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RESEARCH ARTICLE OPEN ACCESS

DELINEATION OF GROUNDWATER POTENTIAL ZONES USING INTEGRATED VERTICAL ELECTRICAL SOUNDING AND GEOSPATIAL TECHNIQUES IN THE BASEMENT COMPLEX OF IJESHA ISU EKITI, SOUTHWESTERN NIGERIA

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ABSTRACT

A combination of multi-criteria evaluation parameters has been deployed to delineate groundwater potential zones using integrated Vertical Electrical Sounding and geospatial techniques in the basement complex of Ijesha Isu Ekiti, Southwestern Nigeria. The area is underlain by migmatite-gneiss, amphibolities, biotite gneiss and the granitic components of the basement complex terrain with suspect groundwater prospects. Wenner vertical electrical soundings (VES) were conducted at 22 stations. The VES interpretation delineated the topsoil, weathered basement / partly weathered/fractured basement and the fresh basement bedrock with resistivity values ranging from 19 - 304, 16 - 417 and 8 - 2784 Ω-m, respectively. Integration of the attributes of the bedrock resistivity, weathered basement resistivity and the overburden thickness in a GIS environment enabled the classification of the study area into very low, low, medium and high groundwater potential zones covering areal extent of 0.004 km^2, 0.18 km^2, 1.85 km^2, and 1.32 km^2, respectively. A weighted combination of attributes would enhance the hitherto low success rate of groundwater targeting in a typical hard rock terrain.

I. INTRODUCTION

Ijesha Isu Ekiti is underlain by the Precambrian basement complex rocks of Southwestern Nigeria. The town depends on rain water, surface water and groundwater for water supplies. The surface water is usually not available all year round owing to the seasonal flow regime of rivers draining the area; and where available and accessible, cannot guarantee the required water quality status required for most domestic activities. Most homes depend on water from wells whose overall yield and quality are influenced by the alternating wet and dry seasons among other factors [1-3].

In a typical hard rock terrain, groundwater is restricted to the fractures and the weathered zones. The hydraulic properties are characterized by extreme variations over short distances which often limit water development in the area to low-yielding well [4-6]. With the marked low success ratio of drilling for potable water in hard rock terrain the use of Geophysics is often compelling, particularly in the absence of lineaments extracted from imagery [1],[7],[8].

According to [6] the poor understanding of the hydrogeological characteristics of the Basement Complex environment is significantly responsible for borehole failures in the terrain. The groundwater potential of a basement complex area is influenced by a complex inter-relationship involving the geology, post emplacement tectonic history, weathering processes and depth, nature of the weathered layer, groundwater flow pattern, recharge and discharge processes [9],[10]. Improvements in the understanding of this relationship will be fundamental to the planning and management of groundwater resources in crystalline basement terrain and reduction of development cost [4]. It is important to evaluate the overall resource and aquifer occurrence more precisely to assist development efficiency and longer-term sustainability.

The study area lies between latitudes 7º45'N and 7º 46'N and longitudes 5º 25'E and 5º 26'E in Ikole Local Government area of Ekiti, State, Southwestwern Nigeria (Figure 1). The area enjoys high annual rainfall of about 1500mm being within the tropics. The area is underlain by migmatite-gneiss, the amphibolities, biotite gneiss and the granitic components of the Precambrian basement complex of southwestern Nigeria. The regolith and fractured bedrocks constitute the aquifers for groundwater. Development of the bedrock component requires interaction with storage available in overlying or adjacent saturated regolith, or other suitable formations such as alluvium [1],[12],[13].

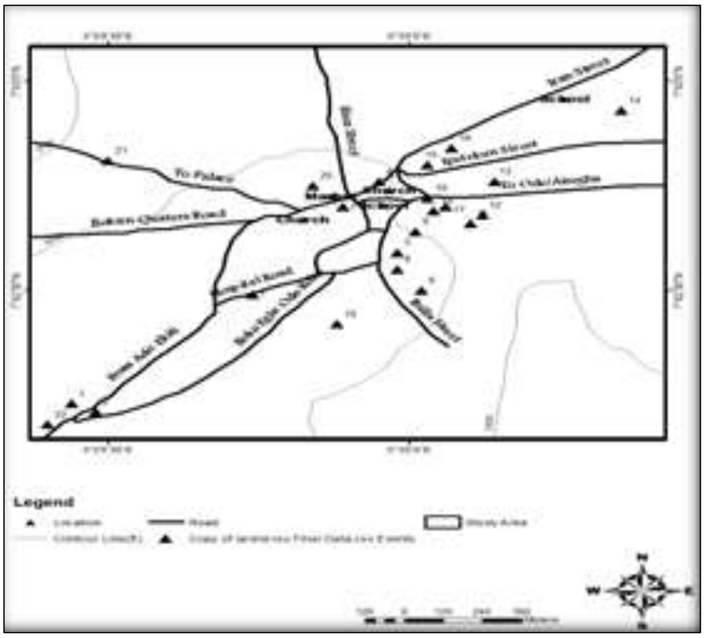

Figure 1: Study Area Map showing the VES Points.
Source: Authors, (2025).

II. THEORETICAL REFERENCE

Electrical Resistivity Method is a non-invasive geophysical technique developed to interpret the nature of the subsurface without altering the dynamic status of the soil mass [10],[11],[16]. Vertical Electrical Resistivity Sounding (VES) technique offers a compact tool for locating promising areas for water boreholes/wells amidst prevailing structural disposition. It has proved very popular with groundwater studies due to the simplicity of the technique, the ruggedness of the instrumentation and the success rate [5],[9]. Geographic Information System (GIS) provides an efficient integration environment. With the implementation of GIS, large volume of geospatial data and information are maintained in a standard format, revised and updated with additional features. Sustainable development and management are thus facilitated at real time [1],[11].

This integrated approach presents a detailed evaluation of the groundwater prospects of Ijesha Isu Ekiti using geoelectric data in a GIS environment.

III. MATERIALS AND METHODS

The geoelectric data acquisition was carried out using Wenner array of Vertical Electrical Sounding (VES) to delineate the subsurface lithological configuration, aquifer characteristics and depth to bedrock. Twenty Two (22) VES points (Figure 1) were fully occupied for data acquisition. The instrument used for the resistance measurement was the ABEM Terrameter SAS 300 B with ABEM 2000 Booster. A Garmin 12-Channel Global Positioning System (GPS) handheld receiver was used to obtain the Eastings (Longitude), Northings (Latitude) and Elevation above mean sea level of each point of interest during the fieldwork. The VES data were interpreted quantitatively by partial curve matching and 1-D computer iteration using the computer algorithm RESIST Version 1.0 [14] to obtain the layer resistivity values and corresponding thicknesses. The curves were inspected to determine the number and nature of the layering [15],[16]. ArcMap 10.2.2 was employed for derivation and re-classification of the thematic layers for spatial analysis. Different classes in each thematic map were assigned a knowledge-based hierarchy of weights [17]. These weights ranged from 1 to 4 for groundwater potential evaluation. In each thematic map, highest weight is given to the class that is most favourable to potential and lowest weight is given to the class that is least favourable for groundwater accumulation.

IV. RESULTS AND DISCUSSIONS

The geoelectric type curves in the study area are presented in Figure 2. They are A, H, KH, HA and Q type curves with the H-curve being the most predominant accounting for 45.4%. This is a consequence of the degree of weathering and fracturing as typical of the basement complex terrain. The analysis of the type curves indicated that the area under study has both weathered layer aquifers and fractured layer aquifers [18],[19].

The geoelectric characteristics are summarized in Table 1. The spatial distributions of the geoeletric parameters are presented in Figures 3 - 8. The resistivity of the topsoil varies from 19 Ω-m to 304 Ω-m with a mean of 79.8 Ω-m and Standard Deviation of 68.7 Ω-m. The skewness of 1.7 shows that the spatial distribution is not uniform. The wide resistivity range is a consequence of the variable composition of this layer.

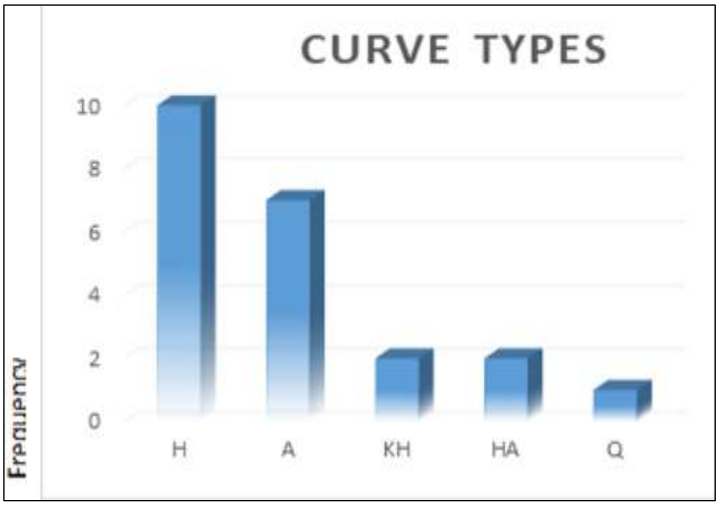

Figure 2: Geoelectric Curve Types.
Source: Authors, (2025).

Table 1: Summary of Geoelectric Characteristics.

Parameters	Min	Max	Mean	Std. Deviation	Skewness
Anisotropy	1	1.8	1.2	0.2	1.9
Top soil Resistivity (Ω-m)	19	304	79.6	68.7	1.7
Top soil Thickness (m)	1.1	8.6	3.9	2.6	0.6

Weathered Basement Resisitivity (Ω-m)	16	417	103.27	103.83	1.7
Weathered Basement Thickness (m)	3.2	19.6	10	3.9	0.4
Overburden Thickness (m)	4.3	25.3	14.5	4.7	0.1
Bedrock Resistivity (Ω-m)	8	2784	645.6	706.3	2.1

Source: Authors, (2025).

The thickness of the topsoil varies from 1.1 m to 8.6 m with a mean of 3.9 ± 2.6 m. The Weathered Basement Resistivity values range from 16 Ω-m to 417 Ω-m. The values indicate varying degree of weathering/fracturing and water saturation. The thickness of the layer ranges from 3.2 – 19.6 m.

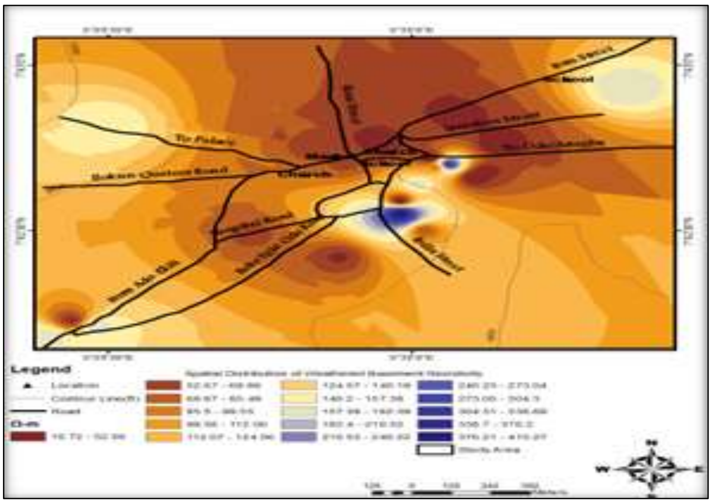

Figure 3: Spatial distribution of Weathered Basement Resistivity.
Source: Authors, (2025).

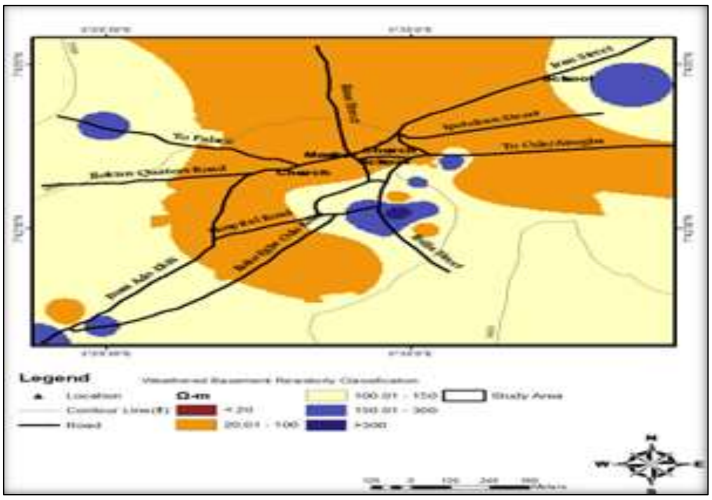

Figure 4: Classification of Weathered Basement Resistivity.
Source: Authors, (2025).

The bedrock resistivity varies from 8 Ω-m to 2784 Ω-m; indicating decreasing impact of weathering/fracturing with corresponding reduction of the groundwater potentials. Localized variations may be attributed to differences in the bedrock mineralogy and structures.

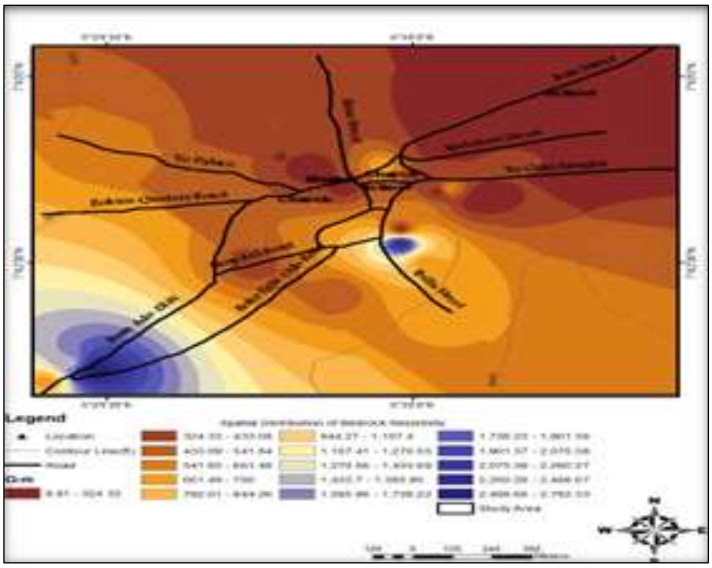

Figure 5: Spatial Distribution of Bedrock Resistivity.
Source: Authors, (2025).

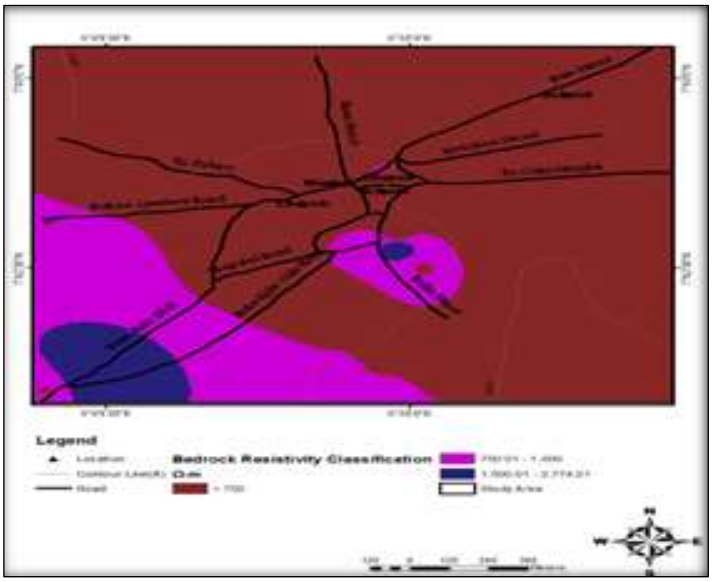

Figure 6: Classification of Bedrock Resistivity.
Source: Authors, (2025).

The overburden thickness varies from 4.3 to 25.3 m. The isopach map of overburden, Figure 7, shows that the southwestern and southeastern regions are characterized by basement highs/ridges with thin overburden cover generally less than 10m. Thresholding produced three classes of overburden thickness of < 10m, 10 - 20m and 20 - 30m with poor, medium and high groundwater potential respectively (Figure 8). The northern flank records increasing value of overburden thickness towards the central portion of the study area thus creating basement depressions at the central portion and Irepodun. An isolated depression has been demarcated along the southern flank of the area. Basement depressions are diagnostic of troughs which are groundwater collecting centres [9],[20].

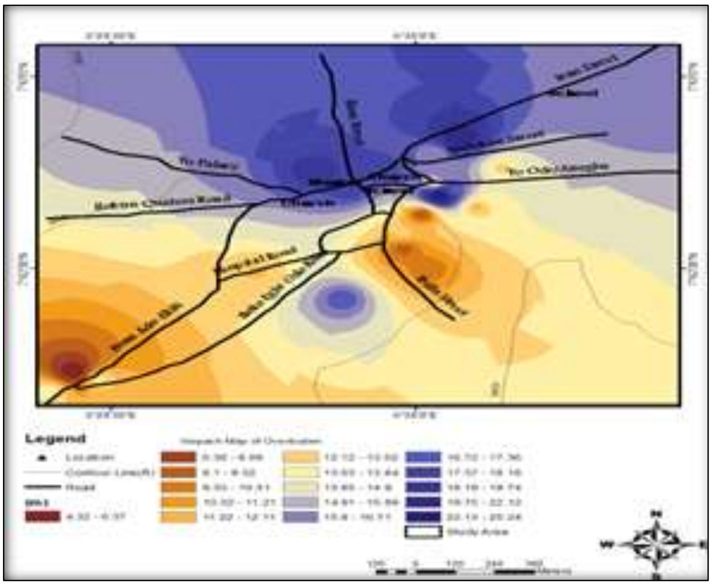

Figure 7: Isopach Map of Overburden.
Source: Authors, (2025).

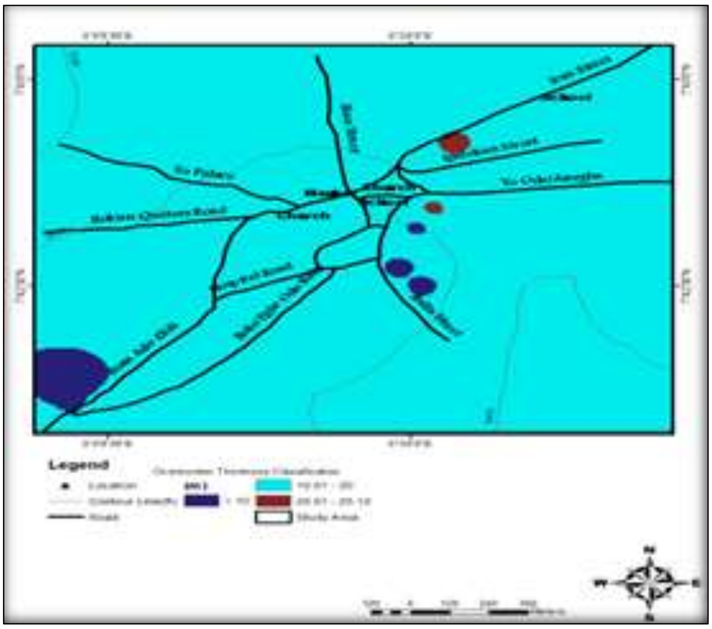

Figure 8: Classification of Overburden Thickness
Source: Authors, (2025).

Maximum possible regolith thickness is required for adequate storativity, transmissivity, and greater drawdown. Optimum weathering offers optimum conditions and groundwater potential [17],[19]. Basement fractures contribute significantly to groundwater yield in a typical basement complex terrain. Fractures readily offer enhanced porosity and permeability and hence increasing the well yield [16],[18],[20]. Bedrock resistivity of less than 750 Ω-m is indicative of high fracture and permeability as a result of weathering with high aquifer potential.

An integration of geoelectric parameters according to the relative importance to groundwater occurrence and accumulation is facilitated in a GIS environment [9], [22-24]. The themati maps were synthesized using the weighting combination (Table 2) for the resulting groundwater potential map, Figure 9. The map classifies the study area into very low, low, medium and high groundwater potential zones covering areal extent of 0.004 km2, 0.18 km2, 1.85 km2, and 1.32 km2, respectively.

Table 2: Multi-criteria evaluation parameters for generation of groundwater potential.

Geoeletric Parameters	Classes	Scale value	Weight
Bedrock Resistivity (Ω-m)	<750 750-1500 1500-3000 >3000	4 3 2 1	45
ouWeathered Basement Resistivity (Ω-m)	<20 20-100 100-150 150-300 >300	3 4 3 2 1	30
Overburden Thickness (m)	<10 10-20 20-30 >30	1 2 3 4	25

Source: Authors, (2025).

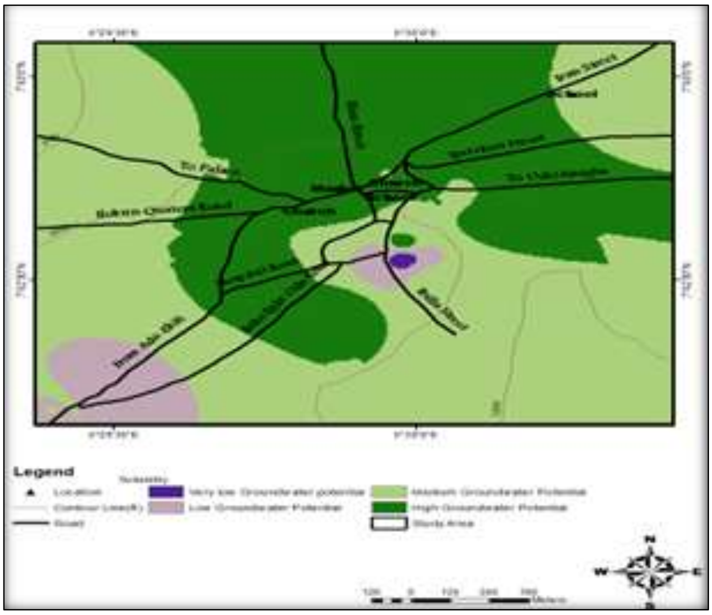

Figure 9: Groundwater Potential Map of the Study Area.
Source: Authors, (2025).

Table 3: Classification of groundwater potential zones (after integration of thematic layer).

Groundwater Potentiality	Area in (km^2)	Percentage
Very Low	0.004	0.1
Low	0.18	5.4
Medium	1.85	55.2
High	1.32	39.3

Source: Authors, (2025).

V. CONCLUSIONS

A geoelectric assessment of the groundwater potentials of Ijesha Isu Ekiti has been conducted in a GIS platform. Integration of attributes in a GIS environment enabled the categorization of the study area into very low, low, medium and high groundwater potential zones. Significant hydro-geologic structures delineated from of the subsurface resistivity distribution included basement ridges and depressions. The basement depressions being the groundwater collecting centres are priority areas for groundwater development. The study provides regional overview of the groundwater resources in the area. It would guide the planning and design of hydrogeophysical investigations for site specific groundwater development. Data density can be improved for further studies.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Ewumi and Ogunlana.
Methodology: Oyedele, Ewumi and Ogunlana.
Investigation: Oyedele, Ewumi and Ogunlana.
Discussion of results: Oyedele, Ewumi and Ogunlana.
Writing – Original Draft: Ewumi and Ogunlana.
Writing– Review and Editing: Ewumi and Ogunlana.
Resources: Oyedele, Ewumi and Ogunlana.
Supervision: Ewumi and Ogunlana.
Approval of the final text: Oyedele, Ewumi and Ogunlana.

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