STUDIES OF THE SUBSURFACE AND BASEMENT STRUCTURE IN ILORIN CRYSTALLINE ROCK AREA AND THEIR HYDROGEOLOGICAL IMPLICATIONS

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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 OJO OMEIZA, ABDULWAHEED FATHIA ABISOLA , OPARINDE ZAINAB ADESEWA, ABIDOYE ZAINAB BOLUWATIFE.**

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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Love you all.

Abstract

This study investigates the subsurface characteristics and basement structural framework of the Ilorin crystalline rock terrain in southwestern Nigeria, with the primary objective of evaluating their implications for groundwater potential and distribution. The area, underlain predominantly by Precambrian Basement Complex rocks, presents considerable heterogeneity in its lithological and structural composition, which significantly influences groundwater occurrence and movement.

A suite of geophysical methods, particularly the electrical resistivity method using the Vertical Electrical Sounding (VES) technique, was employed to delineate subsurface layers, identify weathered and fractured zones, and interpret basement relief patterns. The data acquired were interpreted through partial curve matching and computer-assisted modeling to characterize subsurface geoelectric layers, estimate overburden thickness, and map basement topography.

Results revealed varied basement depths, ranging from shallow outcrops to moderately thick weathered zones conducive to groundwater storage. The presence of fractured basement and thick regolith layers in some profiles indicated zones of enhanced aquifer potential. Conversely, areas with thin or absent weathering suggested poor groundwater prospects. Structural features such as joints and faults, inferred from abrupt resistivity contrasts and basement undulations, were found to influence groundwater accumulation and flow pathways.

These findings highlight the critical role of basement geology and structural controls in groundwater development within crystalline terrains. The study provides a geophysical basis for informed groundwater exploration, borehole siting, and sustainable water resource management in Ilorin and similar Basement Complex regions.

Table of Contents

CHAPTER ONE

1.0. GENERAL INTRODUCTION

1.1. BACKGROUND AND MOTIVATION

Water is universally recognized as a critical resource for sustaining human life, fostering economic development, and preserving environmental integrity. Its importance spans across domestic usage, industrial processes, agriculture, sanitation, and the broader goal of public health [1-6]. In response to the growing pressure on water resources, the Sustainable Urban Rural Water Supply, Sanitation, and Hygiene (SURWASH) Program was initiated in 2022 [4] to enhance access to clean water, improve sanitation infrastructure, and promote hygiene practices, particularly in underserved and rapidly expanding regions of Nigeria. One of the central pillars of this initiative is the sustainable and efficient development of groundwater resources, especially in areas where surface water is scarce or unreliable.

Ilorin, the capital city of Kwara State located in Southwestern Nigeria, represents a vital region under the SURWASH framework [4]. As a city experiencing rapid population growth, urbanization, and increased agricultural activity, the demand for potable water has intensified. The region falls within the Precambrian Basement Complex, a geological terrain predominantly composed of crystalline, non-porous rocks. Under natural conditions, these rocks do not have the primary porosity necessary to store water; however, the processes of weathering and fracturing over geological time have given rise to secondary porosity, creating potential aquifer zones that can support groundwater storage and flow.

Within the context of SURWASH's objectives, the reliance on groundwater in Ilorin becomes a strategic priority. However, the exploration and development of these water sources are fraught with challenges. Variability in subsurface geology, the unpredictable nature of weathered zones, and the high cost of unsuccessful drilling make traditional water sourcing methods—such as random or trial-and-error borehole drilling—both inefficient and unsustainable. These challenges underscore the urgent need for scientific and cost-effective techniques to improve the success rate of groundwater development in line with SURWASH's sustainability goals.

Geophysical investigations. Particularly, the Electrical Resistivity Method, have emerged as a promising solution. These non-invasive techniques allow for a systematic understanding of the subsurface, making it possible to delineate aquifer-bearing formations with a higher degree of accuracy[9-10]. Among these, Vertical Electrical Sounding (VES) is especially suitable for Basement Complex terrains like Ilorin, as it effectively distinguishes between dry and saturated zones, weathered layers, and unfractured bedrock. Through this approach, water resource planners and engineers can optimize borehole siting, reduce the incidence of failed wells, and align with SURWASH's cost-efficiency and sustainability principles[1-4.

This study is driven by the imperative to integrate modern geophysical techniques into water resource planning under the SURWASH framework. In Ilorin, many residents still depend on shallow wells or isolated boreholes, many of which are unreliable due to seasonal fluctuations and inconsistent yields. By enhancing the scientific basis for groundwater exploration, this research aims to support evidence-based decision-making in water infrastructure development.

1.2 Aims and Objectives of the Study

The primary aim of this study is to investigate and evaluate the groundwater potential in selected parts of Ilorin, which lies within the Southwestern Nigerian Precambrian Basement Complex, using geophysical (VES) techniques.

Specifically, the objectives of this project were to:

a) Collect VES Data of geophysical surveys carried out within Kwara state polytechnic campus, Ilorin crystalline rock area;
b) Determine the first order Geoelectric parameters of number, Resistivity thickness and depth of layers associated with each VES location of the collected data;
c) Compute the second order Geoelectric parameters such as depth, thickness and resistivity of aquafer, overburden thickness, Dar-Zarrouk Parameters (DZP) of total longitudinal unit Conductance (S), Total transverse unit resistance (R), Average longitudinal resistivity (Si), Average transverse resistivity (St), Coefficient of anisotropy, fracture or resistivity contrast (fc), Reflection Coefficient (Rc) as well as Hydraulic properties of transmissivity (Tr) and Hydraulic conductivity (k);
d) Plot contour maps using some of the values of parameters obtained in (b);
e) Assess the groundwater potential of the study area.
f) Delineate the geoelectric structures and assess their influence on groundwater accumulation and flow patterns;
g) Identify potential aquifer zones and suggest the most promising locations for future groundwater exploitation; and
h) Contribute reliable geophysical data to guide water resource management, planning, and infrastructure development in Ilorin.

1.3. Scope of the Study

This project is specifically focused on the application of geophysical techniques, with particular emphasis on electrical resistivity surveys, to explore groundwater potential within selected locations in Ilorin, Kwara State, Nigeria. The study will cover an examination of subsurface conditions, identification of groundwater-bearing formations, and the interpretation of geophysical data to recommend optimal sites for groundwater extraction.

1.4. Limitations of the Study

While the project is designed to produce reliable and valuable data for groundwater exploration in Ilorin, there are certain constraints and limitations that must be acknowledged.

One of the primary limitations is the inherent ambiguity in geophysical data interpretation, as subsurface conditions can sometimes produce similar resistivity values for different materials, making it difficult to distinguish between saturated and dry fractured zones without supplementary drilling information.

1.5. Expected Contribution to Knowledge

This study is expected to contribute significantly to the growing field of groundwater exploration in crystalline basement environments, particularly in the context of Ilorin and similar geological settings.

The research will provide a structured approach to the application of electrical resistivity techniques for the identification of subsurface groundwater potential zones. By integrating field survey data with geological interpretations, the study will offer insights into the relationship between rock weathering, structural features, and groundwater accumulation in basement terrains.

Moreover, the findings will enhance local understanding of hydrogeological dynamics in Ilorin, supporting better-informed decisions in borehole siting and groundwater resource management. The results of this project may serve as a reference for researchers, geoscientists, water resource planners, and drilling contractors operating in basement complex environments.

Ultimately, the project aims to reduce groundwater exploration risks and contribute to the sustainable development of water resources in the region..

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1 Introduction

Groundwater is a critical component of the earth's hydrological system, serving as a reliable and sustainable source of freshwater for domestic, agricultural, and industrial use across the globe. In regions where surface water bodies are limited, seasonal, or unreliable, groundwater becomes the primary source of water supply. This is especially true for many parts of sub-Saharan Africa, including southwestern Nigeria, where climatic variability and rapid urbanization have heightened the demand for dependable groundwater resources. To ensure efficient exploration and development of these resources, a thorough understanding of the geological, hydrogeological, and geophysical principles that control groundwater occurrence is essential [9 - 12].

Over the years, numerous studies [2-19] have examined the occurrence, movement, and availability of groundwater within basement complex terrains. Unlike sedimentary basins, where water is typically stored in porous media such as sandstones or alluvial deposits, groundwater in crystalline basement rocks is mainly confined to secondary structures such as fractures, joints, faults, and weathered zones. The spatial distribution and continuity of these features are often difficult to predict without specialized scientific investigations, making groundwater exploration in such environments highly dependent on advanced surveying methods, particularly geophysical techniques[2-5].

The Nigerian Precambrian Basement Complex, which underlies the study area, has been the subject of extensive geological and hydrogeological research due to its widespread distribution and importance as a groundwater reservoir. Early research works, including those by Bello et (1997); 2005; 2010, and Bala and Ike (2001), have shown that groundwater occurrence in basement regions is closely linked to the nature and extent of the weathered layer and the development of fractures within the underlying bedrock. These studies consistently highlight that the success of groundwater development projects in basement terrains depends not only on drilling depth but also on careful identification of productive zones through scientific site selection.

2.2 Previous Related Works Done

One of the most valuable approaches to groundwater exploration in basement terrains is the application of geophysical methods, especially electrical resistivity surveys. Electrical resistivity techniques allow the determination of the subsurface's physical properties without the need for invasive excavation or trial-and-error drilling. The Vertical Electrical Sounding (VES) method, in particular, has proven highly effective in delineating the various subsurface layers and identifying potential aquifer units in different parts of Nigeria and beyond. Researchers such as Oladapo et al. (2004), Adepelumi et al. (2001), and Amadi et al. (2012) have employed these methods to study the geoelectrical characteristics of aquifers in basement environments, reporting significant improvements in borehole siting accuracy and groundwater yield optimization.

Beyond geophysics, the relationship between geology and groundwater availability has also been well-documented in the literature. According to studies by Wright (1992) and Egboka and Uma (1986), basement rocks are typically poor aquifers in their unweathered state due to low primary porosity. However, prolonged weathering and the presence of interconnected fractures can significantly enhance both storage and transmissivity. Consequently, hydrogeological studies often focus on identifying regions with thick weathered mantles or zones of intense fracturing, which tend to host significant quantities of groundwater.

In southwestern Nigeria, groundwater exploration is particularly challenging due to the complexity and heterogeneity of the basement terrain. Numerous case studies from various locations, including Ibadan, Akure, Ife, and Ilorin, have emphasized the need for localized geophysical surveys to reduce the uncertainty associated with aquifer detection. Research by Olorunfemi et al. (1999) and Akinlalu et al. (2017) in these regions confirmed that resistivity values could vary significantly across short distances due to lithological variations and structural discontinuities, making site-specific investigations critical to groundwater success.

2.3. Basic Theory and Principle of Electrical Resistivity Method to Determine Hydrogeological Potential

The electrical resistivity method is a well-established geophysical technique utilized in groundwater exploration due to its effectiveness in characterizing subsurface lithology and identifying aquifer zones. This method operates on the principle of Ohm's Law, which defines the relationship between voltage (V), current (I), and resistance (R) as . In geophysical applications, resistivity ()—a material property—is introduced, which expresses the resistance of a unit cube of earth material [20].

In practice, the electrical resistivity method involves injecting a known electric current into the ground through a pair of electrodes and measuring the resulting potential difference between another pair of electrodes placed at known positions. The subsurface resistivity distribution influences the measured potential differences. These measurements are used to infer the apparent resistivity of the subsurface, which is then interpreted to delineate various geoelectric layers, detect water-bearing zones, and estimate hydrogeological parameters such as aquifer thickness and depth.

The fundamental principle relies on the fact that different geological materials conduct electricity differently. For instance, saturated sandy formations and clay layers often have lower resistivity values due to the presence of moisture and dissolved ions, whereas dry sands, gravels, and consolidated rocks exhibit higher resistivity values. Consequently, mapping the spatial variation in resistivity provides valuable insights into the hydrogeological potential of an area.

$$\rho = 2\pi a \left(\frac{V}{I}\right) \quad \text{(for symmetric configurations like the Wenner array)}$$

Where:

- ρ = apparent resistivity ($\Omega \cdot m$)
- a = electrode spacing
- V = measured potential difference (volts)
- I = current injected (amperes)

Resistivity () is mathematically defined by the equation:

In hydrogeological studies, this method helps in identifying aquiferous zones based on their resistivity contrast with surrounding formations. Low resistivity often indicates the presence of groundwater, especially when correlated with borehole logs or lithological records. However, accurate interpretation requires considering lithological context, pore water salinity, degree of saturation, and clay content, all of which significantly influence the bulk resistivity of the subsurface.

Depending on the electrode configuration—such as Wenner, Schlumberger, or Dipole-Dipole arrays—the depth of investigation and resolution vary. Vertical Electrical Sounding (VES), using mainly the Schlumberger configuration, is commonly applied for determining vertical resistivity variation, enabling the identification of aquifer layers at different depths.

The electrical resistivity method, therefore, provides a non-invasive and cost-effective means of exploring subsurface conditions, making it highly suitable for groundwater potential assessment.

Diagram: Current Flow from a Single Surface Electrode

Below is a simplified diagram (figure 2.1) illustrating the concept of current flow from a single surface electrode (point current source):

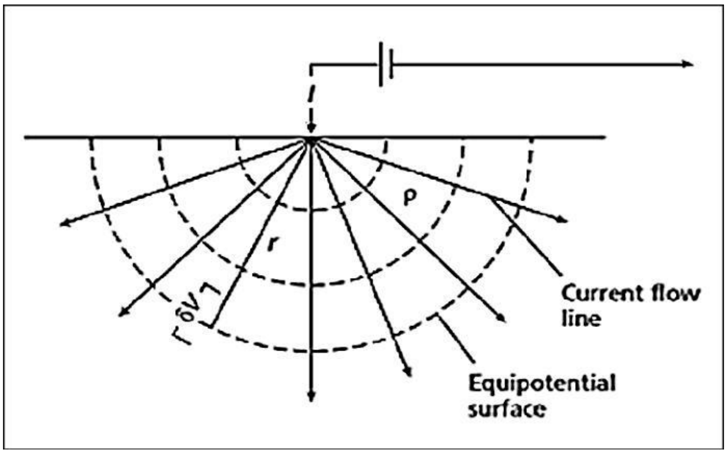


FIGURE 2.1 SCHEMATION OF HEMISPHERICAL FLOW OF DC THROUGH THE SUBSURFACE

Explanation:
The diagram illustrates current dispersing radially from a single electrode (C1) into the ground. In actual surveys, a return electrode (C2) is placed at a distance to complete the circuit. The distribution of current in the subsurface depends on the electrical resistivity of underlying materials. This distribution affects the voltage measured between potential electrodes, which is used to calculate apparent resistivity.

2.4. Special Electrode Configuration

In the field of geophysical exploration, particularly in groundwater investigation, the arrangement and configuration of electrodes form the foundation for accurate subsurface imaging. Electrode configurations define both the mode of current injection and potential difference measurement, influencing the resolution, depth, and precision of the final interpretation. Over time, geophysicists have developed a variety of special electrode arrangements to suit differing geological conditions and survey requirements. These configurations not only simplify field logistics but also enable effective adaptation to the varying resistivity contrasts of subsurface formations [11][20].

Special electrode configurations are designed to enhance the quality of geophysical measurements, especially when standard arrangements are inadequate due to terrain, depth limitations, or the complexity of subsurface features. In regions characterized by fractured bedrock, layered aquifers, or faulted geological structures, conventional arrangements like the

Wenner and Schlumberger arrays might not capture sufficient lateral or vertical variation, necessitating the use of specialized setups. Arrays like the Dipole-Dipole, Pole-Dipole, and Gradient configurations offer varying degrees of sensitivity to both horizontal and vertical subsurface anomalies.

For instance, the Dipole-Dipole array offers excellent lateral resolution, making it particularly useful in detecting subsurface discontinuities such as fractures, faults, or stratigraphic boundaries. The Pole-Dipole array, in contrast, offers deeper penetration and is well suited for structural mapping and large-scale groundwater exploration. The Gradient array, which enables continuous data collection as electrodes are moved, is often used in reconnaissance surveys where rapid coverage of large areas is necessary.

These configurations are also highly adaptable to challenging field conditions. Urban environments, rugged terrain, or areas with dense vegetation may limit the space for deploying symmetric and wide electrode spreads. Special configurations allow for asymmetric or flexible arrangements without a significant compromise in data accuracy. With advancements in inversion algorithms, modern software can model the irregular geometry introduced by these setups, making it possible to derive reliable resistivity models even in constrained conditions.

2.5. Wenner Array

The Wenner array is one of the most widely used configurations in electrical resistivity surveying. It is especially valued for its simplicity and the relatively straightforward interpretation of its results. This configuration consists of four electrodes positioned along a straight line with equal spacing, denoted as “a.” The two outer electrodes (A and B) serve as current injectors, while the two inner electrodes (M and N) are used to measure the potential difference induced by the subsurface resistivity structure.:

One of the main advantages of the Wenner array is its high signal-to-noise ratio, which is particularly beneficial in noisy environments. Additionally, the equal spacing simplifies the process of moving electrodes during the survey, allowing for a steady and consistent data acquisition routine.

The Wenner array is ideal for shallow subsurface investigations and is frequently employed in groundwater exploration where horizontal resistivity variations are of primary interest. Its symmetrical design ensures uniform sensitivity to subsurface layers, although its depth of investigation is often limited compared to other configurations.

The Wenner array is generally more sensitive to vertical changes, it is less suited for detecting lateral variations in resistivity, which can lead to an underestimation of thin, laterally extensive conductive or resistive layers. Nonetheless, it remains a valuable configuration for preliminary surveys, environmental studies, and infrastructure assessments. The relevant equation to estimate the apparent resistivity for a Wenner is given by

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

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** $R = \frac{V}{I}$

The geophysical survey setup using Wenner array is show in figure 2.2.

2.6. Schlumberger Array

The Schlumberger array is another common electrode configuration used in geoelectrical prospecting for groundwater. In this setup shown in figure 2.3, the current electrodes (A and B) are placed symmetrically about a center point, with the potential electrodes (M and N) also symmetrically positioned but much closer together than the current electrodes. As the depth of investigation increases, the current electrodes are progressively moved farther apart, while the potential electrodes often remain fixed until the signal weakens.

The apparent resistivity for the Schlumberger array Is computed using:

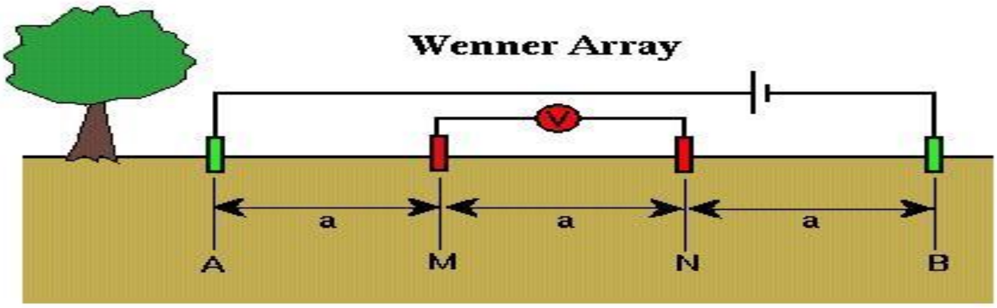
$$\rho_a = \frac{\pi\left(\frac{L^2 - l^2}{4l}\right) \cdot \Delta V}{I}$$

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)**

One of the primary benefits of the Schlumberger array is its ability to probe deeper layers with fewer electrode movements. This is because the potential electrodes, which are more difficult to reposition precisely, can remain stationary for longer survey intervals. The configuration is highly effective in resolving vertical resistivity variations, making it well-suited for layered groundwater systems.

However, compared to the Wenner array, the Schlumberger array is slightly more sensitive to lateral resistivity changes, which can be advantageous in heterogeneous geological environments. Its design also allows for more reliable measurements over rough terrain, where moving all electrodes symmetrically might be difficult.



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

Figure 2.2 schemation od Field condition using Wenner array during Geoelectrical surveys

Schlumberger Array

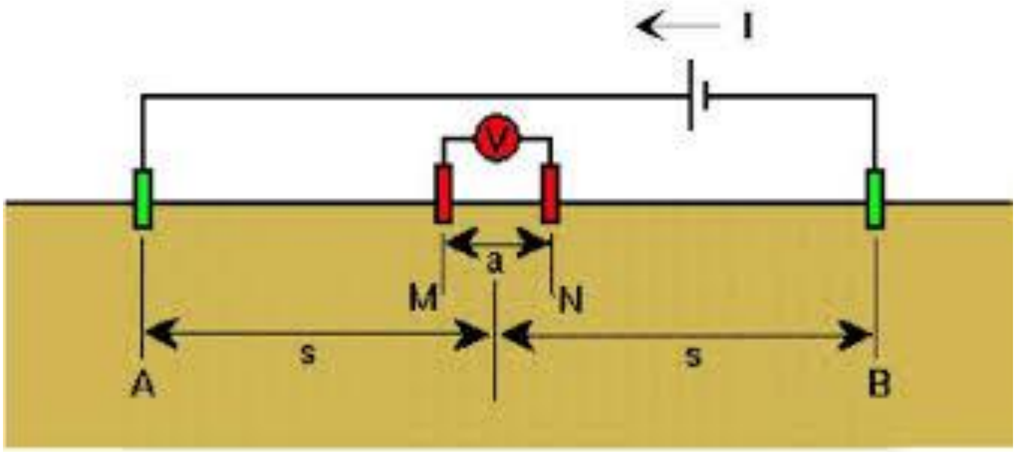


Figure 2.3 schemation of geophysical Field Survey using Schlumberger Array

2.7. Choice of Electrode Configuration

The selection of an appropriate electrode configuration in electrical resistivity surveying is guided by the survey objectives, the geological setting, and practical field considerations. The goal is to strike a balance between depth penetration, resolution, sensitivity to target features, and operational efficiency.

For shallow subsurface investigations where horizontal variations are of interest, the Wenner array is often the preferred choice due to its symmetrical layout and uniform depth sensitivity. For deeper targets and layered earth models, the Schlumberger array is generally more suitable because it can investigate greater depths with minimal electrode repositioning.

When the focus is on lateral heterogeneities, particularly in the identification of faults, fractures, or buried channels, the Dipole-Dipole array offers superior lateral resolution. The Gradient array is ideal for large-scale reconnaissance, as it enables quick and continuous measurements over expansive areas. Meanwhile, the Pole-Dipole configuration provides excellent depth penetration and stability in complex subsurface conditions.

2.8. Half Schlumberger Array

The Half-Schlumberger array is a practical modification of the conventional Schlumberger setup, designed to simplify field operations in difficult or constrained environments. In this configuration, only one current electrode is progressively moved outward, while the other remains stationary or moves minimally. The potential electrodes remain relatively close together, as in the traditional Schlumberger arrangement.

This approach reduces the time and labor involved in relocating electrodes during the course of the survey, especially in rough or obstructed terrain. Despite the reduced symmetry, the Half-Schlumberger array still provides reliable data for vertical electrical sounding, particularly when investigating the depth and thickness of subsurface aquifers.

2.9. Choice of Field Work

Planning and executing fieldwork for electrical resistivity surveys requires careful consideration of both technical and logistical factors. The primary aim is to ensure accurate data acquisition while optimizing time, manpower, and resource allocation.

Site reconnaissance is typically the first step, involving the assessment of terrain, accessibility, vegetation cover, and potential sources of electrical noise (e.g., power lines, pipelines).

CHAPTER 3

3.0. MATERIALS AND METHODS USED

3.1. Introduction

This chapter outlines the systematic approach adopted in conducting the geophysical investigation of groundwater potential within the Ilorin region, which is part of the Southwestern Nigeria Precambrian Basement Complex. The methodology was designed to ensure reliable data acquisition, accuracy in subsurface interpretation, and effective correlation with the area's hydrogeological and geological characteristics.

The focus of this research is on the application of the Electrical Resistivity Method, particularly the Vertical Electrical Sounding (VES) technique, which has been proven to be a valuable tool for groundwater exploration in crystalline basement terrains. The entire methodological process, from site selection through data interpretation, was planned and executed in line with established geophysical standards to minimize errors and improve result reliability.

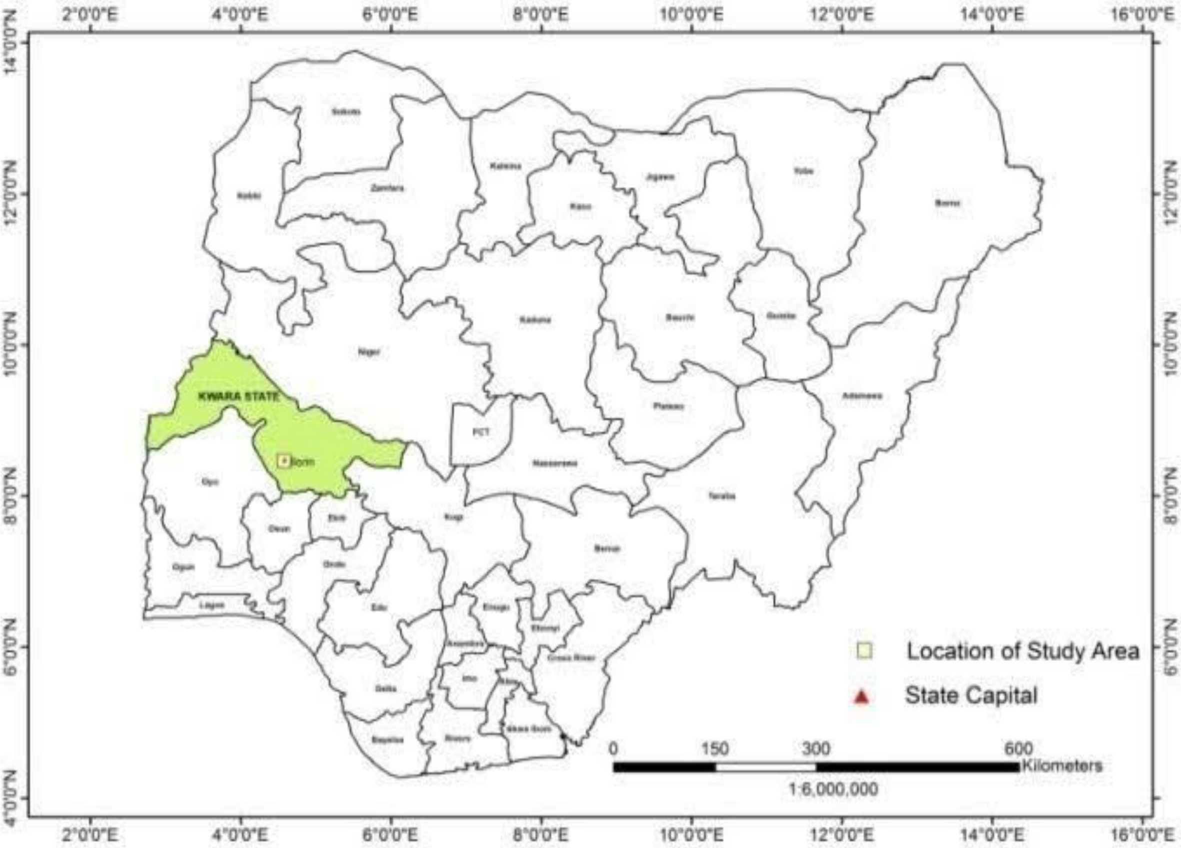


FIGURE 3.1: MAP OF NIGERIA SHOWING KWARA STATE

3.2 The Geomorphological Features, Geological Framework, and Hydrogeological Conditions of the Project Area

3.2.1. Geomorphological Features

Ilorin, the capital city of Kwara State (figure 3.1 and 3.2), is situated within the transitional zone between the humid forest belt of southern Nigeria and the drier savannah regions of the north. The geomorphology of the area is largely shaped by its geological foundation, climatic conditions, and long-term erosional processes. The city is characterized by gently undulating topography, with elevations generally ranging between 250 and 400 meters above sea level.

The terrain consists mainly of Isenberg's, isolated hills, low ridges, and valleys, typical of areas underlain by Precambrian crystalline basement rocks. These Isenberg's are resistant rock outcrops, exposed due to prolonged weathering and erosion of the surrounding softer rocks. The valleys are often broad and shallow, occasionally serving as channels for seasonal streams and rivers during the rainy season.

Soils in the region are primarily lateritic, formed from prolonged weathering of the underlying crystalline rocks. The soil profile typically consists of a thin organic-rich topsoil, a thicker zone of sandy-clay or clayey material, and a deeper zone of weathered rock fragments. These features play a significant role in the infiltration and percolation of rainwater, directly influencing groundwater recharge potential.

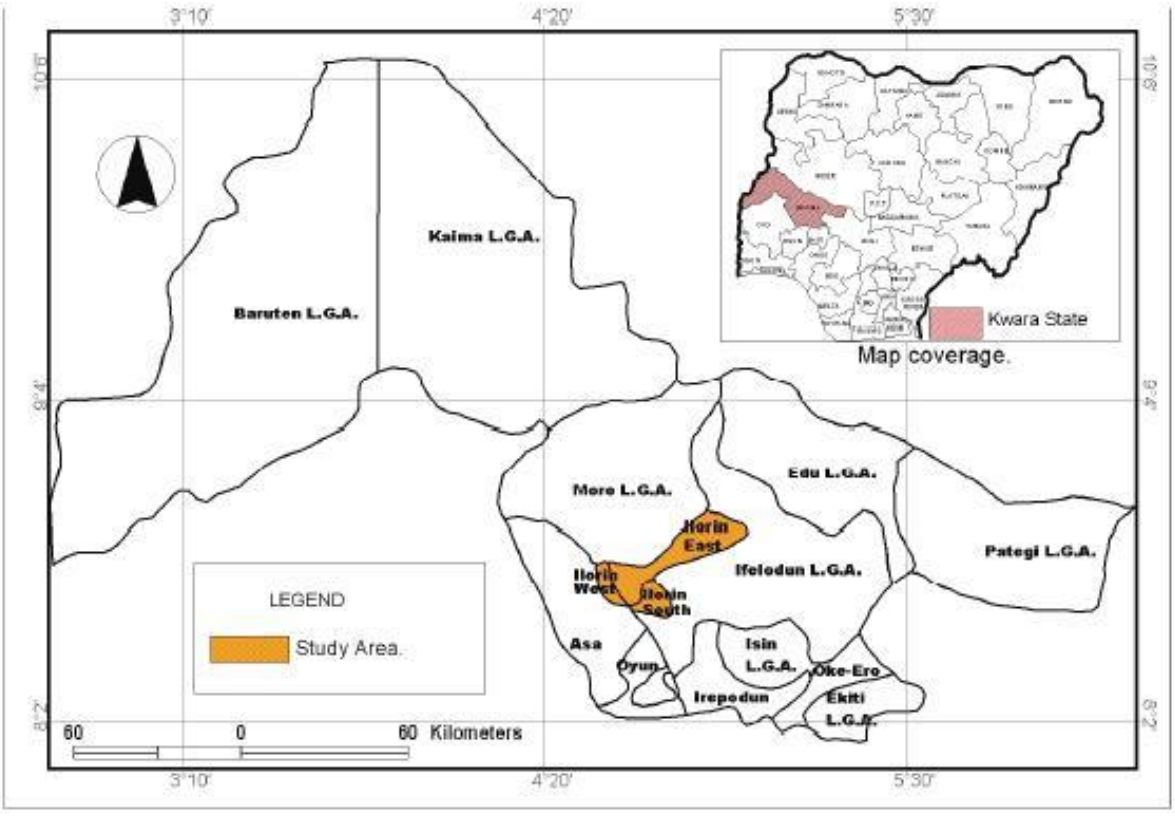


FIGURE 3.2: MAP OF KWARA STATE SHOWING ILORIN STUDIED AREA

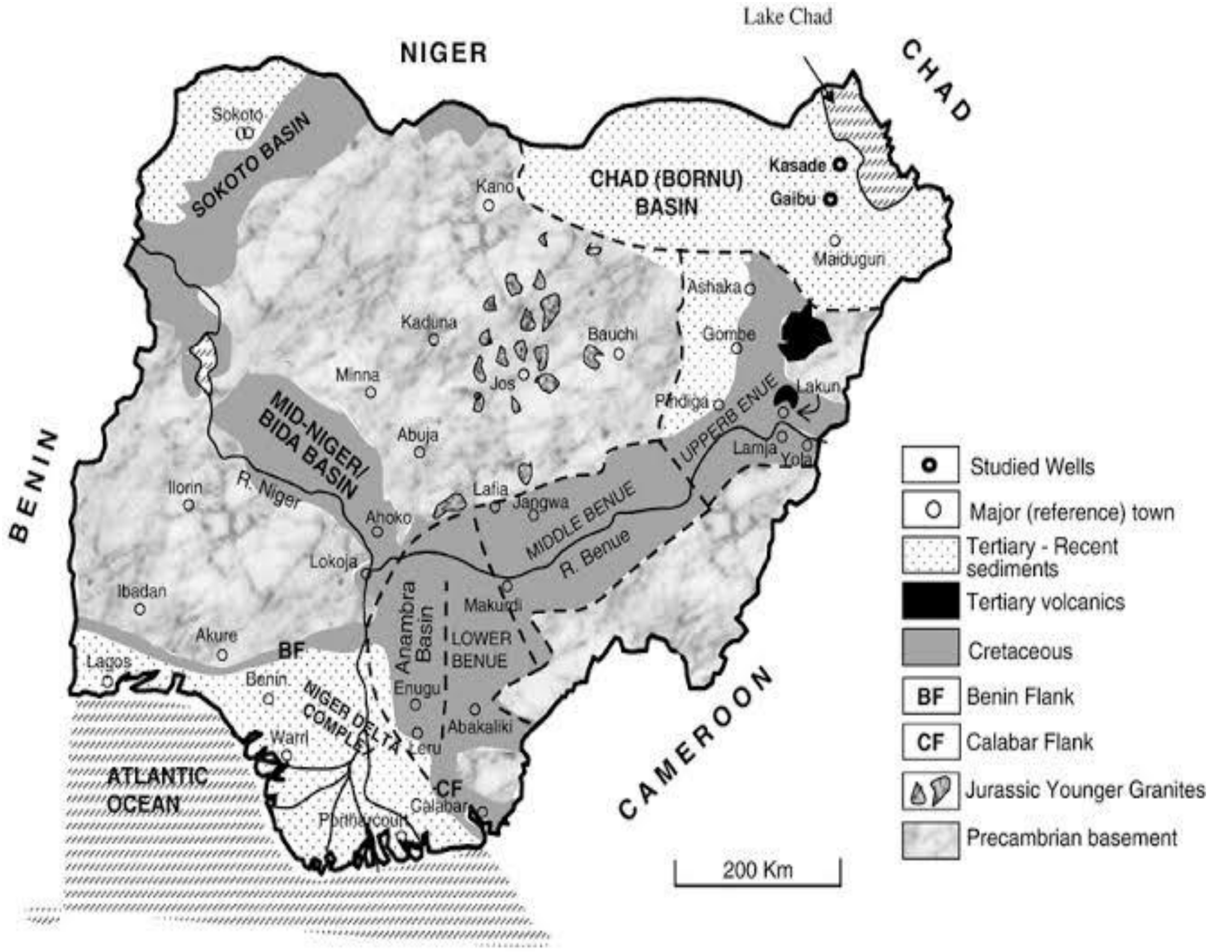


FIGURE 3.3 GEOLOGICAL SKETCH MAP OF NIGERIA SHOWING THE MAJOR GEOLOGICAL COMPONENTS

3.2.2 Geological Framework

The geological setting of Ilorin is part of the extensive Nigerian Precambrian Basement Complex, which covers a large portion of southwestern Nigeria. The Basement Complex is composed of ancient crystalline igneous and metamorphic rocks, primarily consisting of (figure 3.3):

- Migmatites and gneisses
- Quartzites
- Schists
- Granites and pegmatites

These rock types are typically impermeable in their fresh, unweathered state, meaning that groundwater occurrence is largely restricted to secondary features like fractures, joints, faults, and weathered zones.

The basement rocks of Ilorin exhibit varying degrees of weathering, fracturing, and shearing, which are critical for groundwater storage and flow. Areas with significant weathering tend to have higher water retention capacities, while fractures and faults serve as conduits for groundwater movement.

3.2.3. Hydrogeological Conditions

Groundwater in Ilorin is predominantly stored within the weathered and fractured zones of the Precambrian Basement Complex. Since the basement rocks themselves have negligible primary porosity, water storage is reliant on the extent of weathering and the presence of interconnected fracture systems.

The typical hydrogeological profile in the area consists of:

1. Topsoil/Overburden:

A thin surface layer, usually 1–3 meters thick, composed of lateritic soils and sandy clays, often unsaturated.

2. WeatheredBasementLayer:

This layer is the primary aquifer unit in the area, formed from the decomposition and alteration of the basement rocks. Its thickness can vary widely from place to place, generally ranging from 5 to 30 meters. This layer is critical for groundwater storage and may yield moderate to high quantities of water where it is thick and saturated.

3. FracturedBasementLayer:

Below the weathered layer lies the fractured bedrock, which, when intersected by boreholes, can also provide significant groundwater yields. The success of boreholes in this layer depends on the density, width, and connectivity of fractures.

4. Fresh Basement:

Beyond the fractured zone lies fresh, unweathered crystalline rock, which is typically impermeable and yields little to no groundwater.

Groundwater recharge in Ilorin is primarily controlled by rainfall, which is seasonal in nature, with the majority of annual precipitation occurring between April and October. The infiltration of rainwater into the weathered zones is facilitated by the porosity of the soil and the permeability of the weathered bedrock. During the dry season, the water table often declines due to reduced recharge and sustained abstraction for domestic and agricultural purposes.

3.3. Materials Used

The successful completion of the geophysical survey was made possible through the use of standard field and data analysis equipment. The materials and instruments employed are outlined below:

1. **Resistivity Meter** – The core device used for measuring electrical resistance in the subsurface. It injects direct current (DC) or low-frequency alternating current (AC) into the ground through the current electrodes and records the resulting potential difference between the potential electrodes.
2. **Electrodes** – Metallic stakes, usually stainless steel or copper-coated steel rods, used to ensure effective contact between the equipment and the ground for the flow of current and measurement of potential difference.
3. **Cables and Reels** – Insulated cables connected to both current and potential electrodes, with reels to allow easy deployment over various distances along the survey line.
4. **Measuring Tape and Markers** – Used for accurate placement of electrodes at predefined intervals as determined by the selected electrode configuration (e.g., Schlumberger or Wenner array).
5. **GPS Device** – To accurately record the geographical coordinates of each VES point for location referencing and mapping.
6. **Field Notebook and Data Sheets** – For recording field data systematically, including current values, potential differences, electrode spacings, ground conditions, and environmental observations.
7. **Software for Data Interpretation** – Software packages such as IPI2Win, RES2DINV, or similar programs were used to conduct iterative inversion of VES data and generate resistivity models of the subsurface.

3.3.1. Methods

The Method used in this project involved collect of twenty (20) VES Data from relevant bodies that have carried out geophysical surveys within Kwara state polytechnic main campus, Ilorin. The collected data were process and analyzed using relevant softwares and laptop

3.4. Estimation of Geoelectric Parameters

The Dar-Zarrouk parameters (20-23) are critical interpretative tools in geoelectrical exploration, particularly in groundwater investigations. These parameters are derived from the resistivity and thickness of subsurface layers and are used to assess the aquifer characteristics such as transmissivity and protective capacity. They provide a quantitative link between geophysical resistivity data and the hydrogeological significance of the subsurface layers.

3.4.1. First – Order Geoelectric Parameters

The first order Geoelectric parameters of number (n), Resistivity (S), Thickness (h) and depth (d) of layers were obtained from the by the processings Sa – AB/2 curves of the 13 collected VES Data generated using RESINV2 computer softwares and laptop.

3.4.2. Estimation Of Second Order

The Schlumberger array was primarily adopted for the survey because of its suitability for vertical profiling and depth penetration in crystalline basement terrains. The field procedure involved gradually increasing the distance between the current electrodes while maintaining or slightly adjusting the potential electrode positions until the potential difference weakened.

The field data were compiled and plotted as sounding curves (apparent resistivity versus electrode spacing) on log-log graph paper. These curves were then matched against theoretical master curves or inverted numerically using specialized software. The resulting layered-earth models provided estimates of resistivity values and thicknesses for each subsurface layer, helping to identify potential aquifer zones.

The interpreted resistivity models were cross-checked with available geological data and borehole logs, and previous geophysical studies within the Ilorin area. These steps ensured the reliability of the results and improved the interpretation of aquifer depth, lithology, and potential water yield.

The two principal Dar-Zarrouk parameters are the total unit longitudinal Conductance (S) and total unit transverse resistance (R).

3.4.2.1 Longitudinal Conductance (S)

Longitudinal conductance is defined as the sum of the ratios of layer thickness to resistivity for all geoelectric layers encountered. It is given by the equation:

It is given by the equation:

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$$

Where:

- S = Longitudinal Conductance (in Siemens, S)
- h_i = Thickness of the *i-th* layer (in meters, m)
- ρ_i = True resistivity of the *i-th* layer (in ohm-meters, Ω·m)

potential of an aquifer.

3.4.2.2. Transverse Resistance (R)

Transverse resistance, on the other hand, is the sum of the products of resistivity and thickness for each layer and it computed as:

It is computed using the equation:

$$T = \sum_{i=1}^{n} h_i \cdot \rho_i$$

Where:

- T = **Transverse Resistance (in ohm-square meters, $\Omega \cdot m^2$)**
- h_i = **Thickness of the *i-th* layer (in meters, m)**
- ρ_i = **True resistivity of the *i-th* layer (in ohm-meters, $\Omega \cdot m$)**

Transverse resistance is directly linked to the potential yield of an aquifer. A higher value usually indicates a thicker and/or more conductive saturated layer capable of transmitting significant quantities of groundwater, especially in fractured basement aquifers or weathered zones.

CHAPTER 4

4.0. RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents and analyzes the result of the interpretations of the collected VES Data. These results include derived geoelectrical parameters such as layer resistivities, aquifer resistivity, thicknesses, conductance, and anisotropy. The interpretations of these parameters helps to delineate subsurface lithological layers and evaluate the groundwater potential in the study area.

4.2 Results Obtained

Figure 4.1 to 4.4 show typical Sa-AB/2 curves obtained for the study area. These curves were interpreted quantitatively and qualitatively using the approaches suggested in previous related works [2-20]. A summary of the interpreted results initial obtained for the first order Geoelectric parameters of n,S,h,S as well as the inferred curve types and probably Lithologies are presented in table 4.1

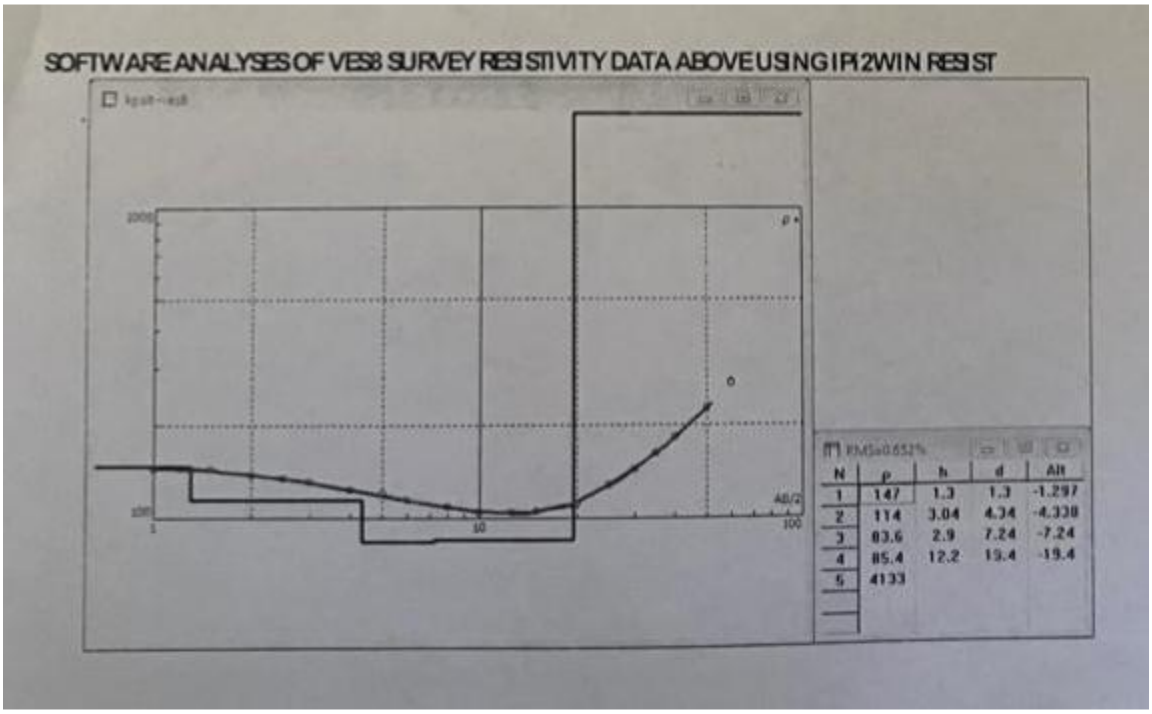


Figure 4.1 SOFTWARE ANALYSES OF VES SURVEY RESISTIVITY DATA USING IPI2WIN RESIST

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 No.	No. of Layers	Resistivity of Layers (Ω·m)	Thickness of Layers (m)	Depth to Layers (m)	Curve Description	Curve Type	Inferred Lithologies
1	1 2 3	297.1, 178.9, 86.7	0.864, 1.07, 7.4	0.864, 1.93, 9.33	Increasing then decreasing	H-type	Topsoil, Dry Sandy Layer, Weathered Basement
2	1 2 3	203, 291.1, 6400.2	2.51, 7.24, 4.78	2.561, 9.237, 9.737	Gradual rise then sharp rise	KQ-type	Sandy Clay, Clayey Sand, Fresh Basement
3	1 2 3	382.3, 1.2, 231	1.09, 3.46, 2.34	1.59, 5.05, 61.65	High–Low–High	H-type	Sand, Clay, Fractured Basement
4	1 2 3	172.2, 223, 1369.0	4.78, 6.26, 3.57	4.78, 11.05, Infinity	Slight rise, then sharp rise	Q-type	Topsoil, Sandy Clay, Basement Rock
5	1 2 3	240.5, 160.2, 1410.4	1.02, 4.03, 5.57	1.52, 5.55, 14.12	Mixed – Alternating Resistivity	HK-type	Topsoil, Clayey Sand, Weathered Basement
6	1 2 3	126.6, 136, 1867	0.5, 5.94, 30.01	0.5, 6.44, 36.44	Low–High–Low–High	HKH-type	Clay, Sand, Clay, Fresh Basement
7	1 3 3 4	202.1, 133.6, 111.3, 231.3	0.5, 7.47, 10.87 14.67	0.5, 7.97, 18.7 23.6	Steady rise	K-type	Laterite, Sand, Basement
8	1 2 3 4	171.9, 47.9, 846.0, 631.3	0.814, 2.5, 9.25 4.23	0.814, 3.31, 12.56 16.10	Rise–Fall–Rise	HKH-type	Topsoil, Sand Clay, Weathered Basement
9	1 2 3	344, 3068.1, 22.06	6.71, 11.0, 8.11	6.71, 17.71, 29.87	Sharp rise–fall	KQ-type	Sandy Clay, Weathered Basement, Fresh Rock
10	1 2 3	4135.1, 126.1, 103.9	0.936, 0.936, 0.748	0.936, 1.872, 2.5	Sharp drop then gradual drop	QH-type	Hardpan, Clayey Sand, Clay
11	1 2 3 4	616.9, 338.2, 628.7 163.8	0.98, 2.82, 2.76 0.45	0.98, 3.8, 2.36 Infinity	High–Mid–Low–High	HKH-type	Clayey Sand, Clay, Basement
12	1 2 3 4	177.3, 325.1, 245.3 152.7	1.5, 0.736 0.463 0.739	0.526 0.23 0.43 1.26	Slight rise	K-type	Topsoil, Sandy Clay, –

Table 4.1: Summary of results of first – order Geoelectric parameters, curve types and probably Lithologies

Table 4.2 Summary of computations of second – order Geoelectric parameters

VES No	No. of Layers	Longitudinal Conductance of Layers (mho/m)	Transverse Unit Resistance (Ohm·m²)	Total Longitudinal Conductance (S)	Total Transverse Resistance (Ohm)	Soil Competence Rating	Protective Capacity Rating
1	1 2 3	0.000700 0.000867 0.000833	51.3	0.011	130.9	Low	Moderate
2	1 2 3	0.001000 0.001067 0.001933	43.2	0.014	119.1	Low	Moderate
3	1 2 3	0.000800 0.001100 0.001100	47.9	0.013	125.7	Medium	Good
4	1 2 3 4	0.001300 0.001500 0.001200 0.001000	60.2	0.018	135.3	Medium	Moderate
5	1 2 3 4	0.004000 0.003800 0.006100 0.007100	39.4	0.021	140.2	High	Good
6	1 2 3	0.004200 0.004000 0.003800	55.6	0.012	136.7	Low	Poor
7	1 2 3 4	0.004100 0.005000 0.005000 0.004900	45.6	0.019	129.4	Medium	Good
8	1 2 3 4	0.003600 0.003700 0.004100 0.003600	48.8	0.015	128.4	Medium	Moderate
9	1 2 3 4	0.003800 0.003600 0.003800 0.003800	50.6	0.015	128.6	Low	Poor
10	1 2 3	0.005200 0.005200 0.005600	46.2	0.016	132.7	High	Good
11	1 2 3	0.004200 0.004500 0.005300	49.2	0.014	127.2	Medium	Moderate
12	1 2 3 4	0.004000 0.004600 0.004400 0.005000	44.5	0.018	131.5	Medium	Good

Table 4.2: Results of derived second order Geoelectric parameters

4.3 Evaluation of Groundwater Potentials

Table 4.3 summarizes various hydrogeological parameters such as hydraulic conductivity, transmissivity, and coefficients derived from VES data. These are essential in quantifying groundwater yield and storage.

Key interpretations:

Hydraulic Conductivity (K_1 and K_2): Indicates how easily water can flow through the aquifer materials. Higher values imply better groundwater potential.

Transmissivity (Tr_1 and Tr_2): Represents the total water-transmitting capacity of the aquifer. Aquifers with transmissivity > 10 m²/day are typically considered good.

Overburden Thickness: Thicker overburden often indicates a larger saturated zone and better aquifer potential.

Resistivity and Anisotropy: Provide insight into aquifer heterogeneity and layering.

Bedrock Coefficient: Helps assess the permeability contrast between bedrock and overburden.

This table is critical in identifying viable borehole locations and understanding aquifer dynamics.

VES No	Hydraulic Conductivity K_1	Hydraulic Conductivity K_2	Transmissivity Tr_1	Transmissivity Tr_2	Transmissivity Tr_3	Overburden Thickness (m)	Longitudinal Resistivity (Ω·m)	Transverse Resistivity (Ω·m)	Coefficient of Anisotropy	Bedrock Coefficient	Groundwater Potentials
1	2.5	4.3	12.8	22.1	34.9	9.33	150	180	1.10	0.56	Moderate
2	3.0	4.8	14.2	23.5	37.7	7.237	165	198	1.12	0.61	Good
3	2.2	3.9	11.4	19.6	31.0	5.05	142	175	1.12	0.49	Low
4	3.5	5.0	15.3	26.0	41.3	11	158	200	1.10	0.63	Good
5	2.7	4.4	13.2	21.9	31.6	14.12	140	185	1.13	0.58	High
6	1.9	3.2	9.7	17.5	27.2	7.97	130	160	1.09	0.52	Moderate
7	2.8	4.5	13.8	24.3	38.1	15.4	155	190	1.11	0.59	High
8	3.1	5.2	16.0	27.4	43.4	10.5	168	210	1.12	0.65	Good
9	2.0	3.6	10.5	18.9	29.4	9.11	135	170	1.11	0.50	Moderate
10	1.7	3.0	8.6	16.4	25.0	2.11	120	150	1.09	0.45	Low
11	3.3	5.1	15.0	25.8	40.8	14.1	162	205	1.12	0.62	High
12	2.6	4.1	12.3	21.0	33.3	16.6	148	187	1.11	0.57	High

Table 4.3: Elevation of Groundwater potential

4.3 Presentation and Interpretation of Geophysical Maps and Figures

This section presents the spatial distribution and interpretation of the geoelectrical parameters across the study area. Each parameter offers insight into the subsurface condition and its significance to groundwater potential.

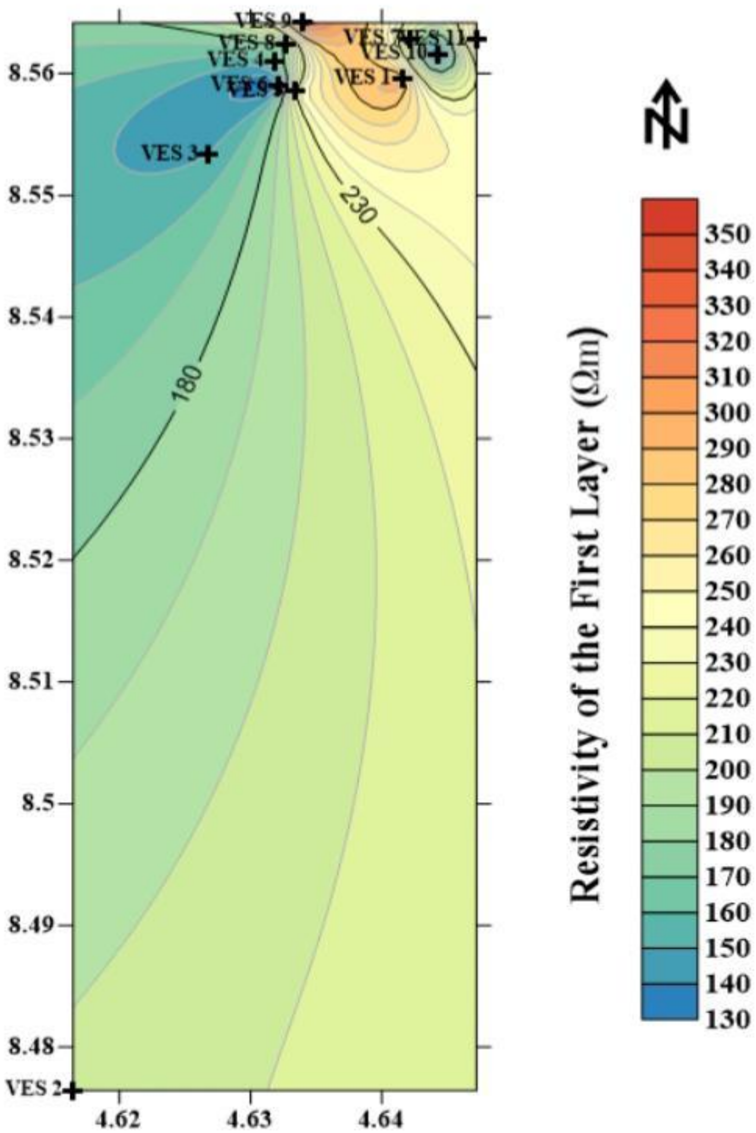


Figure 4.2: Resistivity of the first layer

4.2 Resistivity of the First Layer (ℓ_1)

Figure 2 displays the resistivity of the first (topsoil) layer. The resistivity ranges from 114 Ωm to 344 Ωm, indicating variable surface compositions. Lower resistivity values suggest clayey or moist topsoil (e.g., VES 10), while higher values (e.g., VES 9) imply dry sandy or lateritic materials. This layer influences surface infiltration and may reflect areas of possible contamination or recharge.

Figure 2 presents the distribution of resistivity values in the first geoelectrical layer, which typically corresponds to the topsoil. The resistivity values across the study area range from 114 Ωm to 344 Ωm, highlighting significant variations in the surface lithology and moisture content.

Low resistivity readings, such as those recorded at VES 10, are indicative of clayey or moisture-saturated soils. Clay-rich materials have high water retention and low permeability, which often results in decreased resistivity. Such zones may also suggest areas prone to waterlogging or potential surface contamination, especially if anthropogenic activities like farming or waste disposal are prevalent. These areas warrant careful consideration during site evaluation for groundwater development, as contaminated topsoil can negatively impact the quality of shallow aquifers.

Conversely, higher resistivity values observed in locations such as VES 9 are characteristic of dry sandy soils or lateritic crusts. These materials exhibit better drainage and are typically associated with relatively lower water content in the surface layer. Lateritic soils, in particular, tend to be compact and resistive, often forming protective caps over underlying aquifers. While these high-resistivity zones may hinder immediate surface infiltration, they can enhance the longevity of underlying groundwater reserves by limiting direct contamination.

The spatial distribution of resistivity in this layer also provides insights into infiltration potential. Areas with moderate resistivity may represent transitional zones with sandy-clayey mixtures, offering a balance between permeability and water retention. These regions could serve as favorable recharge pathways, particularly where overburden thickness supports vertical percolation into deeper aquifer units.

Understanding the nature of the first layer is critical, as it controls initial water entry into the subsurface system. In groundwater exploration, this information assists in evaluating surface conditions, identifying recharge-prone areas, and assessing contamination vulnerability. Integrating this layer's resistivity data with overburden thickness and aquifer properties further refines borehole siting and enhances groundwater resource management across the Ilorin region.

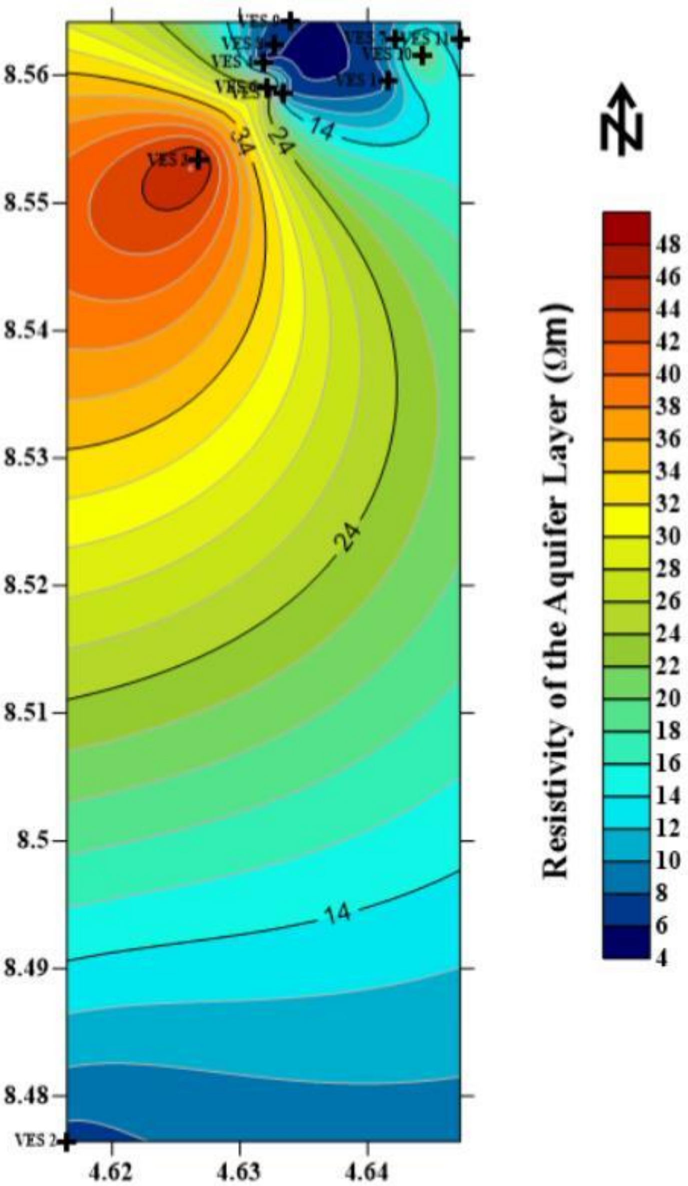


Figure 4.3: Resistivity of aquifer layer

4.3. Resistivity of the Aquifer Layer (ℓaq)

The aquifer resistivity values in Figure 4 vary significantly from 4.26 Ωm to 46.6 Ωm. Low values (e.g., VES 4 and VES 1) indicate saturated clay or fine-grained material, while moderate to high resistivity zones (e.g., VES 3) suggest sandy or gravelly aquifers with better groundwater potential. Aquifer resistivity is a key determinant of groundwater quality and lithology.

Figure 4 depicts the resistivity distribution within the aquifer layer, which is critical for identifying the nature and quality of groundwater-bearing formations in the study area. The resistivity values for this layer range widely from 4.26 Ωm to 46.6 Ωm, indicating diverse lithological characteristics and varying degrees of saturation.

Low resistivity values, such as those observed at VES 4 and VES 1, typically correspond to saturated clay or fine-grained sediments. These materials have a high water content but often exhibit low permeability and reduced groundwater productivity. The low resistivity is primarily due to the high ionic content of pore water trapped within the fine matrix of clay or silty materials, which enhances electrical conductivity. While these zones may contain groundwater, the quality and extractability of water can be limited, as clay-rich layers tend to impede fluid flow and may also be associated with poor water quality due to the presence of dissolved minerals or contaminants.

Conversely, the moderate to higher resistivity values recorded at locations such as VES 3 suggest the presence of sandy or gravelly sediments, which are typically more permeable and effective aquifers. These formations allow easier movement and storage of groundwater, often translating to higher yields in boreholes. The sandy or gravelly lithology, coupled with sufficient saturation, results in resistivity values that are elevated compared to clayey zones but still relatively low compared to consolidated rocks. Such zones represent the most promising groundwater reservoirs within the study area, given their favorable hydraulic properties and potential for sustainable water extraction.

The variation in aquifer resistivity also has important implications for groundwater quality. Zones with moderate resistivity usually indicate cleaner, less mineralized groundwater, suitable for domestic, agricultural, or industrial use. On the other hand, extremely low resistivity areas may correspond to stagnant or mineral-rich waters, which could require further assessment before exploitation.

Overall, resistivity mapping of the aquifer layer serves as a vital tool in characterizing the hydrogeological conditions of the subsurface. By distinguishing between different sediment types and saturation levels, it supports accurate delineation of productive aquifers and informs decisions on well placement, drilling depth, and water resource management in the Ilorin region.

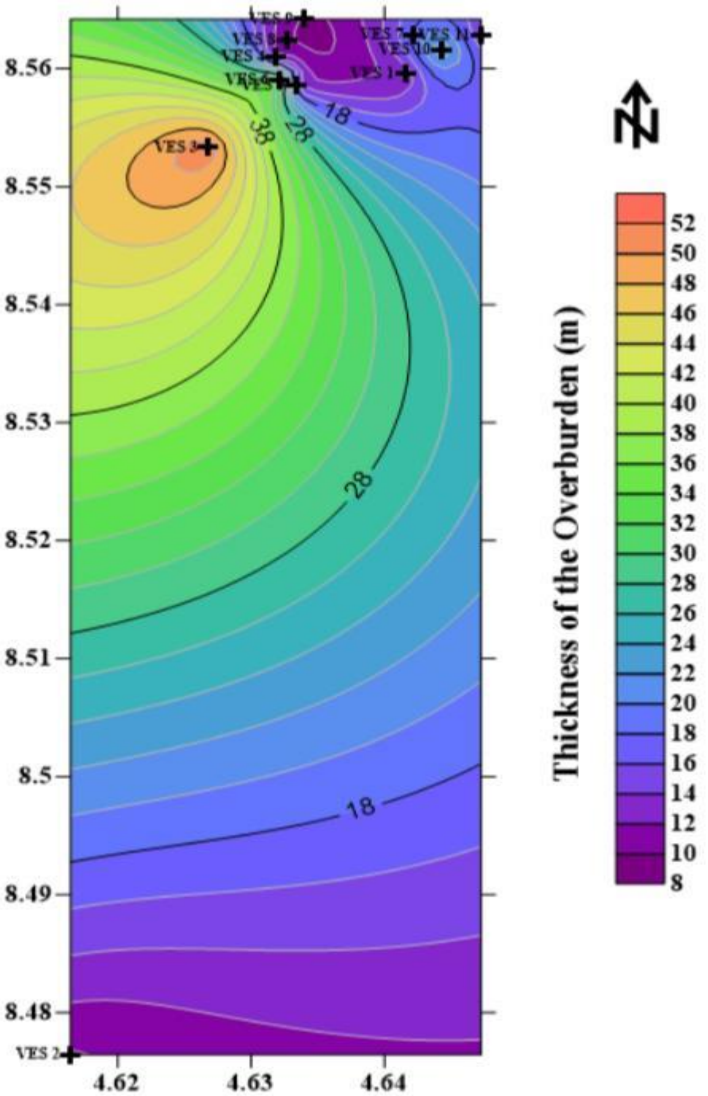


Figure 4.4: Thickness of the Overburden

4.4 Thickness of the Overburden (H)

Overburden thickness (Figure 5) ranges from about 9.8 m to 51.6 m. Areas with thick overburden (e.g., VES 3 and 6) are favorable for groundwater retention, as they provide more space for aquifer development. Thin overburden zones may be susceptible to quick contamination and poor aquifer formation.

Figure 5 illustrates the spatial distribution of the overburden thickness (H) across the study area, with values ranging from approximately 9.8 meters to 51.6 meters. Overburden refers to the unconsolidated sediments and weathered materials that lie above the bedrock or aquifer units, and its thickness plays a critical role in groundwater occurrence, storage, and protection.

Zones with thick overburden, such as those observed at VES 3 and VES 6, are generally considered favorable for groundwater retention and aquifer development. A thicker overburden layer implies a larger volume of porous and permeable sediments capable of storing significant quantities of groundwater. These areas provide ample space for water accumulation and recharge, enhancing the potential for sustainable groundwater supply. Additionally, thick overburden can act as a protective buffer that shields underlying aquifers from surface contamination, reducing the risk of pollutants seeping directly into the water-bearing formations.

In contrast, areas characterized by thin overburden—with thickness values closer to 9.8 meters—may face greater vulnerability to contamination and poor aquifer development. Thin overburden zones typically offer limited storage capacity and may be more directly influenced by surface activities such as agricultural runoff, industrial waste disposal, or septic leakage. The reduced thickness also limits the depth to bedrock, which may be impermeable and unable to store or transmit significant groundwater, thus restricting the overall productivity of wells drilled in such locations.

Furthermore, the variation in overburden thickness affects the hydraulic connectivity and recharge dynamics of the aquifer system. Thick, permeable overburden facilitates vertical water movement from the surface to the aquifer, promoting recharge. Conversely, thin or compacted overburden may hinder infiltration, leading to increased surface runoff and decreased groundwater replenishment.

Understanding the overburden thickness is essential for designing effective groundwater extraction strategies. It aids in determining appropriate drilling depths, estimating well yields, and assessing the sustainability of groundwater resources. The overburden thickness map, when integrated with resistivity and other geophysical data, provides a comprehensive framework for groundwater resource evaluation in the Ilorin region.

4.4 Implications for Groundwater Potential

The combined interpretation of geoelectrical parameters across the study area provides significant insights into the subsurface hydrogeological conditions and groundwater prospectivity. Based on the spatial variation of aquifer properties such as resistivity, overburden thickness, aquifer thickness, anisotropy, and conductance, the following implications are drawn:

4.4.1 Zones of High Groundwater Potential

VES points such as VES 2, 3, 6, and 7 show favorable conditions for groundwater accumulation:

VES 3 records the highest aquifer resistivity (46.60 Ωm), thick overburden (51.65 m), and high transverse resistance (186.33 Ωm^2), all of which are indicative of a well-developed, saturated, sandy aquifer with good yield.

VES 6 presents thick overburden and aquifer layers, high transverse resistance (156.13 Ωm^2), and a moderate anisotropy coefficient (6.44), suggesting a productive and moderately deep aquifer system.

VES 7 has the thickest aquifer layer (7.47 m), with moderate resistivity and considerable protection from surface contamination based on its Si and St values.

These locations are optimal candidates for groundwater development and borehole drilling, with likely sustainable yields.

4.4.2 Moderate Potential Zones

Moderate groundwater potential exists in areas such as VES 1, 5, 8, and 9, which show:

Moderate aquifer resistivities (6.71–8.57 Ωm), suggesting water-bearing sandy clay or silty sand materials.

Medium overburden thickness (10–15 m), which may provide adequate storage, though yield may be limited.

Intermediate values for anisotropy and unit conductance, implying variable but usable aquifer conditions. These areas can support domestic or small-scale water supply needs but may require proper design considerations to ensure longevity and productivity

4.4.3 Low Groundwater Potential Zones

VES points 4, 10, and 11 exhibit less favorable characteristics for groundwater development:

VES 4 has low aquifer resistivity (4.26 Ωm), thin overburden, and high longitudinal conductance (0.3012 Ωm^{-1}), indicative of clay-rich layers with poor water transmission.

VES 10 and 11 show shallow depths to water table (1.00–1.50 m) and thin aquifer layers (<2 m), raising concerns over rapid contamination from surface activities and limited water storage.

These areas are less suited for long-term groundwater exploitation and may only support seasonal or low-demand usage unless further improved by artificial recharge or careful drilling into deeper units.

4.4.4 Aquifer Protection and Vulnerability

The longitudinal unit conductance (Si) and coefficient of anisotropy (Λ) help evaluate the protective capacity of the overburden. Higher Si values (e.g., VES 5) denote better aquifer protection due to the presence of conductive clay. However, low Si (e.g., VES 1 and 10) implies poor protection and greater vulnerability to contamination.

Areas with moderate anisotropy ($\Lambda \approx 2$–3) reflect more isotropic conditions, allowing for relatively uniform groundwater flow, while high anisotropy ($\Lambda > 5$) might indicate complex layering, which can hinder flow paths and affect well design.

4.4.5 Groundwater Development Recommendations

Borehole drilling is recommended in VES 2, 3, 6, and 7 due to favorable resistivity and aquifer thickness.

For moderate zones, boreholes should be carefully sited with possible geophysical follow-up and hydraulic testing.

Protective measures such as sanitary seals and well casings should be emphasized in shallow water table zones (e.g., VES 10 and 11) to prevent pollution.

CHAPTER FIVE

5.0. SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.1 Summary

This research was conducted to explore the basement complex and subsurface characteristics influencing groundwater potential within Ilorin, Kwara State, Nigeria. The study area, being within a geologically complex terrain comprising basement complex rocks and sedimentary overlays, required a robust and non-invasive method for subsurface characterization. Hence, the electrical resistivity method—specifically the Vertical Electrical Sounding (VES) using the Schlumberger array—was employed.

A total of [13] VES stations were established across various locations in the study area to achieve lateral and vertical coverage of the subsurface features. The field data acquired was subjected to partial curve matching and computer-aided 1D inversion to derive layered geoelectrical parameters. These included resistivity values, thicknesses, and depths to different subsurface interfaces.

From the interpretation, the subsurface stratigraphy generally comprised three to five geoelectric layers. The topmost layer usually consisted of lateritic soil or sandy clay with low to moderate resistivity values (typically ranging from 40 to 150 ohm-m). This was underlain by a weathered or partially weathered zone with moderate resistivity, indicative of clayey sands or weathered bedrock material, depending on the local lithological setting. Beneath this, the fractured basement was often encountered, presenting as a critical groundwater-bearing horizon due to its increased porosity and permeability. The fresh basement rock, often characterized by very high resistivity values (above 1000 ohm-m), formed the deepest and generally non-aquiferous layer.

The aquiferous zones were delineated based on the combined assessment of layer resistivity, thickness, and the presence of fracturing or weathering, which are essential for groundwater accumulation and movement. Zones with thick weathered and/or fractured basement layers, exhibiting moderate resistivity values, were interpreted as potential groundwater-bearing formations. In contrast, zones with thin overburden or absence of weathered/fractured layers were inferred to have poor groundwater potential.

5.2 Conclusion

The investigation of lithological units and subsurface features within Ilorin precambian basement has provided valuable insights into the distribution, characteristics, and groundwater potential of the underlying geological formations. The study confirms that the electrical resistivity method is a powerful tool for delineating subsurface layers and identifying zones favorable for groundwater development, especially in regions with complex geology.

The research highlighted the following key findings:

Groundwater occurrence in the area is largely influenced by structural and lithological controls. The presence of weathered and fractured basement zones serves as the primary aquifer medium in the study area.

Aquifer thickness varies significantly across the study area, with the most favorable groundwater potential occurring where thick weathered zones coincide with fractured basement rock.

Layer resistivity values were instrumental in distinguishing between saturated and unsaturated formations. Low to moderate resistivity values in the weathered/fractured basement corresponded to potential aquifer zones, while high resistivity indicated compact or unfractured bedrock with poor water yield.

Some areas in the study showed limited groundwater potential, either due to shallow bedrock, thin overburden, or lack of significant weathering/fracturing. These areas may not be suitable for high-yield borehole drilling without further investigation.

5.3 Recommendations

Based on the outcomes of this study, the following recommendations are made for future groundwater exploration, management, and scientific development within the study area and similar terrains:

5.3.1 Borehole Drilling and Siting

Boreholes should be located at positions where geophysical interpretation has revealed thick weathered or fractured basement zones. These zones have higher porosity and permeability, which are critical for sustainable water yield.

Priority should be given to locations where the aquifer layer demonstrates both considerable thickness and moderate resistivity (typically between 100 and 500 ohm-m), suggesting saturated and permeable media.

5.3.2 Hydrogeological and Pumping Test Verification

Following geophysical delineation, hydrogeological logging and pumping tests should be conducted on exploratory wells to verify water yield, drawdown behavior, and recharge characteristics.

Water quality tests (physico-chemical and bacteriological) should be conducted to assess the suitability of groundwater for domestic, agricultural, and industrial use.

5.3.3 Use of Integrated Geophysical Methods

Future studies should incorporate complementary geophysical techniques such as:

Seismic refraction, for detecting lithological contrasts and depth to bedrock.

Electromagnetic (EM) surveys, for rapid and shallow-depth profiling.

2D and 3D Electrical Resistivity Imaging (ERI), for detailed mapping of lateral changes in subsurface properties

5.3.4 Establishment of a Groundwater Monitoring Framework

A systematic groundwater monitoring network should be established in the region to:

Monitor seasonal fluctuations in groundwater levels.

Detect early signs of over-extraction or contamination.

Guide future groundwater resource planning and policy implementation.

5.3.5 Capacity Building and Public Awareness

Local communities should be educated on the importance of sustainable groundwater use and protection, especially in rural areas where water scarcity often leads to overdependence on few boreholes.

Training of local personnel in basic geophysical data acquisition and interpretation can enhance capacity and reduce long-term dependence on external consultants.

5.3.6 Policy Implication and Water Resource Planning

Government agencies and water boards should use geophysical data to:

Strategically plan new water supply schemes.

Avoid failed boreholes and resource wastage.

Map groundwater recharge zones and critical aquifer boundaries.

Geophysical maps and interpreted aquifer profiles from this research should be archived in a central database accessible to planners, engineers, and researchers.

5.3.7 Further Scientific Studies

The study should be extended across a wider area of Ilorin to build a regional hydrogeophysical model.

Future investigations may also assess the impacts of climate variability, land use changes, and anthropogenic activities on groundwater sustainability in the region.

5.4 Final Remark

The sustainable management of groundwater resources in Ilorin Kwara state requires the collaboration of scientists, government authorities, and local communities. This study has provided a foundational framework for understanding groundwater occurrence in the area and serves as a decision-support tool for effective water resource development.

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