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Aquifer Characterisation and Vulnerability Assessment in a Typical Basement Complex Terrain

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Abstract

The study employed electrical resistivity surveying using Vertical Electrical Sounding (VES) at 30 locations with a Schlumberger array to evaluate the groundwater potential and aquifer vulnerability within the College of Health Technology, Ijero-Ekiti. Results were presented as maps of resistivity, aquifer thickness, overburden characteristics (TLOA), porosity, hydraulic conductivity, and transmissivity. The resistivity map identifies five zones, with low resistivity (13.105–98.285 ohm-m) in the southern and central areas, indicating shallow, saturated clay-rich aquifers that support hand-dug wells but are prone to contamination. Higher resistivity zones suggest deeper or impermeable materials with lower groundwater potential. Aquifer thickness varies from 1.602 to 11.297 m; thicker zones in the south and center support sustainable yields, while thinner margins are more vulnerable to seasonal drying and pollution. TLOA values (0.702–6.897 m) reflect protective cover; low TLOA zones are highly vulnerable, while higher TLOA regions offer better aquifer protection and long-term supply potential. Longitudinal conductance reveals that high-conductance zones (0.305–0.732 S) in the central area provide strong protection, while low-conductance zones (0.005–0.039 S) in the north and southeast are at risk of contamination. Porosity values (24.156–41.53%) indicate high-porosity zones in the center, which are ideal for groundwater development, although they are more vulnerable. In contrast, low-porosity areas may require deep or fracture-specific drilling. Hydraulic conductivity (0.745–35.276 m/day) and transmissivity (1.835–321.004 m²/day) confirm the central and southern zones as most productive. The study recommends prioritizing borehole siting in zones with high resistivity, thickness, and porosity, implementing contamination controls in vulnerable areas, and integrating multiple hydrogeological parameters for effective groundwater development.

Keywords: *Water Characterisation, Basement complex, Hydrogeological mapping, Groundwater protection, Zonation analysis.*

1.0 Introduction

Underground water is an essential and primary source of freshwater for agriculture, domestic, and industrial activities in many regions where surface water availability is limited or unreliable [29]. The importance of groundwater is especially evident in arid and semi-arid regions, as well as in areas underlain by basement complex terrains, where surface water resources are either intermittent or absent [4], [24]. However, the viability of groundwater is progressively endangered by various factors, including excessive abstraction, pollution, and climate change, requiring comprehensive evaluations of aquifer susceptibility. Groundwater contamination, in particular, poses a significant threat to water safety, as pollutants from agricultural, industrial, and domestic activities can infiltrate aquifers and impair water quality, rendering it unfit for human use and compromising ecosystem sustainability [13], [20], [26]. In crystalline basement terrains, groundwater distribution and flow differ significantly from those in sedimentary basins due to the distinct geological and hydrogeological attributes of these regions [35]. Basement complex rocks are mainly constituted of crystalline, impermeable units with negligible primary porosity, meaning that the accumulation and movement of groundwater depend on secondary porosity formed through weathering and fracturing [3], [5]. The weathered overburden, with variable thickness, often serves as the primary storage unit, while fractures and faults act as conduits for groundwater flow [19]. These characteristics result in highly heterogeneous aquifer conditions, making groundwater availability and vulnerability assessment more complex than in porous sedimentary aquifers [9]. Aquifer vulnerability refers to the susceptibility of subsurface water to contamination, determined by both inherent hydrogeologic characteristics and external anthropogenic influences [4]. The extent of vulnerability is determined by factors such as the nature of the overlying soil, depth to the water table, and geologic formations, recharge rates, and the presence of protective confining layers [13]. In basement terrains, where groundwater primarily occurs within fractured and weathered zones, the protective capacity of the overburden materials is often limited, allowing contaminants from the surface to percolate swiftly through fractures and interconnected weathered zones [20]. This renders basement aquifers particularly vulnerable to contamination from agricultural runoff, industrial effluents, sewage seepage, and indiscriminate waste disposal, resulting in considerable degradation of water quality [9], [22]. Several researchers have investigated groundwater potential and vulnerability in different parts of the country, highlighting the challenges associated with water resource management in basement regions [9], [22], [24]. Several models have been developed to assess aquifer vulnerability, with differing levels of reliability across geological settings. The DRASTIC model [4], based on seven hydrogeological indicators, is widely used but yields suboptimal results in basement terrains due to complex groundwater flow [3]. Similarly, the GOD model [13], though useful, overlooks fractures and secondary porosity - key controls on groundwater dynamics in basement complex environments [5]. Traditional vulnerability mapping methods mainly depend on hydrogeological parameters, but recent geospatial and geoelectrical advances have enhanced assessment accuracy [5]. Geophysical tools such as electrical resistivity tomography (ERT) and vertical electrical sounding (VES) have effectively delineated fracture-controlled groundwater flow and protective layer thickness in basement aquifers [20]. However, many models still use static datasets, neglecting temporal variations in recharge and contamination [13]. Moreover, geophysical methods such as electrical resistivity, ground penetrating radar, magnetic method, and seismic refraction methods are informative, less expensive, but require specialized expertise, limiting their use in developing regions [5]. This study integrates geological and geophysical data to characterize the hydrogeophysical properties of the study area and develop aquifer vulnerability models..

1.1 Description and Geology of the Study Area

Ijero-Ekiti is a significant town in Ekiti State, southwestern Nigeria, located at approximately 7.813°N, 5.067°E. It borders towns like Ijurin-Ekiti, Ara-Ekiti, Ikoro-Ekiti, and Aramoko-Ekiti (Figure 1). The area experiences a tropical climate with wet and dry seasons, and annual temperatures between 24°C and 30°C. With a moderate population size, the town serves as a socio-cultural and administrative center. Its economy thrives on agriculture, mineral resources (feldspar, quartz, kaolin), and local crafts. Ijero-Ekiti is easily accessible via major roads connecting it to cities like Ado-Ekiti and Akure, making it strategically important for trade and development. Ijero-Ekiti lies within the Precambrian southwest Nigerian basement complex and is largely underlain by the Ife–Ilesha schist-belt assemblage and various crystalline basement lithologies. Bedrocks include migmatite-/banded-gneiss, biotite and calc-gneiss, amphibole-rich schists, quartzites, epidiorites, and numerous steeply intruded granite–pegmatite bodies (Figure 2) that host rare-metal (lithium, tin, tantalum, niobium, beryllium) and gemstone mineralization pegmatites with lepidolite and tourmaline [11], [30]. Structurally, the area records Pan-African deformation: dominant NNE–SSW to NE–SW trends, folding, faulting, and shear fabrics that control the distribution of schist belts and the emplacement of pegmatites [1], [2]. These structural features also localize fracture-controlled groundwater flow and mineralized zones exploited by artisanal mining [7]. Physiographically, the landscape is typically rugged to undulating with isolated hills (e.g., Kusa mining hill and exposed schist outcrops) and lateritic residual covers in lower–relief areas; laterite and clay deposits overlie the basement in many localities and influence surface drainage, soil development, and shallow aquifer occurrence [23]. Due to complex geology and human activities like mining and urbanization, researchers commonly adopt integrated methods for groundwater and environmental assessment and mineral-potential mapping [31].

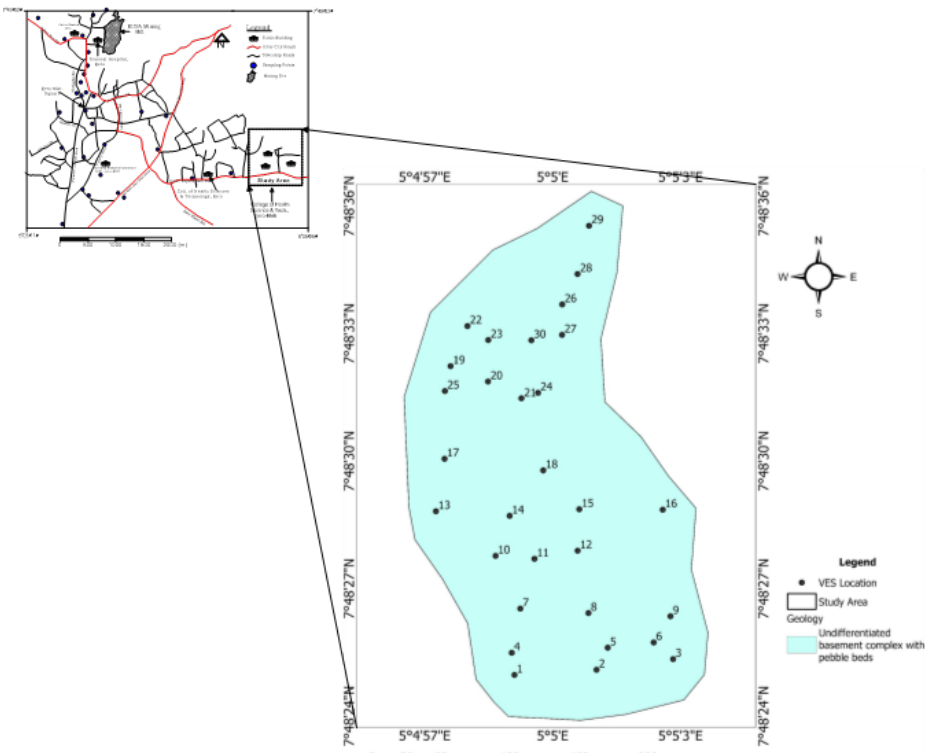

Figure 1: The Location map of the study area

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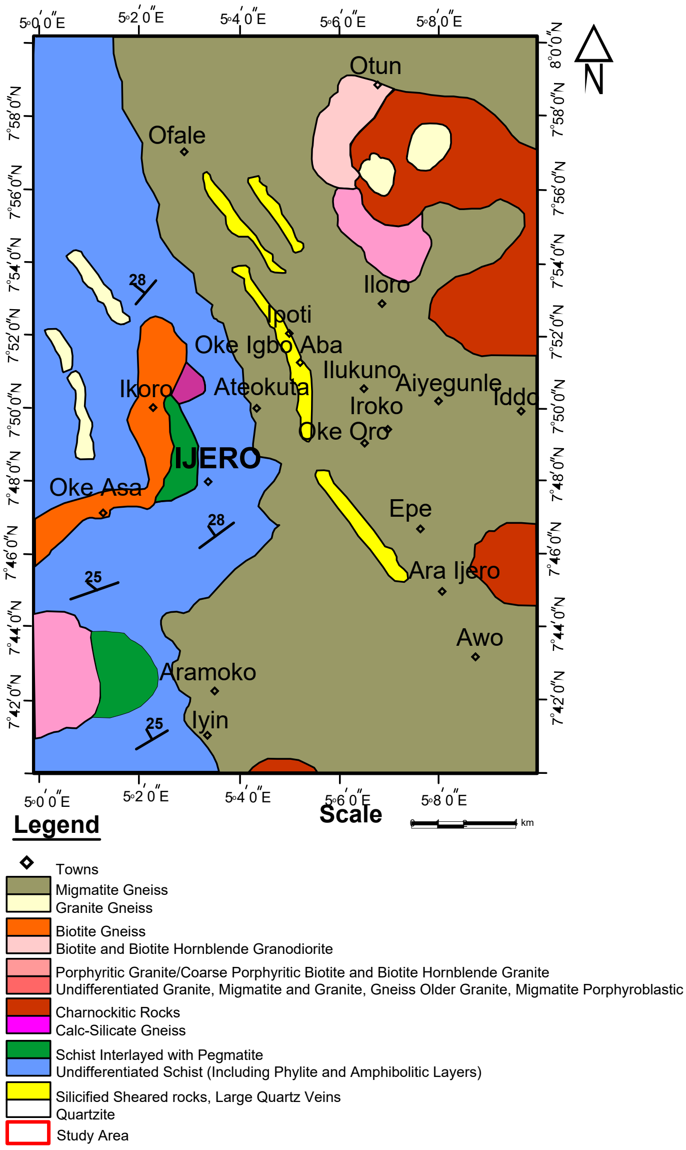

Figure 2: Geological map of Ijero and its environs (Modified after [21]).

2.0 Methodology

The materials and instruments used for the electrical resistivity survey included hammers, stainless steel electrodes, a calibrated measuring tape, a resistivity meter, connecting cables, a GPS receiver, a compass, and a power source. Hammers were employed to drive the electrodes firmly into the ground to ensure good contact and obtain accurate readings. The Schlumberger electrode array configuration, with half-current electrode separation (AB/2) varying from 1 - 65 m, was adopted to measure the variations in subsurface resistivity and layer thicknesses, which reveal differences in soil or rock layers and possible groundwater zones [16]. A calibrated measuring tape was used to maintain accurate electrode spacing, which determines the depth of investigation. The resistivity meter measured the ground's resistance to electrical current, aiding in the identification of saturated zones capable of holding groundwater resources. Connecting cables transmitted current from the meter to the electrodes and conveyed voltage readings back to the instrument. The GPS device and compass were used to record the precise coordinates and orientations of each test station, facilitating accurate mapping and data integration into a Geographic Information System (GIS). A reliable power source supplied the necessary electrical energy for current injection, enabling deep penetration into the subsurface, particularly in hard basement terrains [32]. The vertical electrical resistivity soundings using a Schlumberger electrode configuration were occupied across 30 VES points. Initial project activities included the evaluation of literature related to earlier works and the collection of geographic coordinates necessary for generating the base map of the study area.

The results from the curve matching, including the layer thicknesses and resistivity values, were input into the computer as initial model parameters for an iterated forward modeling process using WINRESIST software [6]. The VES curves obtained provided information on the thicknesses and resistivities of the subsurface layers. The resulting depth sounding curves were classified based on the resistivity contrast between the layers into types H, K, Q, and A, as well as combinations of these types. This classification followed the scheme proposed by [15],

[28]. The modeling process ultimately generated a series of curves with varied layer resistivities and thicknesses. To further assess the aquifer potential and protective capacity of the subsurface layers, derived resistivity and thickness data were used to compute secondary parameters, including longitudinal conductance (S), transmissivity (T), and porosity.

2.2.1 The longitudinal conductance (S)

It is a parameter defined as the sum of the ratio of thickness to resistivity (h/ϱ) for all layers.

$$S = h/\varrho \quad \text{1a}$$

$$S = h1/\varrho1+h2/\varrho2+h3/\varrho3+\ldots\ldots+ hn/\varrho n \quad \text{1b}$$

where S=Longitudinal Conductance, h = layer thickness, ϱ = layer resistivity, σ = conductivity, n = nth layer (1,2...n).

2.2.2 Transmissivity (T)

Transmissivity refers to the ability of an aquifer to transmit groundwater through its full thickness. It depends on the permeability (K) of the aquifer material and the thickness (h) of the saturated zone. Permeability describes how easily water can enter (recharge) or move through (discharge) the aquifer. In this study, transmissivity was estimated using the method proposed by [34]. Higher transmissivity and conductivity values suggest zones of significant groundwater potential, often corresponding to weathered or fractured basement zones [27] as shown in Equation 2.

$$T = Kh \quad \text{2}$$

where T = Transmissivity, K = coefficient of conductivity, and h = aquifer thickness.

The integration of geoelectrical interpretation with these hydrogeological parameters provided insight into both the quantity and quality aspects of the aquifer system, helping to delineate favorable zones for groundwater development and protection strategies.

2.2.3 Hydraulic Conductivity (K)

Hydraulic conductivity estimates how quickly groundwater can flow through soil or rock and is a key factor in evaluating groundwater potential [12]. In this study, it was calculated using Equation 3, developed by [14], which relates hydraulic conductivity to the resistivity (ϱ) of the geological layer.

$$K = (95.5 \times 10\text{-}9)\varrho 1.195 \quad \text{3}$$

where ϱ = the layers' resistivity

This formula is especially useful in areas with porous materials of varying densities. Porosity, the amount of space in a rock or soil, affects how easily water can move through it. The formula includes a power-law relationship (ϱ^1.195), indicating a non-linear link between resistivity and density. However, it's important to note that this equation is based on specific geological conditions and may not apply universally. It was developed from field data in particular environments, so its use should be carefully considered based on the local geology.

2.2.4 Porosity

Porosity (φ) refers to the amount of fluid a geological material can hold, which represents the proportion of void spaces within the material. It is a key factor in understanding how much water an aquifer can store. In this study, porosity is calculated using Equation 4, as proposed by [17].

$$\varphi = 25.5 + 4.5\ln K \quad \text{4}$$

where K is the hydraulic conductivity in m/day.

2.2.5 The Thickness Overlying Aquifer (TLOA)

The Thickness Overlying Aquifer (TOA) is an important concept in hydrogeology. It represents the total thickness of soil or rock layers situated above an aquifer—a water-bearing layer of permeable rock or sediment capable of storing and transmitting groundwater [10]. Understanding TOA is essential for evaluating groundwater resources, as it provides insight into the depth and composition of the materials above the aquifer. These overlying layers can significantly influence both the movement and quality of groundwater [8].

3.0 Results and Discussion

The delineation of aquifer properties and their protective capacity in a typical basement complex terrain is critical for understanding groundwater occurrence, distribution, and protection potential in such geologically complex environments [18]. Basement terrains are predominantly composed of crystalline rocks, which lack primary porosity and depend heavily on secondary features such as weathered layers and fractures to store and transmit groundwater. As a result, aquifer productivity and vulnerability can vary significantly within short spatial intervals. This study integrates geophysical and hydrogeological parameters, including resistivity, aquifer thickness, overburden characteristics, longitudinal conductance, porosity, hydraulic conductivity, and transmissivity, to

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evaluate the groundwater potential and protective capacity of different zones within the study area. The analysis of these parameters provides insight into the subsurface conditions governing groundwater occurrence and guides the delineation of favorable zones for sustainable groundwater development [33]. The following discussion presents and interprets the results obtained from various vertical electrical sounding (VES) data and maps, with a focus on identifying aquifer zones, evaluating their yield potential, and assessing their susceptibility to contamination.

3.2 Primary and Derived Geophysical Data

The primary geophysical information obtained from the electrical resistivity sounding is presented in Table 1. These include: Resistivity, Thickness, and Depth. These parameters help in identifying the aquifer properties, such as the aquifer thickness and aquifer resistivity, which are important factors in groundwater potential [25] and vulnerability assessment. These factors were further used in estimating the derived parameter, which includes the longitudinal conductance, transmissivity, hydraulic conductivity, porosity, and thickness of the layer above the aquifer (Table 2).

Table 1: Summary of VES interpretation results

VES NO	ϱ1	ϱ2	ϱ3	ϱ4	ϱ5	ϱ6	h1	h2	h3	h4	h5
1	523	163	65	2840			0.4	5.9	9.9		
2	161	278	63	2840			0.9	2.9	8		
3	278	80	4554	2712			1.1	10.5			
4	76	169	70				1.5	4.5	8.2		
5	173	87	128	1818			3.7	4.9	6.5		
6	294	85	567	3592	54		1.3	3.9	5.3	8.4	
7	321	1005	99	390	199		0.6	2.8	9.2	29.7	
8	227	72	191	346	3743		4.4	5.5	5.1	8.8	
9	81	272	4404				5.3	5.1			
10	121	125	2363				3	11.3			
11	146	13	644				4.8	9.1			
12	242	414	76				0.8	2.7	8.2		
13	107	151	1337				1	10.2			
14	77	62	3557				2.6	7.1			
15	390	484	69	120	206	737	1	5.9	8.3	8.2	13.6
16	184	41	1081				0.7	1.6			
17	81	737	2894				2.4	4.9			
18	592	69	4484				1.3	3.8			
19	63	818	415				2	6.7			
20	423	517	9475				1.9	8			
21	85	520	2132				1.4	4			
22	350	184	1534	267			0.8	3.6	5.9		
23	131	595	6776				1.4	8.3			
24	85	555	7747				1.9	3.3			
25	71	202	302				2.3	2.3			
26	73	513	24259.9				1.4	1.6			
27	107	397	3477				1.6	6.1			
28	92	199	24140				2.2	1.7			
29	159	172	8361				2.2	3.2			
30	179	691	4376				1.7	8.8			

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Table 2: Summary of derived data

Curve Type	AT (m)	AR (Ohm-m)	LC (S)	K (m/day)	T (m2/day)	TLOA (m)	Porosity (%)
QH	9.9	65	0.18925	7.8686	77.9	6.3	34.78
KH	8	63	0.143005	8.1014	64.81	3.8	34.91
H	10.5	80	0.135206	6.483	68.07	1.1	33.91
KH	8.2	70	0.163507	7.343	60.21	6	34.47
HA	4.9	87	0.02139	5.995	29.38	3.7	33.56
HK	3.9	85	0.00442	6.127	23.89	1.3	33.66
KHK	9.2	99	0.173738	5.314	48.89	3.4	33.02
HA	5.1	191	0.019383	7.153	39.34	4.4	34.35
A	5.1	272	0.08418	2.07	10.56	5.3	28.77
A	11.3	125	0.11519	4.275	48.31	3	32.04
H	9.1	13	0.7328	35.312	321.34	4.8	41.54
KH	8.2	76	0.11772	6.801	55.77	3.5	34.13
A	10.2	151	0.07689	3.584	36.56	1	31.24
H	7.1	62	0.46024	8.223	58.38	2.6	34.98
KA	8.3	69	0.269396	7.442	61.77	6.9	34.53
H	1.6	41	0.0362	12.094	19.35	0.7	36.72
H	4.9	737	0.05726	0.817	4	2.4	24.59
A	3.8	69	0.03993	7.442	28.28	1.3	34.53
K	6.7	818	0.03993	0.742	4.97	2	24.15
A	8	517	0.01996	1.137	9.1	1.9	26.08
A	4	520	0.02416	1.131	4.52	1.4	26.05
K	3.6	184	0.025697	2.981	10.73	0.8	30.42
A	8.3	595	0.024636	0.997	8.28	1.4	25.49
A	3.3	555	0.028298	1.064	3.51	1.9	25.78
A	2.3	202	0.04378	2.732	6.28	2.3	30.02
A	1.6	513	0.022296	1.145	1.83	1.4	26.11
A	6.1	397	0.03031	1.455	8.87	1.6	27.19
A	1.7	199	0.032455	2.771	4.71	2.2	30.09
A	3.2	172	0.032441	3.175	10.16	2.2	30.7
A	8.8	691	0.02232	0.866	7.63	1.7	24.86

LC - Longitudinal Conductance; AT - Aquifer Thicknesses; AR - Aquifer Resistivity; TLOA - Thickness of Layer Overlying the Aquifer; T - Transmissivity; K - Hydraulic Conductivity.

3.3 Aquifer Resistivity Map

Figure 3 is a resistivity contour map of a study area showing the spatial distribution of aquifer resistivity values ranging from 13.105 to 817.444 ohm-m. It is categorized into five zones using a color gradient. The hydrological implications of this resistivity variation are significant and are discussed below:

The low resistivity zone (13.105–98.285 ohm-m) in the southern and central parts of the map indicates saturated, weathered (or clay-rich materials), typical of shallow, water-bearing aquifers. It suggests good groundwater potential but is likely vulnerable to surface contamination. This zone is suitable for hand-dug wells and shallow boreholes. The moderately low resistivity zone (98.286 – 235.903 ohm-m), found mainly in the eastern and central parts of the study area, indicates weathered basement or partially saturated fractured zones. These areas typically have moderate to good groundwater potential and may act as recharge areas for deeper aquifers. The moderate resistivity zone (235.904–458.239 ohm-m), located in the northern and central parts of the area, likely represents sandy or fractured basement materials. It indicates moderate groundwater potential with relatively better water quality and lower vulnerability to contamination compared to low-resistivity zones. The high resistivity zone (458.24–817.44 ohm-m) in the northwestern part likely indicates competent bedrock, dry fractures, or thin weathered layers. It suggests poor groundwater potential due to low porosity and limited recharge, and may require deep drilling to access any productive fractures. Groundwater development should prioritize the blue and green zones due to their higher aquifer potential, verified with borehole data. Blue zones require contamination monitoring and protective land-use controls. High-resistivity (red) zones may require further investigation, such as fracture mapping or deep drilling, to assess the potential of deeper aquifers.

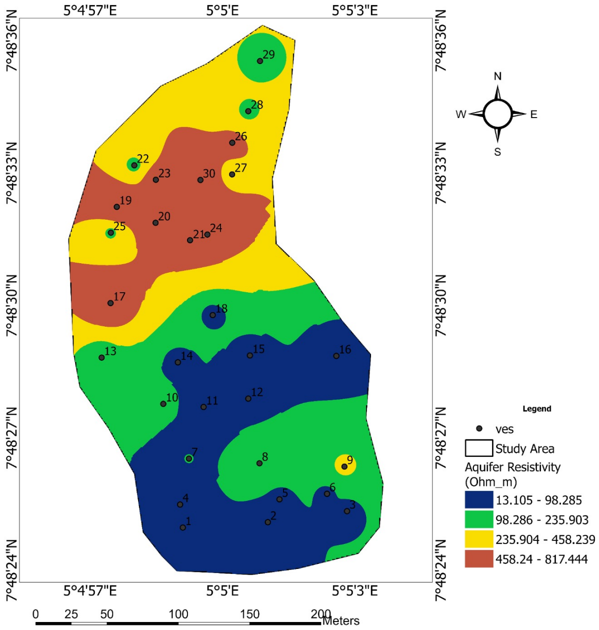

Figure 3: The Aquifer Resistivity Map of the Study Area.

3.4 Aquifer Thickness Map

The aquifer thickness map (Figure 4) shows variations from 1.602 to 11.297 meters, categorized into four zones. Thinner zones (1.6–5.0 m) indicate low groundwater potential and higher vulnerability to seasonal drying and contamination. Moderate thickness zones (5.0–7.8 m) suggest moderate to good groundwater potential. Thicker zones (7.8–11.3 m) represent high-yield aquifers, which are ideal for a sustainable water supply with a lower risk of contamination. The thin aquifer zone (1.602–5.047 m), mostly at the map's edges, represents narrow weathered or fractured layers with limited groundwater storage. It has low yield potential, is prone to seasonal drying, and is more vulnerable to contamination due to its shallow depth. The moderately thin aquifer zone (5.048–6.449 m), mostly in central, eastern, and northern areas, indicates moderately weathered or fractured basement. It has moderate groundwater potential, suitable for low-demand domestic boreholes, with seasonal water level fluctuations and lower contamination risk than thinner zones. The Moderate Aquifer Thickness Zone (6.45–7.851 m) is located in scattered patches in central and southern areas. It features well-developed weathered/fractured layers, offering good storage and yield capacity. This zone is suitable for sustainable groundwater abstraction, has a lower contamination risk, and can support moderate agricultural or commercial use if properly harnessed. The Thick Aquifer Zone (7.852 – 11.297 m), located in southern and isolated central areas, contains well-developed, saturated weathered and fractured layers. This zone has high groundwater potential, making it ideal for high-demand boreholes and long-term water supply projects. It has a stable water table with less seasonal fluctuation and is less vulnerable to contamination due to protective overburden and deeper water levels. The following recommendations are made based on the findings of the study: Priority should be given to high-thickness zones (represented in red and yellow on the maps) for the siting of productive boreholes. Blue zones should be avoided for long-term water supply due to their limited groundwater storage and seasonal variability. An integrated approach that combines aquifer thickness, resistivity, and lithological data is essential to accurately identify permeable and saturated zones suitable for groundwater development. Additionally, recharge and contamination risks should be closely monitored in green and blue zones, particularly in areas near agricultural activities or waste disposal sites.

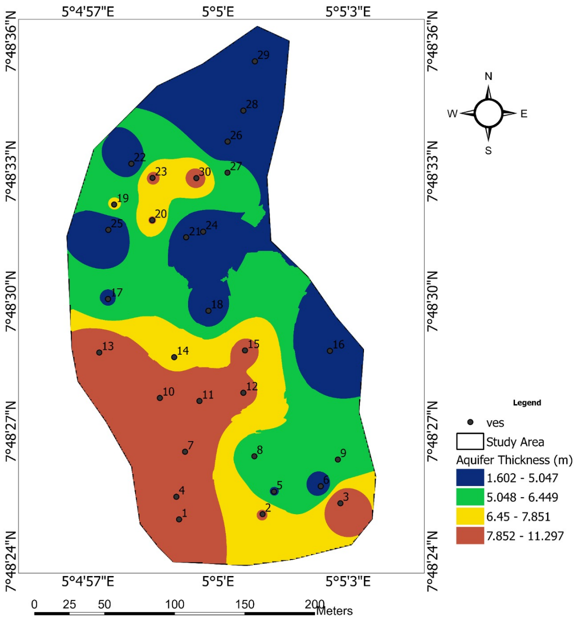

Figure 4: The aquifer thickness map of the study area

3.5 Map of Thickness Layers Overlying the Aquifer (TLOA)

The Thickness of Layers Overlying the Aquifer (TLOA) is a critical hydrogeological parameter that significantly controls aquifer protection, recharge dynamics, and groundwater protective capacity. In these areas, the overburden thickness provides a balanced protection, which is sufficient to filter out some contaminants while still allowing moderate recharge of the aquifer. The low TLOA areas (0.702–2.256 m, dark blue) are highly vulnerable to contamination due to a thin protective cover (Figure 5). These zones require strict land use controls and are unsuitable for waste disposal. Moderate TLOA zones (2.257–3.325 m, green) offer balanced protection and recharge potential, making them suitable for monitored groundwater development. Intermediate to high TLOA areas (3.326–4.637 m, yellow) provide better aquifer protection with possibly lower recharge, and are favourable for sustainable groundwater use with reduced contamination risk. High TLOA zones (4.638–6.897 m, reddish brown) have thick overburden that protects aquifers well but may limit natural recharge; such areas are ideal for long-term water supply, possibly requiring artificial recharge measures. Restricted waste-related activities in low TLOA zones, focusing on groundwater development in moderate to high TLOA areas, and prioritizing water quality monitoring in vulnerable, thin-overburden regions.

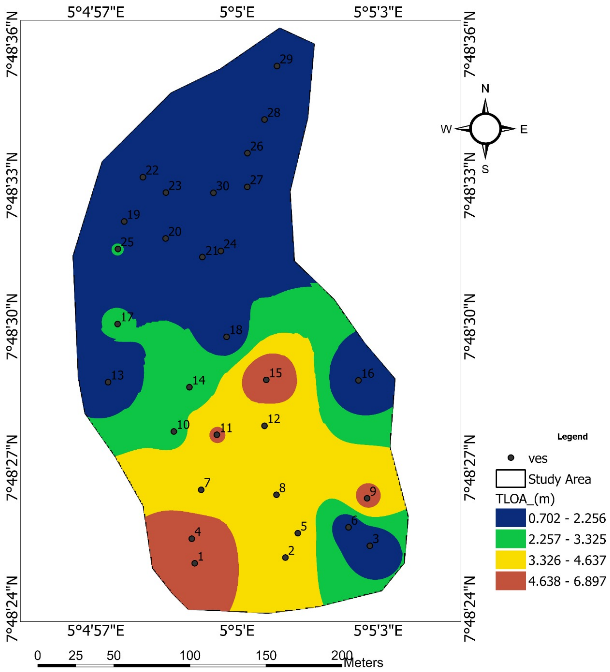

Figure 5: The TLOA map of the study area

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3.6 Longitudinal Conductance Map

The map (Figure 6) displays the longitudinal conductance distribution of the study area, an important parameter for assessing the protective capacity of overburden materials in groundwater studies. Dark blue zones (0.005–0.039 S) in the north and southeast have low conductance, indicating sandy or resistive lithology with poor protection, making aquifers in these areas highly vulnerable to contamination. Green zones (0.04–0.119 S) offer slightly better but still moderate to poor protection, likely consisting of sandy clay or fractured rock, with moderate vulnerability to surface pollutants. Yellow zones (0.12–0.304 S), found mainly in the central and southern parts, suggest moderate to good protective capacity due to clayey or weathered layers, providing reduced contamination risk and good groundwater storage potential. Brown/red zones (0.305–0.732 S) in the central region exhibit high conductance and excellent protective capacity, ideal for safe borehole siting and potable water supply. The central brown/red and yellow zones are most favorable for well development, while blue zones require caution due to high contamination risk. High conductance zones suggest better aquifer potential, and low conductance areas should be prioritized for water quality monitoring. Further integration with additional hydrogeological data is recommended for informed groundwater management.

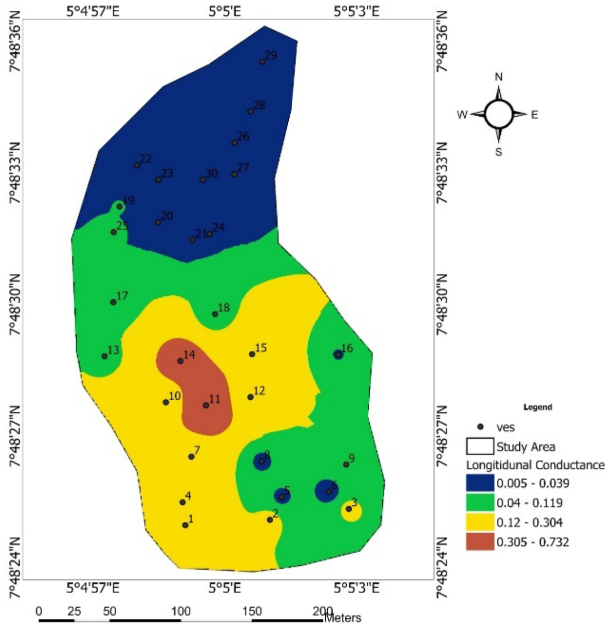

Figure 6: Longitudinal conductance map of the study area

3.7 Porosity Map

Porosity is the percentage of void space in a material, influencing groundwater storage and movement. While higher porosity indicates a greater ability to store water, it doesn't always guarantee high permeability for water transmission. Low Porosity Dark - Blue Zone (24.156–28.131%) (Figure 7). These areas have low water storage capacity, likely composed of compacted sediments or crystalline rocks. Aquifer quality is poor unless fractured, making them low-yield zones that may require deep or fracture-targeted drilling. Moderately Low Porosity - Green Zone (28.132–30.313%). With moderate storage potential, these zones may consist of weathered rock or sand with some clay. They can support domestic water use but have limited recharge potential. Moderate Porosity Yellow - Zone (30.314–34.289%). These areas provide balanced storage and groundwater flow, often found in sandy soils or loose sediments. Suitable for shallow wells and moderate-yield boreholes. High Porosity - Brown-Red Zone (34.29–41.53%). These zones have excellent water storage, typically consisting of sandy alluvium or weathered/fractured rock. They are high-yield and ideal for groundwater development, but may be more vulnerable to contamination. The spatial analysis reveals that VES points 10, 11, 12, 14, and 15 lie within high-porosity zones, making them ideal for groundwater development. In contrast, VES points 19, 20, 22, 23, and 26–28 are located in low-porosity areas in the north, which offer poor groundwater prospects unless fractures are present. The central region, dominated by yellow and red zones, is highly suitable for aquifer development, while isolated green patches in blue zones (e.g., near VES 22 and 29) may indicate promising localized fractured or weathered formations. For hydrological planning, borehole siting should prioritize the yellow and brown-red zones. High-porosity zones must be assessed for pollution vulnerability, while the low-porosity areas require further geophysical surveys to locate viable groundwater sources.

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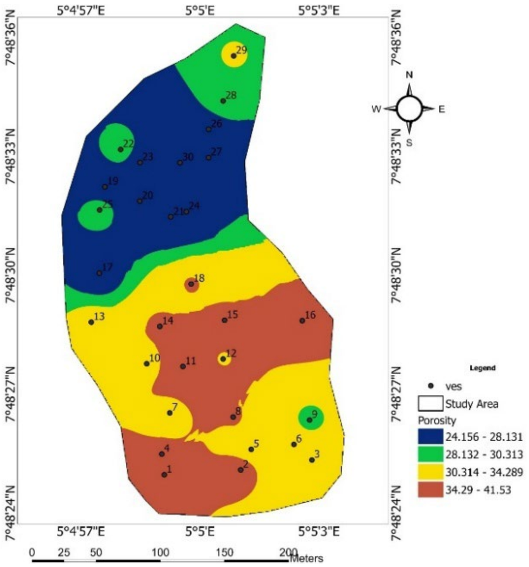

Figure 7: Porosity map of the study area

3.8 Hydraulic conductivity (k) Map

The hydraulic conductivity map (Figure 8) illustrates spatial variations in hydraulic conductivity (K) across the study area. This is essential for assessing groundwater flow, aquifer productivity, and vulnerability. Hydraulic conductivity ranges from 0.745 to 35.276 m/day, divided into five main zones. Low K zones (0.745–1.962 m/day), marked in dark blue and located in the northern-central area (e.g., VES 21, 24, 26, 27, 30), indicate poor aquifer permeability, likely due to compact or fine-grained materials. These areas have low groundwater yield and recharge potential, but reduced contamination risk. Moderate to moderately high K zones (1.963–7.921 m/day) appear in green and yellow, spread across central and peripheral areas (e.g., VES 2, 5, 13, 18, 22). They likely consist of weathered and fractured basement rocks, offering moderate water transmission suitable for domestic or agricultural use, and acting as buffer zones for recharge and lateral flow. High K zones (7.922–35.276 m/day), shown in reddish brown in central and southeastern areas (e.g., VES 1, 4, 8, 10, 11, 12), suggest fractured or highly weathered basement with high aquifer productivity. While ideal for intensive groundwater use, they are also more vulnerable to contamination, especially from nearby human activities. Hydrogeologic analysis shows that low hydraulic conductivity (K) zones have limited groundwater yield but a lower risk of contamination. Moderate K zones are suitable for rural water supply, while moderately high K zones are viable for groundwater abstraction. High K zones provide high-yield aquifers but require strict contamination controls due to their vulnerability. For effective water resource management, it is recommended to prioritize high K zones for borehole siting, accompanied by water quality assessments. Protection zones should be created around high K areas to minimize pollution risks. Recharge monitoring should focus on moderate K areas to enhance aquifer sustainability, and low K zones may need alternative water strategies or deeper drilling to reach more permeable layers.

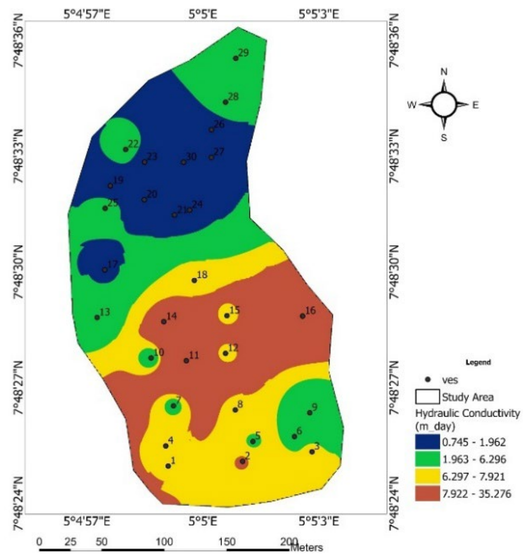

Figure 8: The hydraulic conductivity (k) map of the study area

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3.9 Transmissivity Map

Figure 9 is the transmissivity map, which shows how groundwater movement varies across the study area. This is the product of hydraulic conductivity (K) and saturated aquifer thickness (b). Higher transmissivity indicates better aquifer productivity and capacity to transmit water horizontally. Very low transmissivity zones (1.835–8.092 m²/day), shown in dark blue (VES 17, 20, 28, 29), suggest poor aquifer performance, likely due to compacted clays or unfractured rocks, and are not ideal for sustainable groundwater development. Low to moderate zones (8.093–40.635 m²/day), represented in green, indicate moderate water transmission through weathered or fractured rocks. These zones can support low to medium-yield wells, suitable for domestic or rural use. Moderate to high transmissivity zones (40.636–61.913 m²/day), marked in yellow, offer good aquifer potential and are likely composed of sandy or fractured rock layers. They are suitable for moderate- to high-yield boreholes for community water supply or small-scale irrigation. Very high transmissivity zones (61.914–321.004 m²/day), shown in brown (VES 1, 4, 7, 10, 11, 12), reflect excellent groundwater movement through permeable, saturated layers like clean sands or fractured rock. These zones are ideal for high-capacity wells but are also more vulnerable to contamination, requiring protection. The southern and central regions (e.g., VES 1, 4, 7, 10, 11, 12) are ideal for sustainable groundwater development, while northern areas (e.g., VES 20, 26–29) require caution due to very low transmissivity. Hydrogeologically, brown and yellow zones should be prioritized for productive boreholes, green zones reserved for low-demand uses or monitoring, and blue zones need detailed subsurface assessments before development.

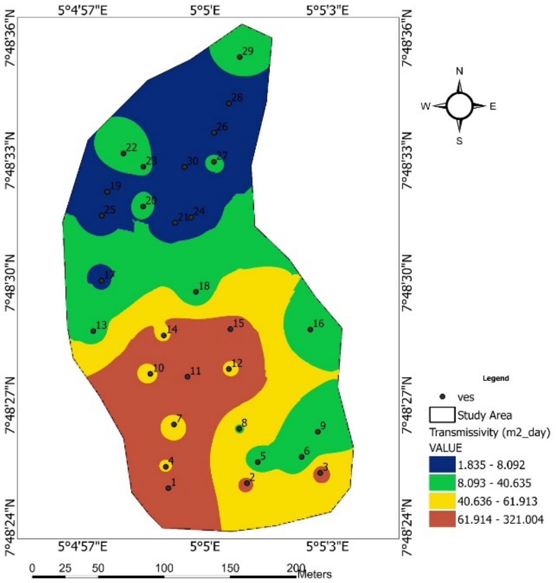

Figure 9: The Transmissivity (T) map of the study area

3.10Table 3: A table showing the summary of results obtained in the study area

Parameter	Range of Values	Spatial Variation	Geological Implications
Aquifer Resistivity	13.105 – 817.444 ohm-m	Low in shallow zones, moderate in fractured basement, and high in compact rocks	Low values indicate water-saturated zones; moderate values suggest productive fractured aquifers; high values reflect poor aquifer potential.
Aquifer Thickness	1.6 – 11.3 m	Thicker in the central and southern zones	Thicker aquifers (>7.8 m) offer high groundwater potential and sustainable yields.
TLOA (Overburden Thickness)	0.702 – 6.897 m	Thin in northern zones; thick in central/southern zones	Thicker overburden provides better protection against contamination, though it may reduce recharge.
Longitudinal Conductance	0.005 – 0.732 S	Very high in VES 10, 11, 14; low in VES 26–30	High conductance indicates good protective capacity and filtration; low values imply vulnerability.
Porosity	24.16% – 41.53%	High porosity at VES 10–12, 14, 15; low at VES 19, 20, 26–28	High porosity enhances groundwater storage, but may increase contamination risk if not protected.
Hydraulic Conductivity	0.745 – 35.276 m/day	Highest near VES 5, 10, 12; lowest in blue zones	High values support strong yields and fast recharge; low values indicate poor permeability.

Transmissivity	1.835 – 321.004 m²/day	Highest near VES 1, 4, 7, 10, 11, 12; lowest in VES 17, 28, 29	High transmissivity zones are ideal for high-yield boreholes; low zones may not support sustainable development.
Regional Suitability	N/A	Favorable in the southern and central zones	These areas combine favorable parameters for groundwater development; northern zones are less suitable.

4.0 Conclusion

The study has demonstrated that groundwater development potential varies significantly across the study area, influenced by factors such as aquifer thickness, hydraulic conductivity, transmissivity, resistivity, and overburden characteristics. Zones with higher aquifer potential—particularly the brown, red, and yellow zones—have been identified as the most favorable for productive borehole siting due to their higher transmissivity, aquifer thickness, and hydraulic conductivity. In contrast, blue zones, while showing some development potential, pose challenges due to low groundwater storage, seasonal variability, and higher contamination risks, particularly in areas near agricultural or waste disposal activities. The integration of geophysical and hydrogeological data is essential for informed and sustainable groundwater development in the area. Borehole development should target the brown, red, and yellow zones with high aquifer thickness, transmissivity, and conductivity, while blue zones should be avoided unless viable aquifers are confirmed. Protection zones must be established around high-transmissivity areas, enforcing strict land-use control near waste and farms. Additional investigations employing resistivity profiling, fracture mapping, and deep drilling are recommended to evaluate the potential of deeper aquifer zones. Water development prioritized in moderate-to-high TLOA areas. Waste activities must be restricted in low TLOA or vulnerable zones.

References

[1] A. A. Adepelumi, B. D. Ako, and T. R. Ajayi, “High-resolution resistivity and hydrochemical methods for the assessment of groundwater quality in a coastal area: A case study from Lagos, Nigeria,” *J. Appl. Geophys.*, vol. 67, no. 3, pp. 207–219, 2009.

[2] A. C. Ajibade, M. A. Rahaman, and M. Woakes, “Proterozoic crustal development in the Pan-African regime of Nigeria,” in *Continental Tectonics*, M. P. Coward, J. F. Dewey, and P. L. Hancock, Eds. London, U.K.: Geological Society, 1988, pp. 259–271, Spec. Publ. No. 37.

[3] B. D. Ako, M. O. Olorunfemi, and O. A. Fashae, “Geoelectric characterization of basement rocks in the Abiola College area, Lagos, Nigeria,” *J. Afr. Earth Sci.*, vol. 56, no. 3, pp. 154–164, 2010.

[4] L. Aller, T. Bennett, J. H. Lehr, R. J. Petty, and G. Hackett, *DRASTIC: A Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings*, EPA/600/2-85/018, U.S. Environ. Prot. Agency, 1987.

[5] E. A. Ayolabi, A. M. Odukoya, and B. Onajobi, “Groundwater vulnerability assessment in a basement terrain using geoelectrical and GIS techniques: Case study from Southwestern Nigeria,” *Arab. J. Geosci.*, vol. 6, no. 5, pp. 1391–1401, 2013.

[6] D. R. Barrett, R. J. George, and D. R. Williamson, “Mapping salt stores and water movement in the root zone with resistivity survey,” *Soil Use Manage.*, vol. 18, no. 4, pp. 334–340, 2002.

[7] R. Caby and J. M. Boessé, “Pan-African nappe system in southwest Nigeria: The Ife-Ilesha schist belt,” *J. Afr. Earth Sci.*, vol. 33, no. 2, pp. 211–225, 2001. doi: 10.1016/S0899-5362(01)80060-9.

[8] A. E. Dasho, G. Sappa, and F. Ferranti, “Integration of geophysical and hydrogeological data to estimate aquifer vulnerability,” *Environ. Earth Sci.*, vol. 76, p. 416, 2017.

[9] A. E. Edet, C. S. Okereke, and S. C. Teme, “Application of remote-sensing data to groundwater exploration: A case study of the Cross River State, Southeastern Nigeria,” *Hydrogeol. J.*, vol. 6, pp. 394–404, 1998.

[10] A. C. Ekwe, K. M. Onuoha, and H. N. Ezeh, “Estimation of aquifer hydraulic characteristics from geoelectric sounding data: A case study of Middle Imo River Basin, Southeastern Nigeria,” *J. Geol. Min. Res.*, vol. 2, no. 3, pp. 44–52, 2010.

[11] A. A. Elueze, “Compositional characteristics and industrial assessment of talcose rocks in part of the Nigerian Basement Complex,” *J. Min. Geol.*, vol. 36, no. 2, pp. 119–126, 2000.

[12] P. O. Ezema, E. K. Anakwuba, and H. N. Ezeh, “Estimating aquifer parameters using VES and pumping test data correlation,” *Environ. Earth Sci.*, vol. 79, p. 81, 2020.

[13] O. A. Fashae, M. N. Tijani, A. O. Talabi, and O. I. Adedeji, “Estimating aquifer vulnerability to contamination using DRASTIC and GIS techniques in parts of southwestern Nigeria,” *Arab. J. Geosci.*, vol. 7, pp. 4291–4303, 2014.

[14] P. C. Heigold, R. H. Gilkeson, K. Cartwright, and P. C. Reed, “Aquifer transmissivity from surficial electrical methods,” *Groundwater*, vol. 17, no. 4, pp. 338–345, 1979.

Received: 08/11/2025; Revised: 18/11/2025; Accepted: 19/11/2025; Published: 24/11/2025

[15] G. V. Keller and F. C. Frischknecht, *Electrical Methods in Geophysical Prospecting*. Oxford, U.K.: Pergamon Press, 1966.

[16] E. Levi, A. Furman, and U. Uzi, "Combined geoelectrical imaging and time domain EM methods for mapping saltwater intrusion," *J. Hydrol.*, vol. 389, no. 1–2, pp. 36–47, 2010.

[17] G. A. Marotz, "Empirical relations between porosity and permeability," *Water Resour. Res.*, vol. 4, no. 5, pp. 1133–1139, 1968.

[18] J. D. McNeill, "Use of electromagnetic methods for groundwater studies," *Geotech. Environ. Geophys.*, vol. 1, pp. 191–218, 1990.

[19] C. Neukum and H. Hötzl, "Standardization of aquifer vulnerability maps: The Bavarian experience," *Hydrogeol. J.*, vol. 15, pp. 1325–1336, 2007.

[20] S. A. Oke, M. O. Olorunfemi, and A. A. Adepelumi, "Hydrogeophysical evaluation of aquifer vulnerability and protective capacity of overburden units in basement terrain of southwestern Nigeria," *J. Afr. Earth Sci.*, vol. 132, pp. 31–43, 2017.

[21] A. O. Okunlola, O. O. Akinola, and A. O. Olorunfemi, "Petrochemical characteristics and industrial features of talcose rock in Ijero-Ekiti, Southwestern Nigeria," *Ife J. Sci.*, vol. 13, no. 2, pp. 317–326, 2011.

[22] M. I. Oladapo, O. J. Akintorinwa, and M. O. Olorunfemi, "Geophysical investigation of suspected contaminated sites in Lagos, Southwestern Nigeria," *Glob. J. Pure Appl. Sci.*, vol. 10, no. 4, pp. 567–576, 2004.

[23] O. Ologe, J. Ahmed, and A. O. Adegoke, "A multipreliminary approach to the delineation of groundwater potential zones: A study of Ijero-Ekiti and its environs, Southwest Nigeria," *Savanna J. Basic Appl. Sci.*, vol. 4, no. 1, pp. 43–53, 2022.

[24] M. O. Olorunfemi, J. S. Ojo, and E. A. Mesida, "Geoelectric investigation of basement terrain in southwestern Nigeria," *J. Min. Geol.*, vol. 35, no. 2, pp. 207–228, 1999.

[25] G. O. Omosuyi and C. O. Oseghale, "Integrated geophysical and hydrogeological studies for groundwater exploration in a typical basement terrain: A case study of Odigbo, southwestern Nigeria," *Int. J. Water Resour. Environ. Eng.*, vol. 4, no. 1, pp. 19–32, 2012.

[26] B. A. Omoyoloye, A. A. Akanbi, and A. I. Olayinka, "Saline water intrusion investigation using vertical electrical sounding in parts of southern Ondo State," *Glob. J. Pure Appl. Sci.*, vol. 14, no. 4, pp. 421–428, 2008.

[27] D. S. Parasnis, *Principles of Applied Geophysics*, 5th ed. London, U.K.: Chapman & Hall, 1997.

[28] H. P. Patra and S. K. Nath, *Geoelectrical Methods in Geophysical Exploration*. New Delhi, India: New Age Int., 1999.

[29] M. A. Rahaman, "Recent advances in the study of the Basement Complex of Nigeria," in *Precambrian Geology of Nigeria*, Geological Survey of Nigeria, pp. 11–41, 1988.

[30] N. B. Salawu, J. O. Fatoba, L. S. Adebiyi, M. M. Orosun, and S. S. Dada, "New insights on the Ife-Ilesha schist belt using integrated satellite, aeromagnetic and radiometric data," *Sci. Rep.*, vol. 11, p. 15314, 2021. doi: 10.1038/s41598-021-94813-1.

[31] A. O. Talabi, L. O. Afolagboye, C. A. Ajayi, and O. Kolawole, "Sanitary surveys and hydrochemistry of groundwater in two urban towns (Ado-Ekiti and Ijero-Ekiti), Southwestern Nigeria," *J. Geosci. Environ. Prot.*, vol. 10, pp. 159–185, 2022. doi: 10.4236/gep.2022.107011.

[32] W. M. Telford, L. P. Geldart, and R. E. Sheriff, *Applied Geophysics*, 2nd ed. Cambridge, U.K.: Cambridge Univ. Press, 1990.

[33] A. A. R. Zohdy, G. P. Eaton, and D. R. Mabey, *Application of Surface Geophysics to Groundwater Investigations*, U.S. Geol. Surv., Tech. Water Resour. Investigations, Book 2, Chap. D1, 1974.

[34] S. Niwas and D. C. Singhal, "Estimation of aquifer transmissivity from Dar Zarrouk parameters in porous media," J. Hydrol., vol. 50, no. 3–4, pp. 393–399, 1981.

[35] P. J. Chilton and S. S. D. Foster, "Hydrogeological characteristics and water-supply potential of basement aquifers in tropical Africa," Hydrogeology Journal, vol. 3, no. 1, pp. 36–49, 1995.

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