonly used in groundwater studies to assess vertical resistivity variation with depth.
- Different electrode configurations—such as Wenner, Schlumberger, Dipole-Dipole, and Pole-Dipole arrays—offer various sensitivities and resolution characteristics, making them suitable for different survey goals, including horizontal profiling and vertical exploration.

2.6 Theory And Principle of Geophysical surveys using vertical Electrical Soundings (VES) Method

Understanding how current flows into the ground from a surface electrode is fundamental to the theory of resistivity surveying. When an electric current is injected into the earth through a single electrode typically paired with a distant return electrode, it disperses radially through the surrounding materials (figure 2.1).

The flow pattern Is governed by the conductivity of the medium:

In homogeneous isotropic ground, the current spreads uniformly in all directions, creating concentric hemispherical equipotential surfaces and radial current flow lines.

In heterogeneous media, the current paths become distorted as they encounter materials with varying resistivity.

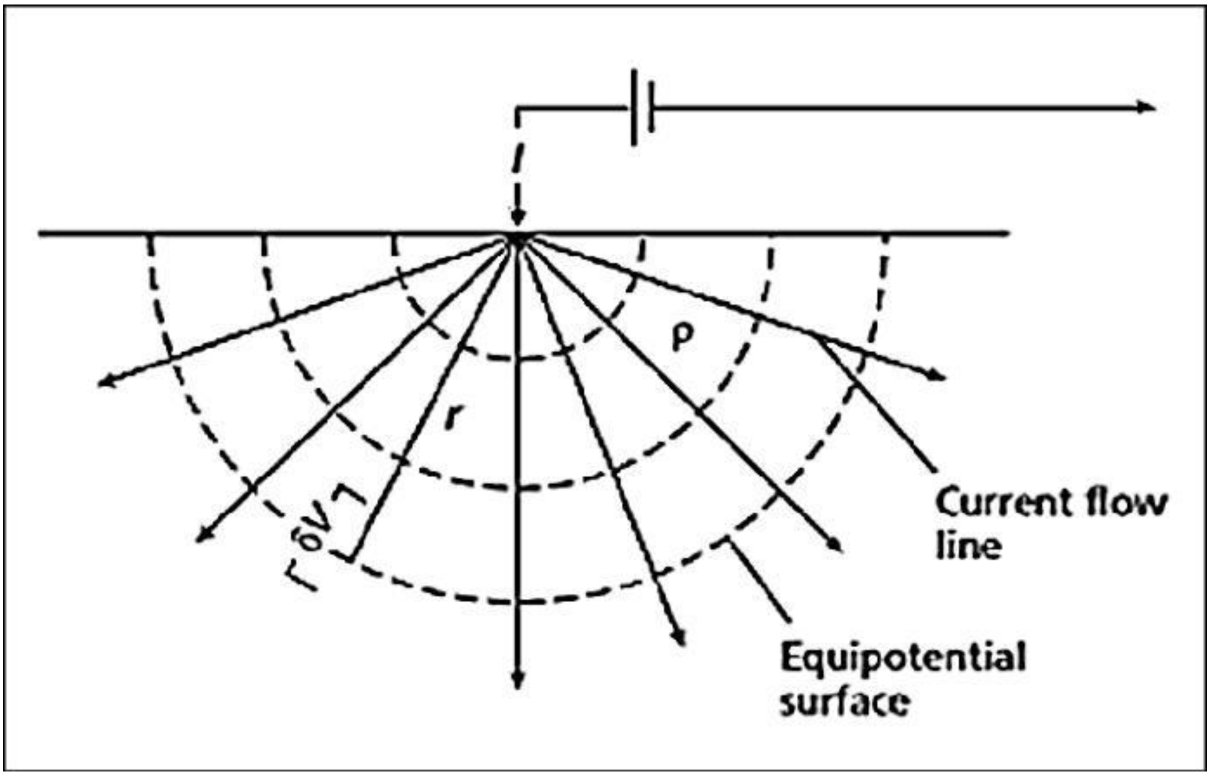
The potential (voltage) at a point in the ground due to a point current source is inversely proportional to the distance from the source. Mathematically, for a point electrode on the surface of a uniform half-space, the electric potential at a distance from the electrode is given by:

This relationship as provided in equation (2.1) forms the foundation for interpreting voltage readings in terms of subsurface resistivity.

$$V = \frac{\rho I}{2\pi r}$$

Where:

- V = potential (volts)
- ρ = resistivity of the ground ($\Omega \cdot m$)
- I = current injected (amperes)
- r = radial distance from the current electrode (meters)



Earth Surface (Ground)

Figure 2.1 Schemation of VES Method

- [C1]: Current injection electrode
- Lines spreading out: Indicate radial current paths through the subsurface
- Horizontal dashed line: Earth's surface
- Flow behavior: Depends on subsurface resistivity distribution

In practice, a second electrode (C2) is placed far away to complete the current loop, and two additional electrodes are used to measure the potential difference created by the flowing current.

The electrical resistivity method, with its robust theoretical foundation and practical flexibility, remains a powerful tool in groundwater exploration. By analyzing how current propagates through the subsurface and interpreting resistivity contrasts, it becomes possible to identify aquifer locations, estimate their capacities, and support water resource management. The technique's compatibility with hydrogeological objectives—especially under initiatives like SURWASH—makes it indispensable for addressing the challenges of sustainable water supply in both urban and rural contexts.

2.7 Electrode Configuration Types

Electrode arrangements refer to how current and potential electrodes are positioned during surveys. The configuration influences data accuracy, penetration depth, and overall resolution.

Various configurations serve specific purposes. These include Wenner, Schlumberger, Pole-Dipole, Dipole-Dipole, Half-Schlumberger, and Lateral arrays. Selection depends on depth of interest, terrain condition, and expected geological structures. The geometric factor for each setup plays a vital role in apparent resistivity computations.

2.7.1 Vertical Electrical Sounding (VES)

VES focuses on how resistivity varies with depth. Current electrode spacing is expanded progressively to probe deeper layers.

Data from VES are plotted as apparent resistivity against spacing, typically on log-log scales. Curve analysis and inversion software help identify layer properties such as depth, thickness, and resistivity.

This approach is especially valuable in Shonga and Tsaragi-Edu areas for pinpointing aquifers based on resistivity contrast, facilitating efficient borehole siting and groundwater potential assessment

2.7.2 Wenner Configuration

The Wenner array is simple and widely employed. It involves four equally spaced electrodes, where the outer pair injects current and the inner pair measures the voltage.

Its advantages include heightened sensitivity to vertical resistivity variations and ease of field setup. Its main drawback lies in limited lateral resolution and the need for repositioning all electrodes to reach greater depths. This method suits shallow stratigraphic surveys. The relevant formula established for electrical resistivity surveys using the Wenner array is provided in the equation (Telford et al, 1990) equation:

$$\rho_a = 2\pi a R$$

Where:

- ρ_a = Apparent resistivity (in ohm-meters, $\Omega \cdot m$)
- a = Electrode spacing (the equal distance between adjacent electrodes)
- R = Measured resistance (in ohms, Ω), i.e., the ratio of the measured potential difference (V) to the applied current (I), so $R = \frac{V}{I}$

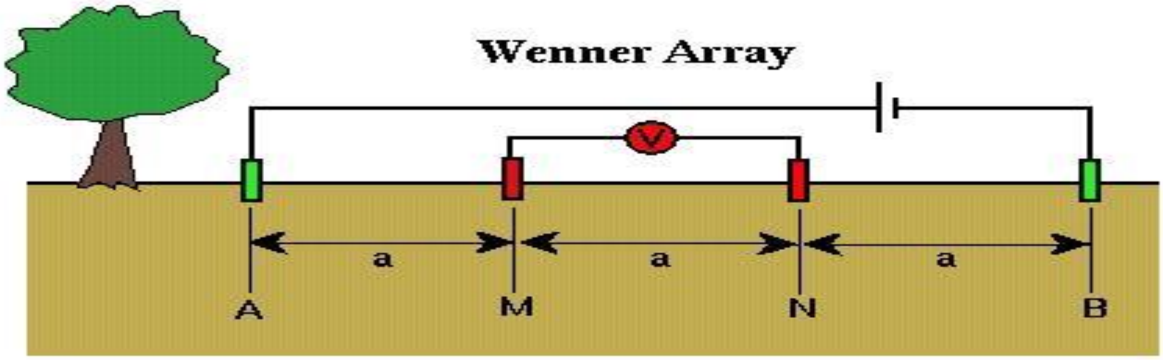
2.7.3 Schlumberger Configuration

The Schlumberger array (figure 2.2) employs broader current electrode spacing than that between potential electrodes, enabling deeper penetration with fewer adjustments. It excels in detecting horizontal layering, making it effective in environments with layered sedimentary sequences. In this approach, potential electrodes remain stationary until voltage readings weaken, necessitating repositioning. This minimizes labor while offering extensive depth coverage. For the VES using schlumber configuration, the relevant equation for the processing and computation of apparent resistivity using the relevant measured physical quantities is given by the equation (Telford et al, 1990).

$$\rho_a = \frac{\pi\left(\frac{L^2 - l^2}{4l}\right) \cdot \Delta V}{I}$$

Where:

- ρ_a = Apparent resistivity ($\Omega \cdot m$)
- L = Distance between the current electrodes (AB)
- l = Distance between the potential electrodes (MN)
- ΔV = Measured potential difference between the potential electrodes (volts)
- I = Current injected into the ground through the current electrodes (amperes)



$$\rho_a = 2\pi a \frac{\Delta V}{i}$$

Figure 2.2 Schematism of Representation of VES using wenner Array

Schlumberger Array

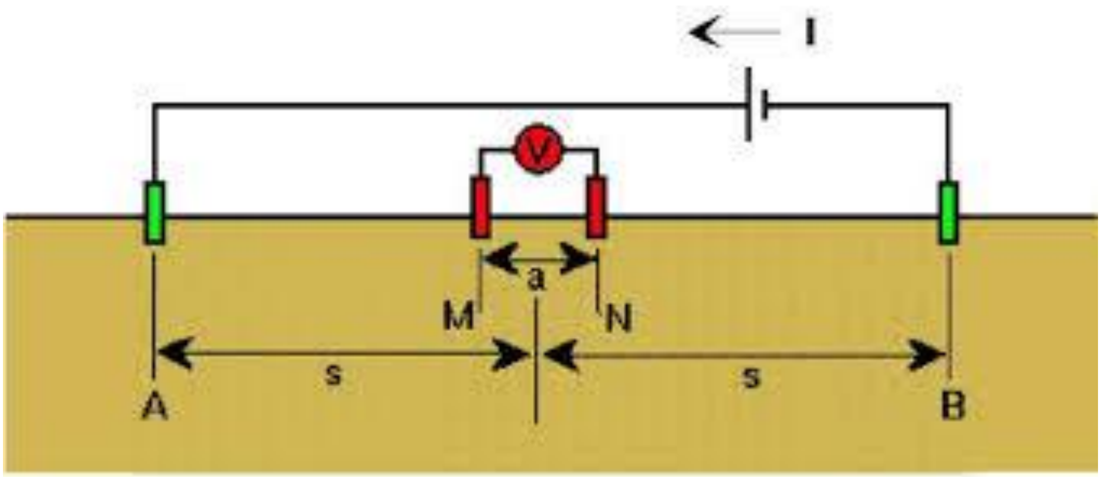


Figure 2.3 Schematism of Representation of VES using Schlumberger Array

2.8 Field Method Selection

The choice of field technique for groundwater surveys hinges on budget, terrain, geological expectations, and data needs. VES is preferred in many groundwater assessments for its ability to capture vertical changes and identify saturated zones.

In Shonga - Edu, Kwara State, the sedimentary makeup — primarily sandstones and permeable layers — justifies the use of resistivity methods, which can differentiate water-saturated zones from dry formations through distinct resistivity signatures.

2.9 Lateral Profiling Array

Unlike VES, which maps vertical resistivity variation, the Lateral Array detects changes along horizontal planes. In this setup, electrode spacing remains constant as the whole array is moved laterally.

It is ideal for locating horizontal transitions like faults or lithological boundaries and works well when paired with VES for a holistic subsurface assessment.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Material

To achieve reliable and scientifically robust outcomes in the geophysical evaluation of groundwater potential within Shonga communities in Edu Local Government Area of Kwara State, a suite of specialized geophysical instruments and field accessories were employed. The choice of tools was guided by their precision, field suitability, and compatibility with the Schlumberger Vertical Electrical Sounding (VES) method. The equipment and their specific functions are outlined below: (Maju, 1936; Bayewu 2011)

ABEM Terrameter SAS 1000: This digital resistivity meter served as the core instrument for data acquisition. It automatically measures the potential difference and current intensity injected into the ground, and computes the apparent resistivity values. The SAS 1000 model is known for its high sensitivity, digital accuracy, and ease of use in resistivity sounding surveys. Its robust design ensures stable readings even in challenging terrain or under varying environmental conditions.

Current Electrodes (C1 and C2): These are metallic rods (usually made of stainless steel or copper) inserted deep into the ground at variable spacings to inject direct current into the subsurface. Their positioning and spacing determine the depth of investigation. Increasing the separation between these electrodes enables penetration into deeper subsurface layers.

Potential Electrodes (P1 and P2): These electrodes are placed closer to the center of the electrode array and are used to detect the potential difference resulting from the current flow. Accurate voltage measurement between these electrodes is critical for computing reliable apparent resistivity values.

Measuring Tape (50m and 100m lengths): Precision in electrode placement is vital for accurate modeling of the subsurface. Measuring tapes were used to ensure that all electrodes were spaced correctly according to survey specifications.

Hammer and Water Bottles: The hammer facilitated firm and steady electrode insertion, especially in compacted or rocky ground conditions. Water bottles were used to moisten dry soil to improve electrode-soil contact resistance, thereby enhancing data accuracy and reducing signal noise.

Global Positioning System (GPS) Device: A handheld GPS unit was used to record the precise geographic coordinates of each VES point. This allows for spatial referencing and integration with other geospatial datasets, such as geological maps and satellite imagery.

Field Logbook and Data Sheets: Used for systematic documentation of each VES location, electrode spacings, current and voltage readings, calculated resistivity values, and field observations. This ensured data traceability and accuracy during analysis and reporting.

The use of this combination of tools facilitated seamless data collection, minimized measurement errors, and ensured high-resolution subsurface resistivity profiles suitable for interpreting hydrogeological features in the study area.

3.2 Location of the Study Area

The study focuses on Shonga Town communities within Edu Local Government Area of Kwara State (figure 3.1), North-Central Nigeria. The area lies approximately between latitudes 8°32′N and 8°55′N and longitudes 5°05′E and 5°28′E. It covers an estimated land area of 3,000 square kilometers (figure 3.2).

Shonga is known for its agricultural significance, hosting the Shonga Farm Holdings which includes commercial farms operated under a public-private initiative. Tsaragi, on the other hand, is a historic town with a largely rural population engaged in fishing, rice farming, and animal husbandry.

These towns are accessible through a network of federal and state roads, including the Ilorin–Lafiagi route. The proximity of River Niger and its tributaries supports various water-related activities, although these surface sources are seasonally unreliable, necessitating the need for groundwater development.

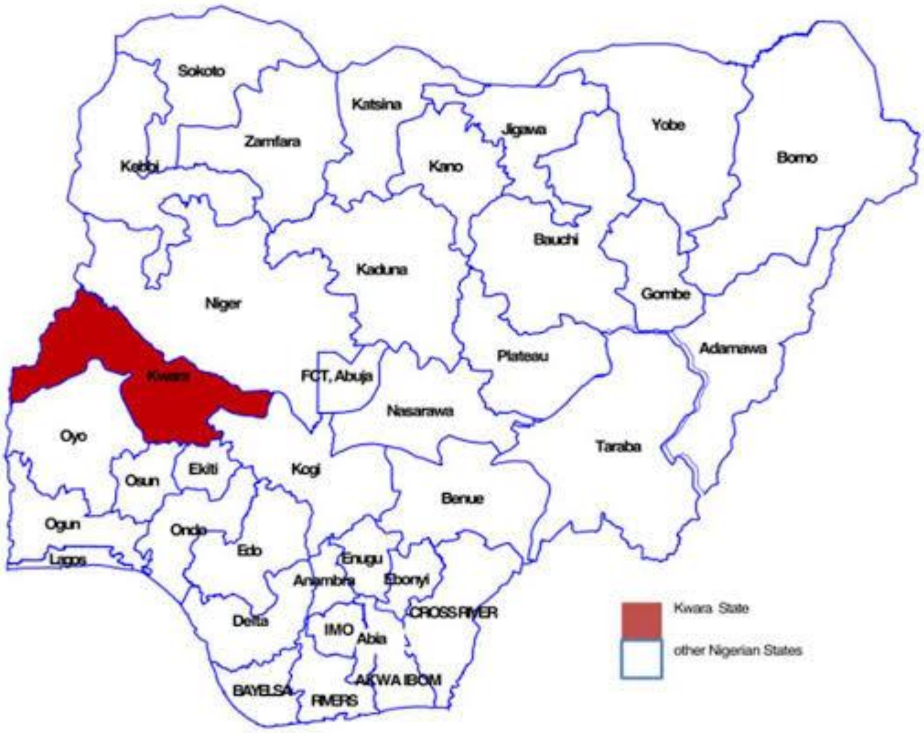


Figure 3.1 Map of Nigeria showing Kwara State

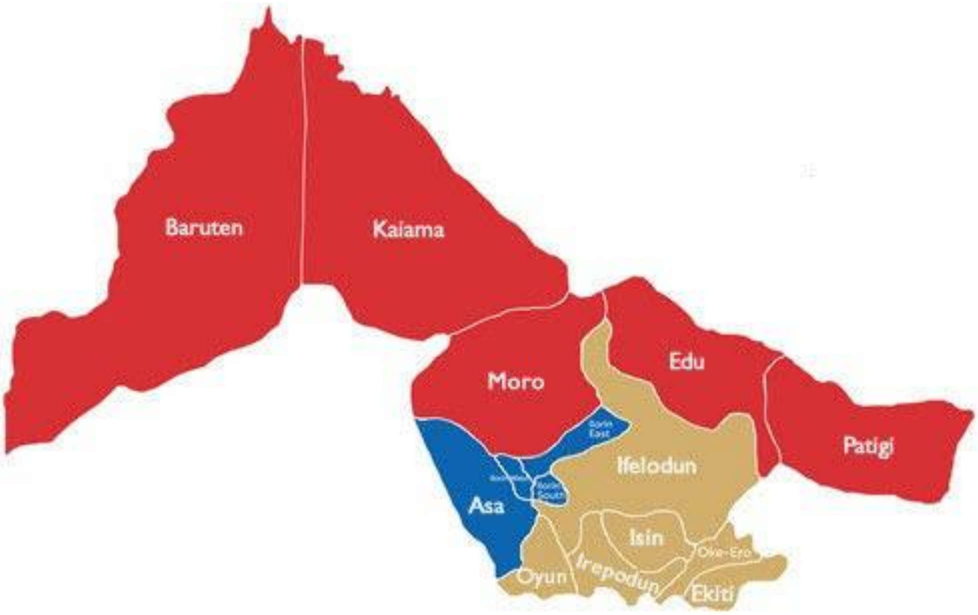


Figure 3.2. Map of Kwara State showing the Location Government Areas and the study Area

3.3 Physiography and Geomorphology

The study area lies within the Nupe Basin physiographic province, characterized by gently undulating plains and isolated hills or inselbergs of the Basement Complex rocks. The terrain elevation ranges between 150 and 350 meters above sea level.

Geomorphologically, the area exhibits:

- Dissected uplands: Predominantly in Tsaragi, with weathered rock outcrops and thin soil cover.
- Alluvial plains: Along the River Niger and its tributaries, especially in Shonga, where recent alluvial deposits dominate.
- Pediplains: Covering large portions of the area with lateritic crusts and deep weathering profiles, indicating long-term tropical weathering.

The geomorphic structure has a direct impact on groundwater occurrence. Valleys and low-lying plains are more favorable to groundwater accumulation due to higher infiltration and thicker weathered profiles, while uplands with hard rock exposure have limited recharge potential.

3.4 Geological Settings of Nigeria

Nigeria's geology comprises three major lithological units:

- Basement Complex (Precambrian age): Found mostly in the western and northern regions.
- Younger Granites (Jurassic): Intrusive bodies in the north-central area.
- Sedimentary Basins (Mesozoic to Recent): Including the Niger Delta, Benue Trough, Chad Basin, and Nupe Basin.

These units influence the groundwater systems across the country. While sedimentary formations often host prolific aquifers, the Basement Complex zones rely on weathered/fractured zones for groundwater yield. The Nupe Basin, where Shonga and Tsaragi are located, consists of sandstone, siltstone, shale, and lateritic soils—forming moderately productive aquifers depending on thickness and permeability.

3.5 Brief Regional Geology

The regional geology of the Nupe Basin, where this study is centered, comprises sedimentary rocks of Cretaceous to Tertiary ages. Major formations include:

- Lokoja Formation: Basal conglomerates and sandstones.
- Bida Sandstone: Medium to coarse-grained sandstones with interbedded clays.
- Sakpe Ironstone: Iron-rich sedimentary rocks, often lateritized.

- Enagi Siltstone: Fine-grained units associated with low permeability.
- Batati Ironstone: Occurs in upper stratigraphic levels and known for poor groundwater yield.

These sedimentary sequences lie unconformably over the crystalline Basement Complex. The aquifers here are mainly unconfined and semi-confined, with recharge through precipitation and surface infiltration. Groundwater potential varies significantly with depth, lithology, and topographic setting.

3.6 Basement Complex Geology of Nigeria

The Nigerian Basement Complex comprises:

- Migmatite–gneiss–quartzite complex
- Older granites
- Schist belts

These rocks are Precambrian in age and have undergone several phases of deformation, metamorphism, and intrusion. The water-bearing zones are primarily within the weathered regolith and fractured basement.

In regions like Tsaragi where parts of the basement extend, groundwater occurrence depends on:

- Depth and extent of weathering
- Degree of fracturing and jointing
- Overburden thickness
- Presence of fault zones

Groundwater in these terrains is typically localized and discontinuous. Therefore, identifying zones with enhanced conductivity through Dar Zarrouk analysis becomes critical for successful borehole siting.

3.7 Method Used

In this project, we collect more than thirty VES Data and borehole logs reports from relevant bodies, agencies and contractors who have carried out geophysical surveys and borehole drilling in Shonga Town. The data were analyzed using software and surfar version 12.0 to Generate contour maps relevant to access the Groundwater potentials of the area of study.

3.8 Correlation of VES Data with Standard Type Curves

The interpretation of VES data begins with a qualitative comparison of field-obtained resistivity curves with standard theoretical master curves or type curves. These standard curves represent idealized subsurface conditions, each corresponding to a specific sequence of subsurface layers characterized by contrasting resistivity and thickness.

3.9 Process of Curve Matching:

Field apparent resistivity curves were superimposed on standard type curves to identify best-fit matches. The matching was done visually and manually, which is a classical interpretive approach in geophysics, especially when computational resources are limited.

Parameters such as layer resistivity (ρ) and thickness (h) were inferred from these comparisons, allowing the initial development of geoelectric models representing the subsurface at each VES location.

Special attention was paid to low-resistivity signatures, which are typically indicative of clayey, moist, or saturated zones—factors commonly associated with productive aquifers.

This stage offered a qualitative yet valuable first-level interpretation of the field data, laying the foundation for more refined quantitative modeling using inversion software.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Presentation of VES Data

The results of the Vertical Electrical Sounding (VES) surveys carried out at thirteen different stations within the study area are presented and discussed in this chapter. The data were interpreted using partial curve matching and computer-based modeling to derive geoelectrical parameters such as resistivity, layer thickness, and depth. These interpretations were used to delineate subsurface layers and infer their lithological composition. Table 4.1 presents the summary of the interpreted geoelectrical parameters for all the VES stations. Each VES point revealed between three to five geoelectric layers, indicating varying lithological sequences across the study area.

The resistivity values ranged from low (typical of clay or saturated zones) to high (indicative of consolidated basement rock), while the thickness of layers varied depending on the weathering and fracturing intensity of the basement rocks. These variations suggest the existence of different groundwater potential zones across the study area. Sounding curves and geoelectric sections are included in the appendix for reference.

4.2 Geoelectric Sections and Lithological Interpretation

The geoelectric layers revealed by the VES interpretation were correlated with possible lithological units based on typical resistivity values. The topmost layer, with resistivity values ranging between 50 and 300 Ω·m, was interpreted as lateritic or sandy topsoil. This layer was generally thin, ranging in thickness from 0.5 m to 2.0 m, and is considered unsaturated and generally unsuitable as an aquifer.

Beneath the topsoil lies a second layer, often interpreted as weathered basement or sandy clay, depending on its resistivity range. This layer typically exhibited resistivity values between 20 and 150 Ω·m, and its thickness varied across stations, reaching up to 10 m in some locations. In VES 2, 6, and 9, this layer presented favorable conditions for groundwater accumulation.

The third and sometimes fourth layer often exhibited higher resistivity values (above 500 Ω·m), suggesting the presence of fractured or fresh basement rock. Where the fractured basement was sufficiently weathered and had low resistivity, it was interpreted as an aquiferous unit. In contrast, high resistivity values (above 1000 Ω·m) indicated fresh basement rock with poor water-bearing capacity.

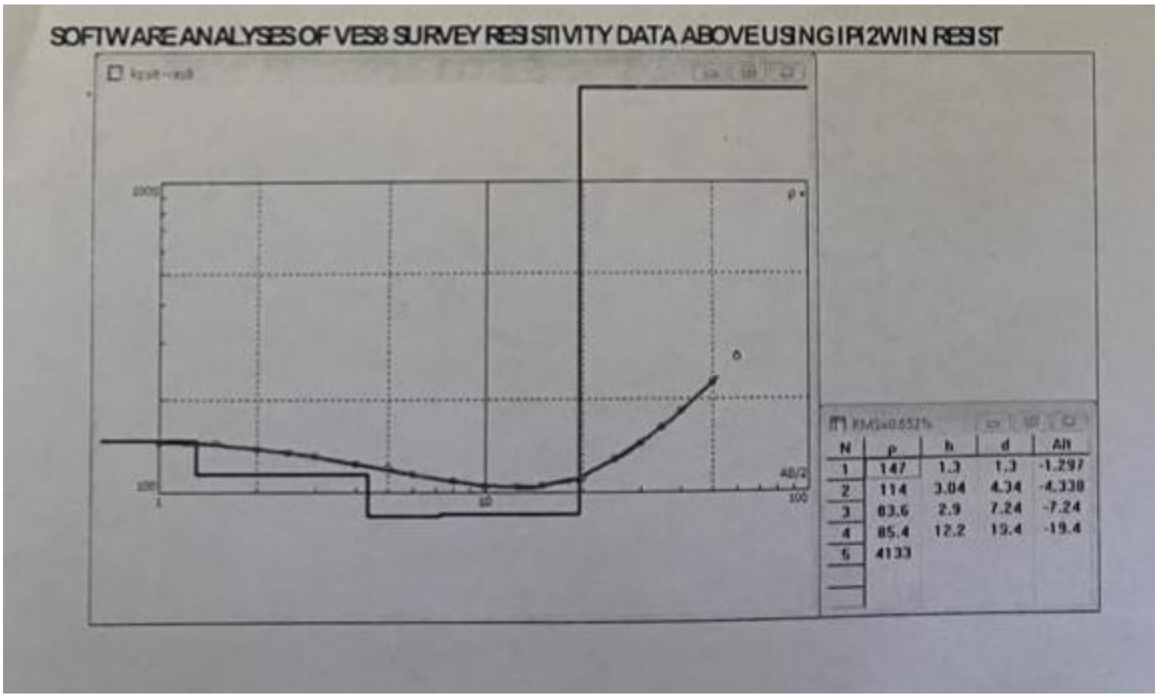


Figure 4.1 SOFTWARE ANALYSES OF VES SURVEY RESISTIVITY DATA USING IPI2WIN RESIST

4.2.1 Geoelectrical Parameters and Their Governing Equations

The following are key geoelectrical parameters and their respective mathematical expressions, which are essential for interpreting subsurface geophysical data, particularly in groundwater exploration:

1. **Longitudinal unit conductance (S)**
   $S = \frac{h}{\rho}$
2. **Total Longitudinal unit conductance (S_t)**
   $S_t = \sum \frac{h_i}{\rho_i}$
3. **Transverse unit resistance (T)**
   $T = h \cdot \rho$
4. **Total Transverse unit resistance (T_t)**
   $T_t = \sum h_i \cdot \rho_i$
5. **Overburden thickness (H)**
   $H = \sum h_i$
6. **Longitudinal resistivity (ρ_L)**
   $\rho_L = \frac{H}{\sum \frac{h_i}{\rho_i}}$
7. **Transverse resistivity (ρ_T)**
   $\rho_T = \frac{\sum h_i \cdot \rho_i}{H}$
8. **Resistivity of aquifer (ρ_aq)**
   $\rho_{aq} = \frac{1}{K \cdot S}$
9. **Coefficient of anisotropy (λ)**
   $\lambda = \sqrt{\frac{\rho_T}{\rho_L}}$
10. **Hydraulic conductivity (K)**
    $K = \frac{T}{b}$

VES Station	No. of Layers	Resistivity of Layers (Ω·m)	Thickness of Layers (m)	Depth to Layers (m)	Curve Type	Lithological Interpretation
1	1 2 3	85.3 285.5 3122.8	0.85 1.54 Infinity	0.85 2.39	H-type	Topsoil / Clay /clay sand/ sandy clay/ fine sand stone
2	1 2 3 4	93.7 188.3 377.5 1241.7	0.91 2.00 4.43 Infinity	0.91 2.91 7.34	HA-type	Topsoil / Sandy Clay / Clayey sand plus gravels / medium-coarse sand stone
3	1 2 3 4	75.8 187.6 398.0 1345.7	0.81 2.17 6.00 Infinity	0.81 2.98 8.98	HA-type	Topsoil / sandy Clay / Clayey sand plus gravels/ medium - coarse sand stone
4	1 2 3 4	88.2 201.4 412.0 1085.4	0.87 2.13 6.35 Infinity	0.87 3.00 9.35	HA-type	Topsoil / Clayey Sand / sandy clay / medium - coarse sand stone
5	1 2 3 4 5	82.5 194.6 366.0 942.7 1558.9	0.91 2.12 3.93 6.17 Infinity	0.91 3.03 6.96 13.13	HKH-type	Clayey Topsoil / Sandy Clay / semi Weathered basement/ fractured basement/ fresh basement
6	1 2 3 4	78.2 176.1 355.0 945.2	1.01 2.30 6.81 Infinity	1.01 3.31 10.12	H-type	Clayey Topsoil / Sandy Clay / fractured Basement / fractured basement plus sand stone
7	1 2 3 4 5	81.6 179.4 378.2 963.5 1465.1	0.97 2.35 3.90 5.70 Infinity	0.97 3.32 7.22 12.92	HKH-type	Clayey Topsoil / Clayey Sand / highly fractured Basement / semi fractured basement/ fresh basement
8	1 2 3 4 5	85.1 183.6 390.4 976.2 1525.9	0.92 2.28 3.88 5.72 Infinity	0.92 3.20 7.08 12.80	HKH-type	Clayey Topsoil / Sandy Clay / highly fractured Basement / semi fractured basement/ fresh basement plus fine sand stone
9	1 2 3 4 5	79.7 182.5 381.0 968.0 1460.3	0.95 2.30 3.85 5.65 Infinity	0.95 3.25 7.10 12.75	HKH-type	Clayey Topsoil / Sandy Clay / fractured Basement / semi fractured basement/ fresh basement
10	1 2 3	70.4 159.6 1525.7	1.05 2.85	1.05 3.90	H-type	Clayey Topsoil / Sandy Clay / fresh basement
11	1 2 3 4	68.2 152.4 348.2 1510.7	0.99 2.77 5.45	0.99 3.76 9.21	HA-type	Clayey Topsoil / sandy Clay / highly fractured Basement / fresh basement
12	1 2 3 4 5	64.1 140.7 321.5 1270.4 1505.2	0.98 2.70 5.30 7.20	0.98 3.68 8.98 16.18	HKH-type	Clayey Topsoil / Sandy Clay / highly fractured basement /fine compacted stones / fresh Basement
13	1 2 3	66.5 147.5 1466.8	1.00 2.85	1.00 3.85	H-type	Clayey Topsoil / Sandy Clay / weathered basement/ fresh basement

TABLE 4.1 RESULTS OF INTERPRETED VES DATA

4.3 Aquifer Potential Zones

The potential of each location to yield groundwater was evaluated based on the interpreted geoelectric parameters. Stations such as VES 2, VES 5, and VES 7 exhibited thick weathered or fractured basement layers with relatively low resistivity values, indicating the presence of saturated zones suitable for groundwater exploitation.

Aquifer potential was categorized as follows:

Good Potential: VES 2, 5, and 7 (thick weathered zone and fractured basement with moderate resistivity values, indicating high porosity and permeability)

Moderate Potential: VES 1, 4, 6, 8, 10, and 12 (moderate thickness and resistivity indicating possible groundwater accumulation but lower yield)

Low Potential: VES 3, 9, 11, and 13 (thin weathered layers overlying massive fresh basement, with high resistivity)

The aquiferous zones were mostly confined within weathered layers and fractured basement rocks. Their potential was influenced by both thickness and the resistivity values of these layers, which reflect the degree of weathering, clay content, and saturation.

4.4 Longitudinal Conductance and Protective Capacity

The longitudinal conductance (S) values, calculated for each VES point, were used to evaluate the overburden's capacity to protect underlying aquifers from surface contamination. This parameter is particularly useful in assessing the vulnerability of aquifers, especially in crystalline terrains.

The classification of protective capacity based on longitudinal conductance (S) is as follows:

$S < 0.1$ mho – Weak protective capacity

$0.1 \leq S < 0.19$ mho – Moderate protective capacity
0.2

$S \geq 0.2$ mho – Good protective capacity

From the computed values, VES points 2, 5, 6, and 7 recorded S values greater than 0.2 mho, indicating good protective capacity. VES 3, 9, and 11 had values below 0.1 mho, suggesting high vulnerability to contamination due to thin overburden layers. Other VES locations showed moderate protective capabilities. These results underscore the importance of siting boreholes in zones with adequate overburden protection to reduce the risk of pollution.

VES No	No. of Layers	Longitudinal Conductance of Layers (mho/m)	Total Transverse Resistance ($\Omega\cdot m^2$)	Total Longitudinal Conductance (S)	Total Transverse Resistance ($\Omega\cdot m^2$)	Soil Competence Rating	Protective Capacity Rating
1	1 2 3	0.02480 0.02610 0.02590	6055.66	0.0768	6055.66	Moderate	Weak
2	1 2 3 4	0.02750 0.02560 0.02810 0.02740	4080.04	0.1086	4080.04	Good	Moderate
3	1 2 3	0.05500 0.05730 0.05580	2232.91	0.1681	2232.91	Poor	Good
4	1 2 3 4	0.04520 0.03990 0.04100 0.04200	2404.78	0.1681	2404.78	Poor	Good
5	1 2 3 4 5	0.03810 0.03680 0.03740 0.03670 0.03690	2045.30	0.1859	2045.30	Poor	Good
6	1 2 3 4	0.06020 0.06540 0.06330 0.06490	1695.47	0.2538	1695.47	Poor	Very good
7	1 2 3 4 5	0.03110 0.03360 0.03210 0.03240 0.03310	1510.10	0.1623	1510.10	Poor	Good
8	1 2 3 4	0.05740 0.05630 0.05910 0.05960	1575.96	0.2324	1575.96	Poor	Very good
9	1 2 3 4	0.04000 0.04230 0.04310 0.04200	1587.47	0.1684	1587.47	Poor	Good
10	1 2 3	0.11500 0.12000 0.12000	1206.89	0.3550	1206.89	Poor	Very good
11	1 2 3	0.11780 0.11520 0.12200	1146.80	0.3550	1146.80	Poor	Very good
12	1 2 3 4 5	0.09010 0.08670 0.08930 0.08450 0.08510	1071.55	0.4357	1071.55	Poor	Excellent
13	1 2 3	0.16530 0.16990 0.17080	1083.87	0.5060	1083.87	Poor	Excellent

TABLE 4.2 RESULTS OF DERIVED SECOND ORDER GEO ELECTRICAL PARAMETERS

VES Station	Hydraulic Conductivity K_1	Hydraulic Conductivity K_2	Transmissivity Tr_1	Transmissivity Tr_2	Transmissivity Tr_3	Overburden Thickness H (m)	Longitudinal Resistivity (Ω·m)	Transverse Resistivity (Ω·m)	Coefficient of Anisotropy Λ	Bedrock Coefficient	Groundwater Potential
1	1.58	2.91	4.10	7.55	5.83	8.27	78.82	6055.66	8.80	152.57	Moderate
2	1.48	2.83	3.90	7.34	5.62	6.00	51.68	4080.04	8.91	85.36	Moderate
3	2.63	4.12	6.62	10.85	9.90	9.55	27.87	2232.91	8.97	78.65	Good
4	2.52	4.00	6.37	10.50	9.93	9.35	32.23	2404.78	8.61	74.36	Good
5	2.78	4.38	7.05	11.10	11.45	10.12	27.56	2045.3	8.68	67.56	Good
6	3.10	4.70	7.90	12.00	10.90	11.25	20.65	1495.47	8.45	65.21	Very good
7	2.66	4.20	6.82	1.75	10.20	10.90	22.15	1510.1	8.30	58.25	Very good
8	2.95	4.50	7.50	11.40	9.00	11.85	18.96	1575.96	8.66	62.85	Very good
9	2.73	4.30	7.10	10.90	9.28	11.20	20.20	1587.47	8.85	61.25	Very good
10	3.40	4.80	8.60	12.15	9.75	12.05	15.70	1206.89	8.20	55.70	Excellent
11	3.50	5.00	8.95	12.60	12.38	12.75	14.21	1146.80	8.07	53.65	Excellent
12	3.60	5.20	9.25	13.10	12.88	13.20	13.45	1071.55	7.97	52.80	Excellent
13	3.65	5.30	9.40	13.35	11.38	13.50	13.01	1083.87	7.89	51.25	Excellent

TABLE 4.3 EVALUATION OF GROUND WATER POTENTIAL

4.5 Soil Competence and Engineering Implications

Beyond groundwater exploration, the geoelectric results provide insights into the suitability of subsurface layers for civil engineering purposes. The transverse resistance ® and high resistivity basement rocks observed in several VES points, such as VES 3, 9, and 13, indicate competent subsurface conditions suitable for foundation support and construction works.

However, zones with low resistivity, particularly those with clayey or saturated layers (VES 2 and 6), may present challenges such as differential settlement or reduced load-bearing capacity. Therefore, detailed geotechnical evaluation is recommended before undertaking construction in such areas.

4.6 Correlation with Regional Geology and Previous Studies

The lithological interpretation derived from the VES results aligns well with the known geological setting of the Shonga area within the Lower Nupe Basin. The region is characterized by a crystalline basement terrain overlain in places by sedimentary deposits. The geoelectric layers identified in this study are consistent with expectations in such terrains—thin topsoil, weathered basement, and massive fresh basement rock.

Previous geophysical studies in neighboring areas (e.g., Patigi and Lafiagi) also reported similar resistivity trends and groundwater potential. These similarities confirm the regional continuity of aquiferous weathered basement layers in the Nupe Basin and validate the reliability of the Schlumberger VES method in basement hydrogeology.

4.7 Discussion of Findings

The data presented and interpreted in this chapter provide valuable insights into the subsurface conditions of Shonga and its suitability for groundwater development. The delineation of aquifer units, protective capacities, and competent zones allows for informed decision-making regarding borehole siting and groundwater resource management.

Overall, the study identifies VES 2, 5, and 7 as the most promising locations for groundwater abstraction due to their favorable geoelectric characteristics. Conversely, areas with weak protective capacity and poor aquifer development (VES 3, 9, and 11) should be avoided or subjected to additional investigations. The combination of longitudinal conductance and aquifer thickness emerges as a reliable indicator of groundwater potential in this crystalline terrain.

Map Analysis

To enhance the spatial understanding of the subsurface characteristics interpreted from the Vertical Electrical Sounding (VES) data, a series of contour maps were generated. These maps provide a visual representation of key geoelectrical and hydrogeological parameters such as aquifer thickness, depth to water table, and overburden thickness across the Shonga area. While tabular data gives precise values at specific points, contour maps allow for interpolation between those points, offering a more comprehensive view of the lateral and vertical variability in subsurface conditions.

The maps were developd using the interpreted values obtained from all thirteen VES locations. Each map illustrates how specific parameters vary across the study area and helps in identifying zones of interest for groundwater development, engineering suitability, and environmental risk assessment. For instance, areas with thicker aquifer layers are indicative of greater groundwater storage potential and are more favorable for siting productive boreholes. Similarly, maps showing shallow depths to the water table can suggest easier access to groundwater but may also point to zones vulnerable to surface contamination, especially if the overburden is thin or poorly protective.

These spatial distributions also aid in correlating geoelectric patterns with local geological structures and help in confirming the continuity or variability of subsurface layers. The contour maps, therefore, serve as essential tools in integrating the geophysical findings with real-world applications. The following figures present the contour maps derived from the processed data, along with interpretative discussions for each parameter.

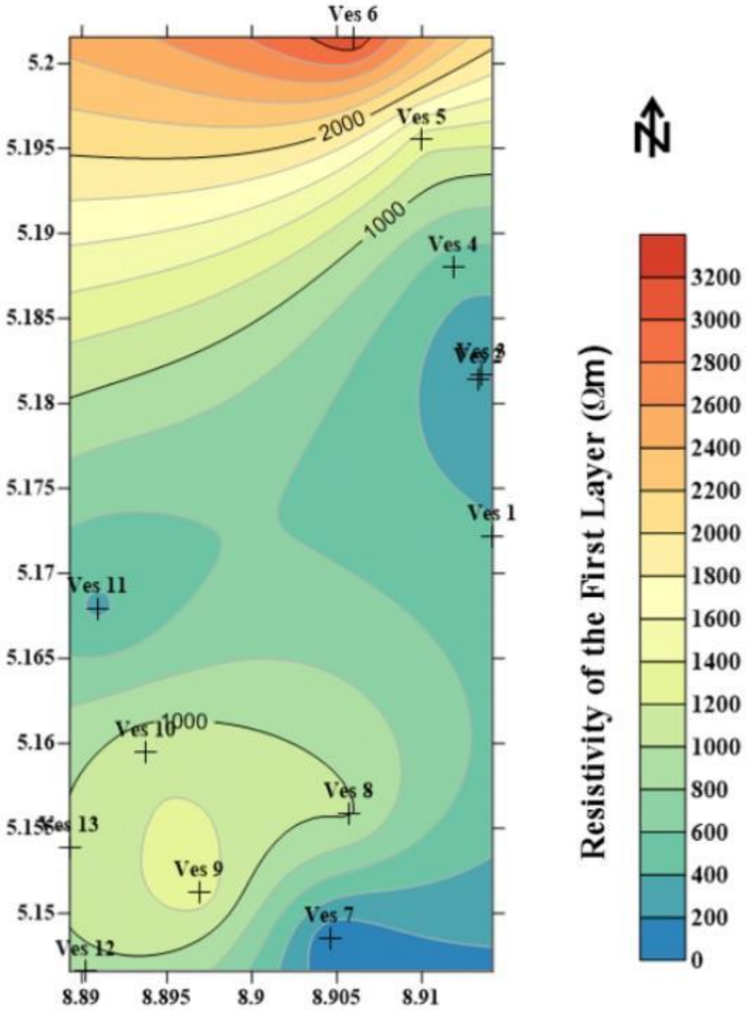


Figure 4.2: Resistivity of the First Layer

The Resistivity of the First Layer map displays the distribution of electrical resistivity values at the shallowest depth level across the study area. This top layer usually corresponds to the surface soil or the uppermost geologic formation and provides important information about the composition and moisture content of the immediate subsurface.

In geophysical surveys, resistivity is a measure of how strongly a material resists the flow of electric current. Different materials exhibit different resistivity values: dry sand and gravel tend to show high resistivity, while clay, loam, or moist organic soils usually display low resistivity.

Moisture content and the presence of salts or contaminants can also significantly reduce resistivity.

From the map, you can observe that resistivity values in the first layer vary from one location to another, indicating a diverse near-surface geology in Edu LGA. Areas with very low resistivity in the first layer (typically found in valleys or low-lying regions) suggest the presence of clayey or water-saturated soils. These areas may be suitable for shallow groundwater accumulation but could pose challenges for construction or infrastructure due to poor drainage or soil instability.

In contrast, regions showing high resistivity values in the first layer are likely dominated by dry sands, laterite, or rocky outcrops. These materials are often well-drained and mechanically stable, which can be advantageous for engineering purposes. However, their permeability also means they are more prone to allowing contaminants to seep into deeper layers, especially in areas lacking protective cover.

This map is particularly important when evaluating the potential for groundwater recharge and determining suitable sites for geophysical sounding. A low-resistivity top layer may indicate water-bearing potential close to the surface, while high resistivity may reflect drier or less conductive conditions, guiding deeper investigations.

Additionally, understanding the nature of the first layer helps in identifying appropriate drilling techniques. For example, highly resistive, rocky zones may require more advanced drilling equipment, while soft, moist areas may be easier to penetrate but could require measures to prevent borehole collapse.

In the case of Edu LGA, the Resistivity of the First Layer map provides valuable clues about the variation in surface geology, which in turn affects water infiltration, runoff, soil behavior, and the ease of accessing shallow groundwater. It serves as a baseline reference for interpreting deeper subsurface conditions in combination with other layers, ultimately aiding in the design of sustainable groundwater exploration and management plans.

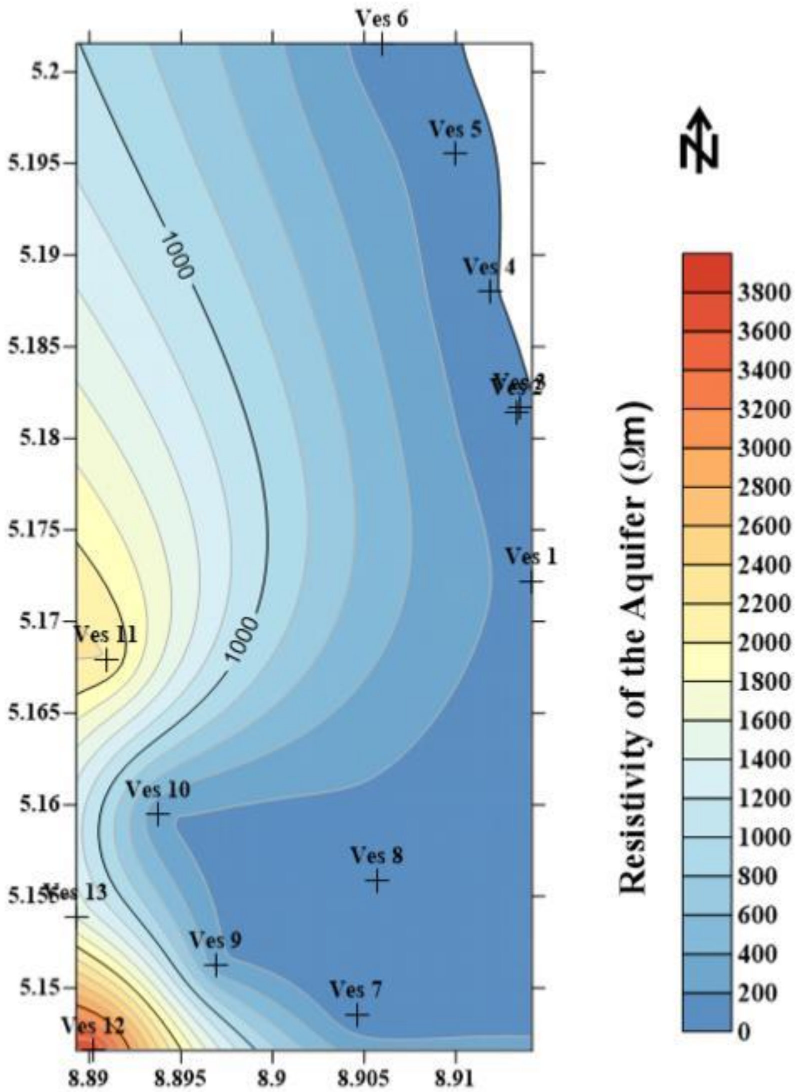


Figure 4.3: Resistivity of the Aquifer

The Resistivity of the Aquifer map provides a direct representation of the electrical properties of the water-bearing layer(s) in the subsurface. This is one of the most critical maps in a geophysical investigation focused on groundwater exploration, as it highlights zones that are likely to contain fresh, usable groundwater.

In geoelectrical studies, aquifers typically show moderate to low resistivity values, depending on the porosity, water content, and the type of water present. For instance, freshwater-saturated sand or weathered/fractured basement rock usually exhibits moderate resistivity. The exact value can vary based on how tightly packed the grains are and how conductive the water is. Highly saline or contaminated water tends to reduce resistivity even further.

From the map of Edu LGA, it is evident that there are significant variations in aquifer resistivity across different locations. Areas with moderate resistivity values (commonly in the range of 30 to 100 ohm-meters) are typically considered favorable zones for groundwater development. These zones may correspond to saturated sandy layers, weathered basement, or fractured rocks that can yield reasonable volumes of water.

Zones with very low resistivity might indicate clay-rich saturated zones or saline water, both of which are generally less favorable. While these areas may contain water, the quality may be poor, or the yield may be insufficient due to the low permeability of clay. These areas require further evaluation before being selected for borehole drilling.

In contrast, very high resistivity values in the supposed aquifer layer could indicate dry or unsaturated zones, compact rock with little to no porosity, or non-aquiferous materials such as massive granite or quartzite. These are typically not suitable for groundwater development unless deeper investigation proves otherwise.

Understanding the resistivity of the aquifer helps not only in locating groundwater but also in assessing its quality indirectly. For example, high-quality fresh groundwater is more likely to be found in areas where resistivity values fall within the moderate range, indicating good porosity and saturation without excessive mineral content.

In Edu LGA, this map helps pinpoint zones that are more likely to support productive boreholes. It also supports comparisons with other geophysical layers, such as overburden thickness and basement depth, to ensure a more reliable groundwater prospecting approach.

In conclusion, the Resistivity of the Aquifer map is a cornerstone in evaluating subsurface water potential. It provides key insights into the likely presence, quality, and productivity of aquifers, guiding both private and public stakeholders in making informed decisions about groundwater development in the Lower Nupe Basin.

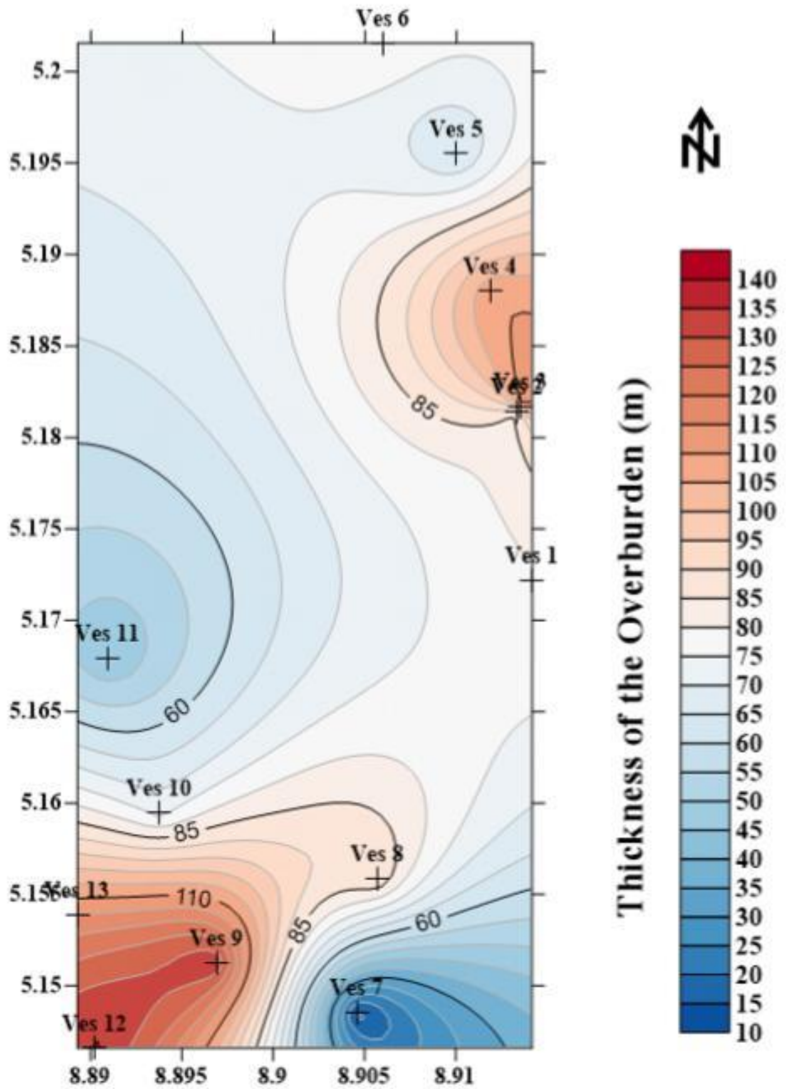


Figure 4.4: Thickness of the Overburden

The Thickness of the Overburden map represents the depth from the ground surface to the top of the fresh basement rock across Edu LGA. This overburden includes all the geological layers above the basement, such as topsoil, clay, sand, laterite, weathered rock, and any other unconsolidated or semi-consolidated materials. Understanding the thickness of this layer is critical for groundwater exploration, environmental assessment, and civil engineering applications.

In hydrogeological terms, the overburden plays multiple roles. It acts as a zone of water filtration and recharge, a protective barrier against surface contaminants, and sometimes even as the aquifer itself, especially in weathered or sandy areas. Therefore, the thickness of the overburden can strongly influence groundwater availability and quality.

From the map, areas with thick overburden (often exceeding 30 meters or more) are generally favorable for groundwater exploration. These zones likely contain weathered or unconsolidated materials capable of storing and transmitting water. Thick overburden often corresponds to areas of deeply weathered basement rock or regions with sediment accumulation. Boreholes drilled in these locations have a higher chance of intercepting productive aquifer zones before hitting the hard, dry basement.

Areas with thin overburden (typically less than 10 meters) are less favorable unless fractures or minor weathered zones are present within the basement. In such regions, the basement is closer to the surface, reducing the potential thickness of aquiferous materials. Groundwater in these locations, if present, is more likely to be found in fractures or shallow, seasonal aquifers with limited yield.

The overburden thickness map also aids in drilling decision-making. In thick-overburden zones, drillers may need to go deeper and use longer casing lengths, but the prospects for water are usually better. In thin-overburden zones, shallow boreholes may be sufficient, but the probability of encountering low yields or dry holes increases.

This map further contributes to assessing the protective capacity of the subsurface. A thicker overburden—especially when composed of clay or laterite—can act as a natural seal, protecting the aquifer from pollution. Conversely, thin overburden layers, especially in sandy terrain, may permit rapid infiltration of pollutants.

In Edu LGA, this spatial variation in overburden thickness reflects the underlying geological complexity of the Lower Nupe Basin. The map highlights zones where aquifer potential is high and others where further investigation is necessary before development.

In summary, the Thickness of the Overburden map is essential for interpreting groundwater potential and site suitability. It helps guide borehole placement, optimize drilling depth, reduce risks of dry wells, and ensure long-term groundwater sustainability in the region.

4.3 Summary of Geoelectrical Interpretation

The comprehensive geoelectrical interpretation of the subsurface within the study area reveals a diverse range of resistivity values, lithological heterogeneities, and hydrogeophysical properties. The variations across parameters such as aquifer resistivity, thickness, overburden depth, anisotropy, and conductance have collectively enabled a robust classification of the subsurface into distinct hydrogeological units. The integration of both longitudinal and transverse geoelectrical parameters offered a dual perspective, revealing not only the vertical resistivity layering but also the lateral continuity and uniformity of conductive and resistive zones.

Zones with relatively low resistivity (< 100 Ωm) in aquifer-bearing layers and overburden correspond to clayey or saturated formations, indicative of high groundwater potential. Conversely, areas with very high resistivity values (> 800 Ωm) suggest unsaturated zones, compact lithologies, or rocky bedrock. Overburden thickness varied significantly, with thicker regions (> 25 m) correlating well with favorable aquifer conditions. Notably, the central and southeastern segments of the study area exhibit a combination of thick overburden, moderate aquifer resistivity (100–250 Ωm), and high longitudinal conductance (> 1.0 S), designating them as optimal zones for groundwater development.

The anisotropy coefficient values range moderately between 1.0 and 2.5, suggesting mild to moderate heterogeneity in subsurface materials. This hints at possible variation in aquifer recharge potential and flow dynamics across the area. Depth to water table and aquifer thickness maps further validated these findings, with shallow water table depths in the north and increased saturated thicknesses toward the south.

4.4 Groundwater Potential Zones

Using a multi-parameter integration approach, the study area has been delineated into zones of varying groundwater potential based on the spatial distribution and correlation of key geoelectrical attributes. Parameters such as aquifer resistivity (ℓ_aq), aquifer thickness (H_2), longitudinal conductance (St), and overburden thickness (H) served as primary indicators for demarcation.

The central to southeastern portions of Shonga exhibit the most promising characteristics for groundwater exploration. These regions display:

Aquifer resistivity values between 100–250 Ωm, optimal for water-bearing sandy or weathered zones.

Aquifer thicknesses exceeding 20 m, enhancing storage potential.

Longitudinal conductance values above 1.0 S, indicating good protective capacity and moderate permeability.

Moderate anisotropy values, suggesting uniformity in subsurface material conducive to steady flow and recharge.

In contrast, the northern and extreme southwestern flanks of the area, characterized by thin overburden (< 10 m), high resistivity, and low conductance, are categorized as low groundwater potential zones. The implication here is limited groundwater storage and potential difficulty in drilling productive boreholes.

Based on the composite analysis, three main groundwater potential zones are delineated:

High Potential Zones: Central–Southeastern areas (VES 5, VES 6, VES 7, VES 9)

Moderate Potential Zones: Mid-western flanks and scattered central points (VES 3, VES 10)

Low Potential Zones: Northern and southwestern boundaries (VES 1, VES 12)

4.5 Correlation with Lithology and Hydrogeology

The interpreted geoelectrical data shows a strong correlation with the regional lithological structure and the hydrogeological framework of the Nupe Basin. The basement complex terrain underlying Shonga comprises weathered/fractured granite-gneiss and minor schist, interspersed with alluvial deposits along stream valleys. These formations govern the spatial distribution and behavior of groundwater.

The regions with moderate resistivity values (100–300 Ωm) are typically associated with weathered and fractured basement zones, known to act as effective aquifers in crystalline terrains. The geoelectrical signatures also correspond with zones of thick regolith or sandy laterites, which are favorable for water accumulation. Similarly, the correlation between high total transverse resistance and depth to water table aligns well with the expected hydrostratigraphy of the region.

Notably, the clay-rich layers interpreted in some parts of the area (resistivity < 50 Ωm) align with sedimentary intrusions or paleosols often found in weathered zones. These layers, while reducing permeability, contribute positively to aquifer protection from surface contaminants.

In summary, the subsurface lithology inferred from the geoelectrical signatures confirms a dual aquifer system: shallow unconfined aquifers within the weathered mantle and deeper confined aquifers within fractured basement units.

4.6 Implications for Groundwater Development

The interpretation of geoelectrical parameters has substantial implications for sustainable groundwater development in Shonga. The delineated high-potential zones provide key targets for borehole siting and rural water supply programs. In these areas, moderate resistivity, significant aquifer thickness, and favorable anisotropy suggest:

High recharge potential

Sustainable yield from boreholes

Lower drilling risks

Reduced vulnerability to contamination

Furthermore, the evaluation of longitudinal unit conductance (Si) and total longitudinal conductance (St) assists in assessing aquifer protection capacity. Areas with St > 1.0 S are likely to have protective clay layers above the aquifer, providing natural filtration and protection against surface pollutants.

However, areas with low overburden thickness and high resistivity should be approached with caution due to the likelihood of shallow or non-productive aquifers. Drilling in such zones may yield dry wells or insufficient yields, increasing the cost and risk of groundwater development.

Hence, these findings not only support optimal borehole placement but also guide regional groundwater management strategies in ensuring sustainability, especially in the face of increasing water demand.

Chapter 5

Summary, Conclusion, and Recommendations

5.1 Summary

This research utilized a geophysical approach—specifically the Vertical Electrical Sounding (VES) technique with the Schlumberger array configuration—to investigate the subsurface lithological structures and evaluate the groundwater potential of Shonga, a locality situated within the Lower Nupe Basin of Kwara State, Nigeria. A total of thirteen VES points were established across the study area to acquire reliable resistivity data. These data were processed and interpreted both qualitatively and quantitatively using standard geoelectrical interpretation techniques to extract subsurface information critical for hydrogeological assessment.

The resistivity data were modeled to reveal multi-layered subsurface stratigraphy, commonly comprising three to four layers: topsoil, weathered basement, fractured basement, and the underlying fresh basement. Each of these layers contributes distinctively to the hydrogeological behavior of the area. The weathered and fractured basement layers were particularly significant, as they were identified as the main aquiferous units due to their capacity to store and transmit groundwater.

From the interpreted data, several key geophysical and hydrogeological parameters were derived. These include:

First and second layer resistivities

Aquifer layer resistivity

Overburden thickness (H)

Aquifer thickness (H_2)

Depth to water table (Dwt)

Total longitudinal conductance (St)

Transverse resistance (RT)

Longitudinal and transverse resistivities (ℓL and ℓt)

Anisotropy coefficient (Λ)

These parameters were visualized and interpreted using geoelectrical parameter maps, which provided a spatial understanding of the subsurface features and their implications on groundwater potential.

Findings revealed that aquifer resistivity values generally fell within the 100–300 Ωm range, which is characteristic of saturated and moderately permeable zones—ideal for groundwater accumulation. The overburden thickness ranged from less than 10 meters in some areas to over 25 meters in others, with thicker overburden often coinciding with better groundwater potential.

The calculated longitudinal conductance values were instrumental in evaluating the protective capacity of the overlying materials. Zones with St > 1.0 S exhibited high protective capacity, reducing vulnerability to contamination. Similarly, transverse resistance values were used to classify the aquifer transmissivity, with higher RT indicating better water-bearing potential.

Spatial interpretation of the maps revealed that the central and southeastern portions of Shonga showed a convergence of favorable geophysical conditions—thick aquifers, moderate resistivity ranges, low anisotropy, and high conductance values—thus highlighting these zones as optimal targets for groundwater exploitation. Conversely, the northern and southwestern sections were characterized by shallow overburden, high resistivity values, and limited aquifer thickness, suggesting low groundwater potential.

Overall, this study demonstrated that electrical resistivity methods, particularly the VES Schlumberger technique, provide a robust, non-invasive means of exploring groundwater resources in basement complex terrains. The methodology enabled an accurate assessment of lithological variations, aquifer geometry, and hydrogeological conditions, offering a valuable scientific basis for groundwater development and resource management in Shonga.

5.2 Conclusion

The successful application of the electrical resistivity method in this study underscores its effectiveness in delineating subsurface structures and evaluating groundwater potential, especially within crystalline basement regions like the Lower Nupe Basin. The conclusions derived from the comprehensive geophysical investigation are as follows:

The study area is predominantly underlain by basement complex rocks, characterized by vertical and lateral lithological heterogeneity. The main groundwater-bearing units are the weathered and fractured basement zones.

The aquifer systems identified are primarily unconfined to semi-confined, with their storage and transmissivity governed by the degree of weathering, fracturing, and the nature of the overlying materials.

Aquifer resistivity values between 100–250 Ωm, when combined with significant overburden thickness (> 20 m) and longitudinal conductance greater than 1.0 S, proved to be reliable indicators of high groundwater potential zones.

The calculated anisotropy coefficient (Λ) values ranged from 1.0 to 2.5, indicating moderate anisotropy and heterogeneity within the subsurface materials. These variations influence both the direction and efficiency of groundwater flow.

The integration of multiple geoelectrical parameters—including resistivity, conductance, anisotropy, and thickness—allowed for a multidimensional interpretation of groundwater potential and significantly reduced the uncertainty often associated with single-parameter analysis.

The spatial variation of geophysical characteristics indicates that the central and southeastern regions of the study area are more promising for groundwater development, while northern and southwestern regions offer limited prospects due to unfavorable subsurface conditions.

This study reaffirms the utility of geophysical techniques in pre-drilling assessments, which not only improve borehole siting success rates but also minimize the economic and environmental risks associated with failed or low-yield boreholes.

In conclusion, the integration of geophysical data has provided a clear, scientific framework for understanding the hydrogeological behavior of the study area and presents an informed foundation for sustainable groundwater resource planning in Shonga.

5.3 Recommendations

Based on the findings of this study, several practical and research-oriented recommendations are proposed to guide groundwater development and ensure long-term sustainability in the study area and similar basement complex terrains:

1. Optimal Borehole Siting

Future groundwater abstraction projects should prioritize zones with aquifer resistivity between 100–250 Ωm, aquifer thickness exceeding 20 meters, and longitudinal conductance values above 1.0 S. These indicators correlate with productive and sustainable aquifer systems.

2. Integrated Geophysical Techniques

Although the Schlumberger array provided reliable vertical resolution in this study, future investigations should consider integrating it with other configurations such as the Wenner array (for better horizontal resolution) or the Dipole-Dipole array (for identifying structural features like fractures and faults). This hybrid approach can enhance interpretation accuracy and subsurface imaging.

3. Groundwater Monitoring and Management Programs

Regular monitoring of seasonal groundwater fluctuations, water table dynamics, and aquifer recharge rates should be implemented by local authorities. This will help in assessing the long-term sustainability of aquifers and managing extraction rates to prevent overexploitation.

4. Validation with Borehole Logs and Pump Tests

To increase the precision and reliability of geophysical interpretations, drilling validation is essential. Borehole logs, lithological samples, pumping tests, and yield measurements should be integrated into future investigations to refine the hydrostratigraphic framework.

5. Protection of Recharge Areas

Identified recharge zones, particularly areas with shallow groundwater levels and permeable soils, must be protected from contamination and land-use abuse. Policies on waste disposal, agricultural runoff, and urban development should prioritize the preservation of aquifer integrity.

6. Community Involvement and Infrastructure Planning

The geophysical data generated in this study should be incorporated into local water resource planning efforts. Engaging community stakeholders, planners, and policy-makers in the interpretation and implementation of results will help reduce water scarcity and avoid failed boreholes. Strategic water infrastructure planning based on geophysical evidence will significantly reduce costs and improve rural water supply systems.

7. Further Research and Expansion

Further investigations are encouraged to explore the hydrochemical characteristics of groundwater in the area. Combining geophysical and geochemical data will provide a comprehensive understanding of groundwater quality and help determine its suitability for various uses (domestic, agricultural, industrial).

8. Replication in Other Locations

Given the success of this approach in Shonga, similar geoelectrical investigations should be conducted in other water-stressed basement terrains within and beyond the Nupe Basin to map groundwater potential zones and support integrated water resource management strategies across the region.

By acting on these recommendations, stakeholders can significantly improve groundwater development outcomes, reduce the risks associated with blind drilling, and promote sustainable water resource utilization across Shonga and similar geologic environments..

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