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Lithological and Structural Factors Affecting Groundwater Occurrence in Eruwa, South West Nigeria

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ABSTRACT

The subsurface Lithological and Structural framework was investigated to understand its effects on groundwater aquiferous occurrence in this study, underlined by the Precambrian Basement Complex of Nigeria, with granite, gneiss, and schist occurring as the dominant rock types. To successfully map the subsurface, fifty-two (52) Vertical Electrical Sounding points were probed to a depth of current electrode spacing of 100m depth to obtain the variation in the resistivity measurement of the underlying weathered basement and basement rock in the subsurface. Apparent resistivity values and current electrode spacing are plotted on a bi-logarithm plot and correlated to standard curves to estimate subsurface layers' depth, thickness, and resistivity values. WinResist software uses a mathematical algorithm to estimate further the geoelectric parameters to find the best-fit model that matches the observed data. Golden Surfer software was used to represent the geoelectric parameters to aid in geospatial representation. Results show 3-5 lithological layers, which include Topsoil, Clay, Laterite, Sand, Sandy Clay, and Fresh Basement with resistivity value range 82.1Ωm - 2648.2Ωm, 21.8Ωm - 98.4Ωm, 102.3Ωm -167.5Ωm, 404.6Ωm - 2468.2Ωm and 606.8Ωm - 20,535.90Ωm indicating a weathered and fresh unweathered basement rocks layers with H, KH, HA, HKH, KHKH, QH and A geophysical curve which are also typical geometry of weathered material and limited or no fractures basement rock layer. Basement rock resistivity, Overburden thickness, Reflection coefficient, longitudinal conductance, Anisotropy coefficient range (606.8Ωm-20535.9Ωm, 2.6m - 35.6m, 0.3-1.0, 0.01-0.86 and 0.7-3.3) respectively which a typical value of shallow to deep overburden layer with limited or no-detected fracture basement rock). Incorporating the geoelectric parameters value obtained and calculated reveal limited structural deformation of the basement rocks to yield fracture capable of creating secondary porosity in the area while the lithology of the weathered layers becomes the exploitable source for groundwater recovery in the study area.

Keywords:
Lithological,
Structural,
Groundwater,
Aquiferous,
Occurrence.

INTRODUCTION

The concept of exploration of groundwater is born out of the importance of these natural resources to several human functions (either domestic or industrial purposes), which makes it very important to explore its reservoirs more and make it easily exploitable and available for human usage to aid sustainable development (Elshall*et al*., 2020, Ariyo *et al*., 2003, Mosuro *et al*., 2022). Generally, the occurrences of groundwater have been generally influenced by the structural or lithological characteristics of the rocks as they are hosts beneath the earth's surfaces (Sivaramakrishnan *et al*., 2015) within geological confinement with high pore spaces (porosity) and fractures within rocks (as in case of the crystalline basement environment). However, the geological environment under exploration in research determines the possible expectancy of the occurrences of groundwater in the subsurface (Kabeto*et al*., 2022, Panahi *et al*., 2017). Groundwater occurrences in crystalline basement geological environments can basically be from weathering zone of the basement rock or within fractured basement rock. The weathered zone of the earth comprises regions in which several physical and chemical weathering processes have disintegrated the rocks into small fragments to form loose soils above the basement rock (Doro *et al*., 2023).

The weathered lithological zone in the basement environment results from the weathering of the rock and thereby leads to the formation of a weathered zone of soil that possesses characteristic properties to store and transmit water infiltrated into them by precipitation and surface water runoff recharge source (Asiwaju-Bello *et al*., 2020, Lachassagne*et al*., 2021). Also, the occurrence of groundwater within the basement rock is as a result of tectonic activities, the creation of cracks and joints during the solidification of magma which becomes a weakness zone that can aid further weakness zones. The interconnectivity property of the fractures within the basement rock can serve as a pathway for the movement of water through the rock, thereby aiding the flow of groundwater, especially in areas where the size and spacing of the fractures are big and long, respectively, with the ability of the rock to aid more saturation and high hydraulic conductivity of the rock (Preeja*et al*.,2011).

The inability to physically observe or examine the presence or occurrences of groundwater has resulted in the development of several exploration tools, methods, and techniques that provides a clue about their occurrences in the subsurface using several indirect methods that relate the measurement of the physical properties of the subsurface earth materials, giving birth to the field of geophysics (Balasubramanian, 2017). The Vertical Electrical Sounding (VES) survey method of geological exploration has shown the capacity and capability of measuring the electrical properties of the subsurface earth materials down-depth using simple and non-destructive energy source generation (Shendi, 2020). This method based on the electrical resistivity of rocks principles has been found to have a great correlation with the degree of saturation of the soil, which predicts porosity, weathering, and fracture in the subsurface (Samouëlian*et al*., 2005, Lachassagne*et al*., 2021). The success of this method becomes the basis of adopting it for the investigation of occurrences of groundwater in the crystalline basement area of Eruwa, southwestern Nigeria, to know the effect of lithological or structural factors on groundwater occurrences by using geo-electric parameters. This work is mainly aimed at using electrical resistivity method in delineating geological structures that are capable of holding groundwater for portable groundwater yields.

Description and Geology of study location

Eruwa is geographically located in Ibarapa East Local Government Area of Oyo State, southwestern Nigeria covering about 107 square kilometers. Its topographical settings are majorly undulating hills and valleys with an elevation of about 400- 600 meters above sea level (Odewande and Olayinka, 2018). River Oluwa, Ose, and Ona flow through the town with a dendritic pattern configuration where the tributaries join into the mainstream and flow Northwest to Southeast direction. Eruwa exhibits a tropical climate with two distinct seasons: the rainy and dry seasons. The rainy season lasts from April to October, with peak rainfall occurring between June and September. The dry season lasts from November to March, with relatively low rainfall and high temperatures cumulating to an average of approximately 1,200 millimeters of annual rainfall (Owoade, 1989). Geologically, Eruwa is located on the Precambrian Basement Complex of Nigeria, with granite, gneiss, and Migmatite occurring as the dominant. The study area's geological history dates back to the Precambrian era when the study area is part of the West African Craton (over 2.5 billion years old basement rock). The Pan-African orogeny event (about 600-800 million years ago) resulted in the collision of the West African Craton with the other cratons leading to the supercontinental formation of Gondwana, giving rise to the deformation and metamorphism of some of the igneous rocks, which are typical rocks found in the study area (Figure 1).

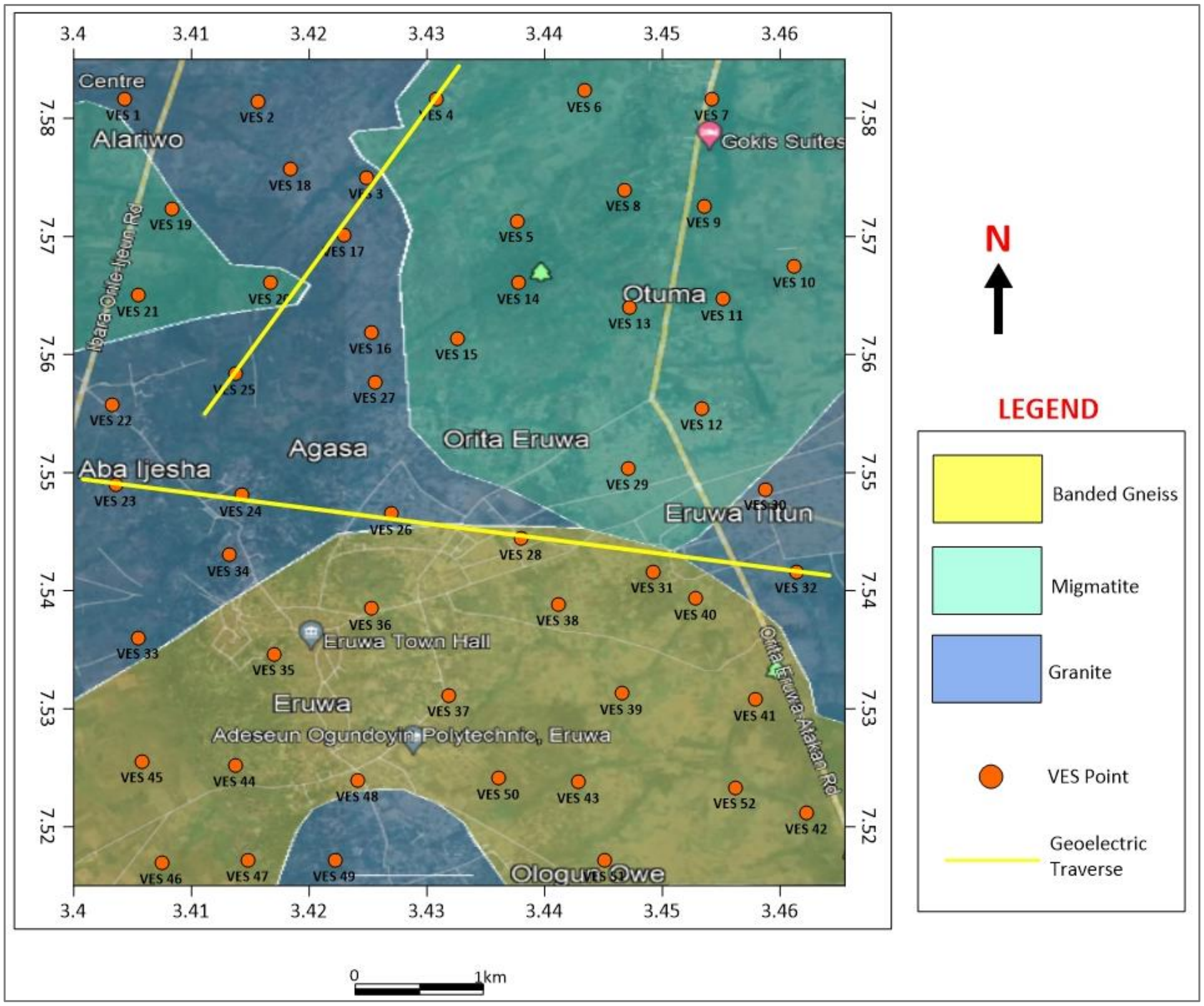


Figure 1:- Geological map of the study area (from independent geological field mapping) superimposed on the study location map of the study area indicating accessibility routes in the study area.

MATERIALS AND METHODS

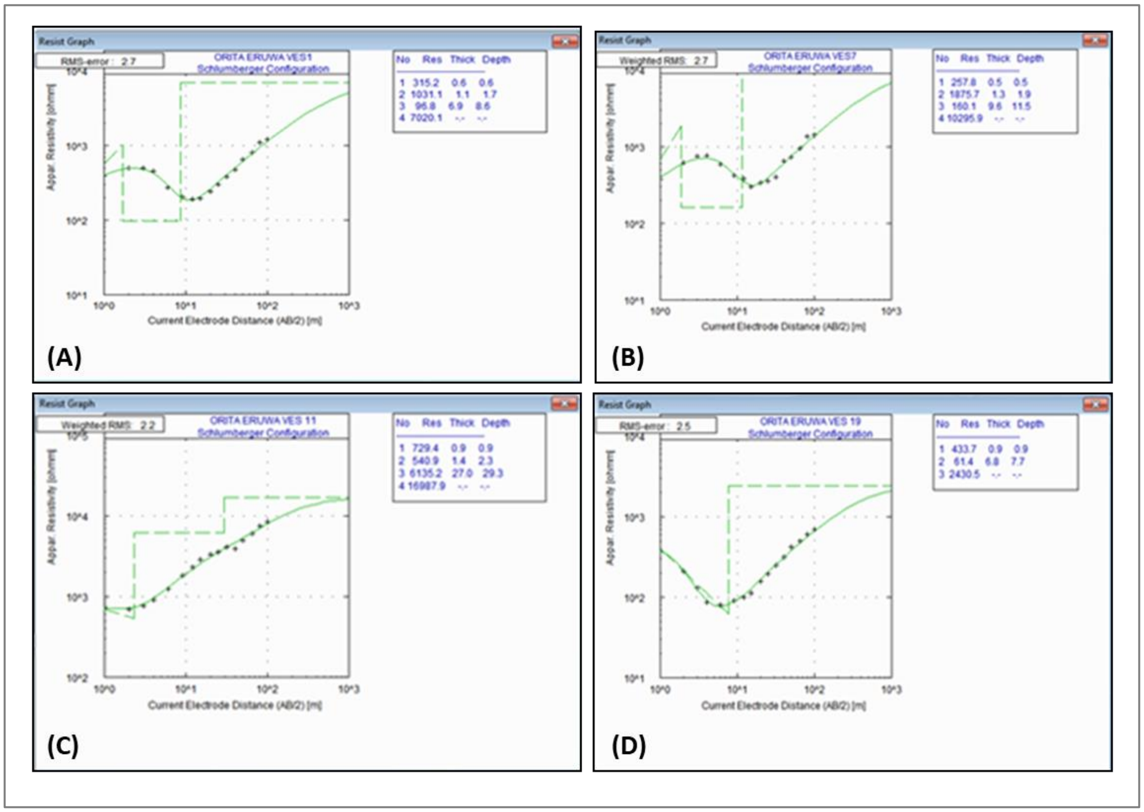
The data acquisition of this survey involves the collection of fifty-two (52) Vertical electrical sounding using the ABEM SAS 2000 Terameter / Resistivity Meter (Main Equipment), which is ensured to be in good condition and properly calibrated; with this are the incorporating materials that include cables, electrodes (two potential and current), and harmer (supporting equipment). The equipment is strategically layout on the field with its electrodes inserted into the ground with respect to the array configuration adopted. In this case, which entails the use of the Schlumberger array configuration, the current electrodes (C1 and C2) are at a specified distance from each other (AB), and the potential electrodes (P1 and P2) equidistant from the current electrodes from the center of the acquisition point, representing a distance term as AB and MN respectively. The resistivity meter is used to measure the potential difference (V) between the potential electrodes for each current electrode configuration (AB). The resistivity meter is equipped with software that automatically calculates the apparent resistivity (ρa) value using the measured potential difference and the known values of AB and MN. The measurements of the apparent resistivity values are repeated for most readings at some point for high precision and accuracy, and the same procedures of acquisition are repeated for other probe points.

The apparent resistivity value obtained from the field and the current electrode spacing is plotted on a bi-logarithm plot to obtain the geometry of the curve, which is further subjected to the curve-matching processing approach, which involves its comparison with a set of standard curves or master curves that are generated using a known model or geologic interpretation of the subsurface. For every match between both curves, the depth and thickness of the subsurface layers and their resistivity values are estimated based on the standard curves using some elementary computations. This estimated parameter value is further processed using computer-based WinResist version 1.0 software to compute the Computer Iteration process, which is a mathematical algorithm to iteratively solve the forward problem to obtain the best-fit model that matches the observed VES data to understand and facilitate the interpretation of the subsurface geology.

Further processing of the data entails the representation of the geo-electric parameters with the Geosoft Surfer 16 Software to present the geospatially quality of the values in the study area. The interpretation of the processed data is based on incorporating the principle of the electrical methods with the geological settings history of the study area and geological imagination to better understand the lithological unit and structures of the characteristic signal of the subsurface.

RESULTS AND DISCUSSION

The subsurface layer underlying the study location varies from 3-5 lithological layers, which include Topsoil, Clay, Laterite, Sand, Sandy Clay, and Fresh Basement with resistivity value range 82.1Ωm - 2648.2Ωm, 21.8Ωm - 98.4Ωm, 102.3Ωm -167.5Ωm, 404.6Ωm - 2468.2Ωm and 606.8Ωm - 20,535.90Ωm. The bi-logarithm plot of the apparent resistivity with the current electrode spacing in Figure 2 shows varying geoelectric curves, which depict the pattern of variability of the subsurface materials and a typical pattern of basement terrain (Olayinka, 1996 and Ariyo Adeyemi, 2009), the vertical electrical sounding geophysical curve shows H, KH, HA, HKH, KHKH, QH and A with an occurrence percentage of 52%, 32%, 6%, 4%, 2%, 2%, and 2% respectively implying the subsurface in the study area shows varying weathered material geo-electric properties, and also the basement rock occurs as the last layer to be encountered in the study area with limited or no fracture (Figure 3). The diagrammatic representation of the present lithological layers delineated in the study area is presented with a geoelectric section along a traverse line that shows the thin topsoil layer, which ranges 0.7-3.1m and 0.6-1.6m in Figure 4 and Figure 5 respectively. The consideration of the thickness of the Weathered layer shows a thickness of 0.6-20.5m and 3.3-7.7m, respectively. Without considering VES 23 in traverse 1, the thickness of the overburden increases from the eastern region to the western region, while Traverse 2 shows reveal an increase in the thickness of the weathered layer from the southwestern region to the northeastern region. The respective resistivity values of all the established points were mathematically computed to derive hydrogeophysical parameters, which are good indicators of the subsurface lithological layer. The calculated parameters in this study are presented in Table 1.



No	Res	Thick	Depth
1	315.2	0.6	0.6
2	1031.1	1.1	1.7
3	95.8	6.9	8.6
4	7020.1	-.-	-.-

(A)

No	Res	Thick	Depth
1	257.8	0.5	0.5
2	1875.7	1.3	1.9
3	160.1	9.6	11.5
4	10295.9	-.-	-.-

(B)

No	Res	Thick	Depth
1	729.4	0.9	0.9
2	540.9	1.4	2.3
3	6135.2	27.0	29.3
4	16987.9	-.-	-.-

(C)

No	Res	Thick	Depth
1	433.7	0.9	0.9
2	61.4	6.8	7.7
3	2430.5	-.-	-.-

(D)

Figure 2:- Resistivity value against Current electrode spacing plot / curve obtained from the computer iteration -inversion process.

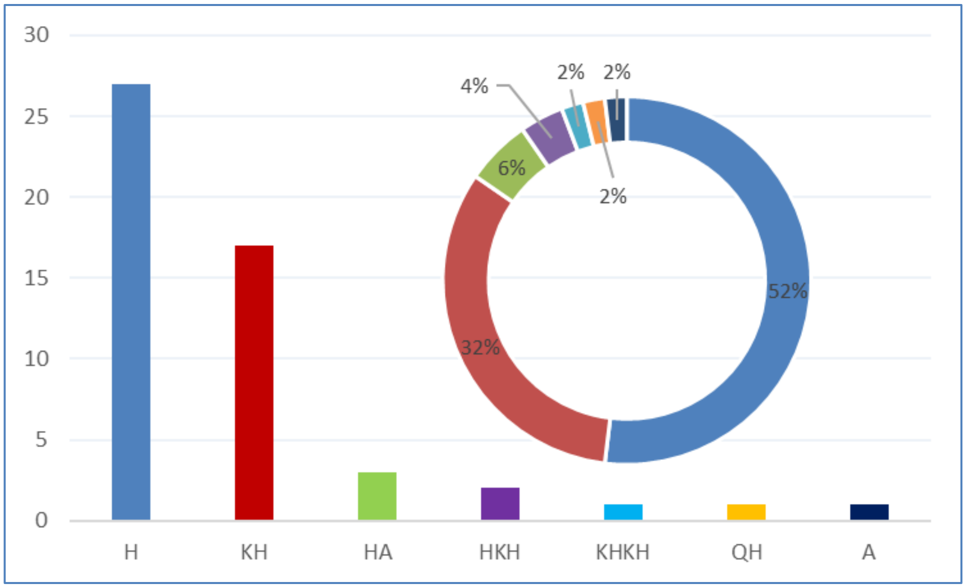


Figure 3:- Infographic representation of the geophysical curve of the VES point (bar chat representing the occurrence of the curve types and the pie chat indicating the percentage occurrence of the curves).

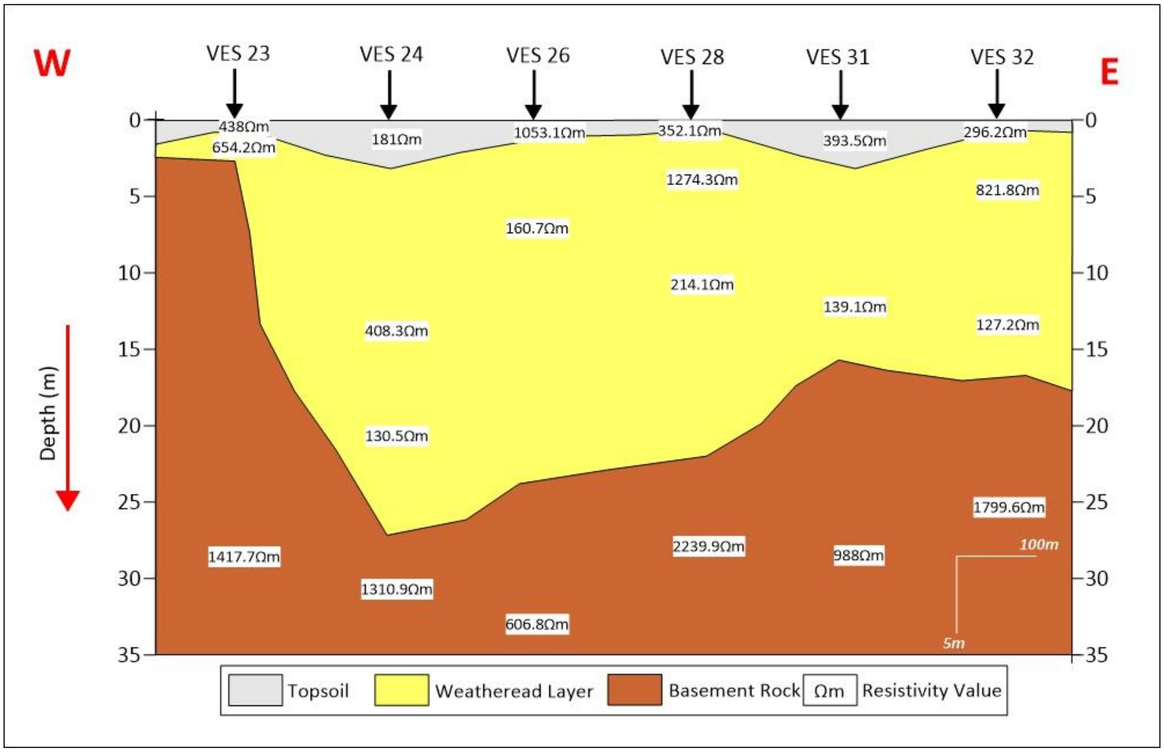


Figure 4:- Geoelectric section of traverse 1 revealing the depth to the various lithological layers.

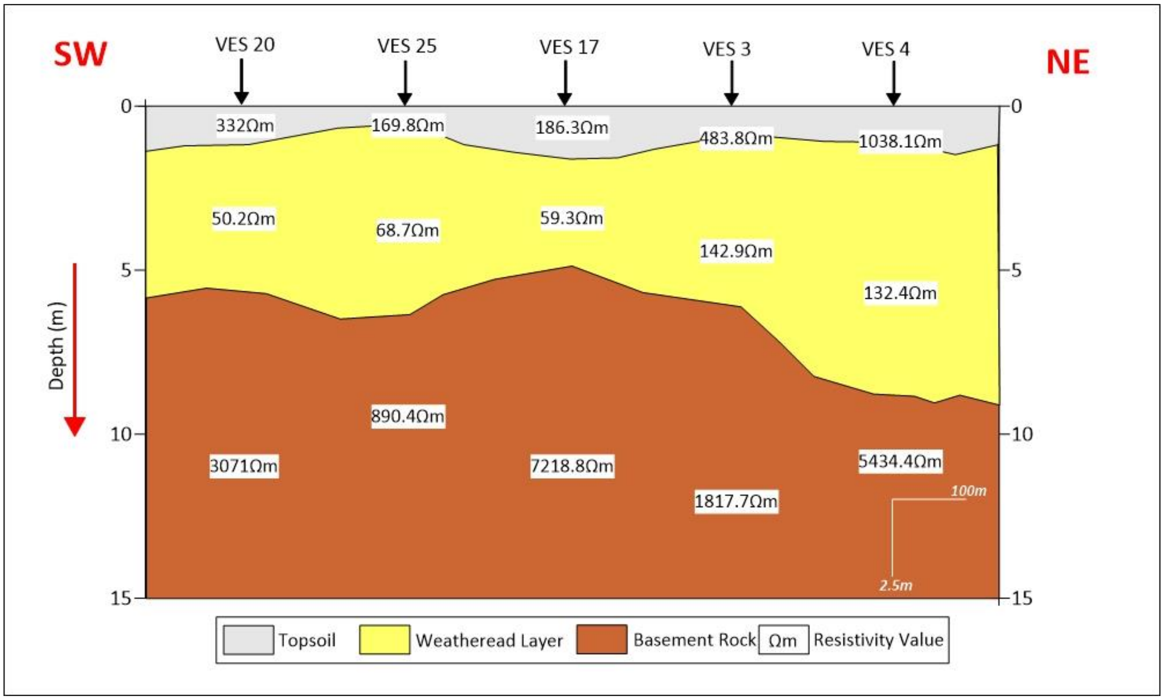


Figure 5:- Geoelectric section of traverse 2 revealing the depth to the various lithological layers.

Table 1:- Derived and calculated Geoelectric parameters of the established VES points

VES No.	Basement Resistivity	Overburden thickness	Reflection coefficient	Longitudinal conductance	Anisotropy coefficient
1	7020.1	6.9	1.0	0.1	1.4
2	5892	4.0	1.0	0.1	1.5
3	1817.7	5.1	0.9	0.0	1.2
4	5434.4	7.7	1.0	0.1	1.4
5	20535.9	6.9	1.0	0.0	1.3
6	10880.7	9.4	1.0	0.1	1.2
7	10295.9	9.6	1.0	0.1	1.7
8	8071.8	5.6	1.0	0.1	0.7
9	6237.5	8.3	1.0	0.1	1.2
10	7862	4.0	1.0	0.0	1.0
11	16987.9	27.0	0.5	0.0	1.3
12	4994.5	14.6	0.5	0.0	1.8
13	10880.1	2.9	1.0	0.0	1.2
14	7721.9	9.3	1.0	0.1	1.1
15	4904.9	2.6	1.0	0.3	3.3
16	7612.2	6.6	1.0	0.0	1.1
17	7218.8	3.3	1.0	0.1	1.2
18	8437.9	5.2	1.0	0.1	1.2
19	2430.5	6.8	1.0	0.1	1.2
20	3071	4.5	1.0	0.1	1.3
21	5497.8	12.9	1.0	0.2	1.5
22	4653.2	28.1	0.8	0.0	1.3
23	1417.7	35.6	0.8	0.2	1.2
24	1310.9	27.1	0.8	0.1	2.2
25	890.4	6.4	0.9	0.1	1.0
26	606.8	7.1	0.6	0.0	1.3
27	1128.1	11.9	0.8	0.1	1.1
28	2239.9	22.3	0.8	0.1	1.1

29	754.9	16.1	0.3	0.0	1.0
30	2266.3	15.9	0.9	0.2	1.2
31	988	15.8	0.8	0.1	1.1
32	1799.6	16.8	0.9	0.1	1.2
33	1689	13.5	0.9	0.1	1.2
34	3006.3	34.0	0.7	0.0	0.7
35	1101.2	8.5	0.8	0.1	1.0
36	746.7	12.8	0.7	0.1	1.0
37	844	8.1	0.9	0.1	1.1
38	714.4	16.0	0.7	0.1	1.1
39	891.1	8.0	0.7	0.1	1.0
40	2036.7	16.7	0.9	0.1	1.0
41	2015	11.4	0.9	0.1	1.1
42	1216.4	5.2	0.8	0.0	1.0
43	2756.8	8.9	0.9	0.1	1.0
44	11960.2	8.1	1.0	0.9	1.2
45	1538.2	5.5	0.9	0.1	1.1
46	1380.3	7.6	0.8	0.0	1.1
47	12776.7	9.7	1.0	0.1	1.9
48	5629	20.7	1.0	0.4	2.1
49	1213.1	31.5	0.9	0.3	1.3
50	4102.1	5.6	1.0	0.2	1.5
51	1214.9	9.5	0.9	0.1	1.0
52	1040.2	5.5	0.8	0.1	1.2

The Hydrogeophysical Parameters calculated for the established vertical electrical sounding point reveal that the basement rock resistivity in the study area has a resistivity range of 606.8Ωm-20535.9Ωm. The geospatially of this value reveals the basement resistivity in the study area is relatively high throughout the established point, but more classification of the value shows the higher resistivity value is within the northern and southwestern indicating an increment northeastern and southwestern while the basement resistivity decreases towards the other part of the study area, most especially in the central part of the study area (Figure 6). The higher values indicate the non-aquiferous potential of the underlying basement rock in the study area.

The understanding of the highly saturated weathered layer, and fracture basement rock as the best host of groundwater in a basement terrain cumulative into the calculation of all the overlying layer thickness to this aquiferous layer in the study area (Ariyo, *et.al*,2018)). The Overburden thickness, which is a typical depth from the surface to the aquiferous layer, shows the thickness of the overlying weathered material to range 2.6m - 35.6m. The value indicates the overburden thickness ranges from shallow to high overburden thickness. The geospatial map representation reveals the overburden thickness is high in the eastern, western, and southern parts of the study area, while the northern part shows low overburden thickness depicting a possible shallow aquifer (Figure 7).

The Reflection coefficient, which is an interface attribute between the last layers and the second to the last layer within the study area, ranges 0.3-1.0. The reflection coefficient of the study area reveals a low value in the central part of the study area and increases towards the other region of the study area (Figure 8). The implication of the high reflection coefficient region suggests the presence of relatively impermeable or low-porosity layers (Bayewu, et.al, 2021 and Bayewu, *et. al.*, 2018).

The longitudinal conductance value ranges 0.01-0.86, the longitudinal conductance map shows generally low values except for the southwestern region of the study area (Figure 9). The implication of the low longitudinal conductance reveals less conducting subsurface material, which signifies a non-aquiferous layer because aquifers generally have high longitudinal conductance (Ariyo, *et.al*, 2018)

The Anisotropy coefficient ranges 0.7-3.3, the observed coefficient of anisotropy in the study area reveals mostly low values in most parts of the study area except few regions in the southern and northern parts of the study area (Figure 10). The implication of the anisotropy coefficient, which is a determinant degree of variability in the subsurface geology, reveals the study area has limited variability.

Structural and lithological determination of factors affecting groundwater in the study area can best be predicted from the geoelectric derivation from the reflection coefficient value and the overburden thickness, and this parameter was incorporated to successfully infer the groundwater yield of the established points (Table **2**). The presence of high overburden thickness value and a high reflection coefficient indicates the possible expected yield of groundwater will have its source from lithological layers, while less reflection coefficient value indicating fracture, which is a sign of structural deformation in the underlying basement rock, gives rise to an aquiferous layer from the bedrock thereby giving high yield when aided with high overburden lithological thickness but might result into a moderate yield when the overburden is shallow. The study area groundwater potential yield delineation in a geospatial representation shows the northern and southern region of the study area shows a low groundwater potential yield, and the central part shows both moderate and high groundwater yield (Figure 11). However, it is observed that the high groundwater yield region is towards the core center of the study area. Generally, the groundwater potential yield in the study area reduces from the central part of the study area.

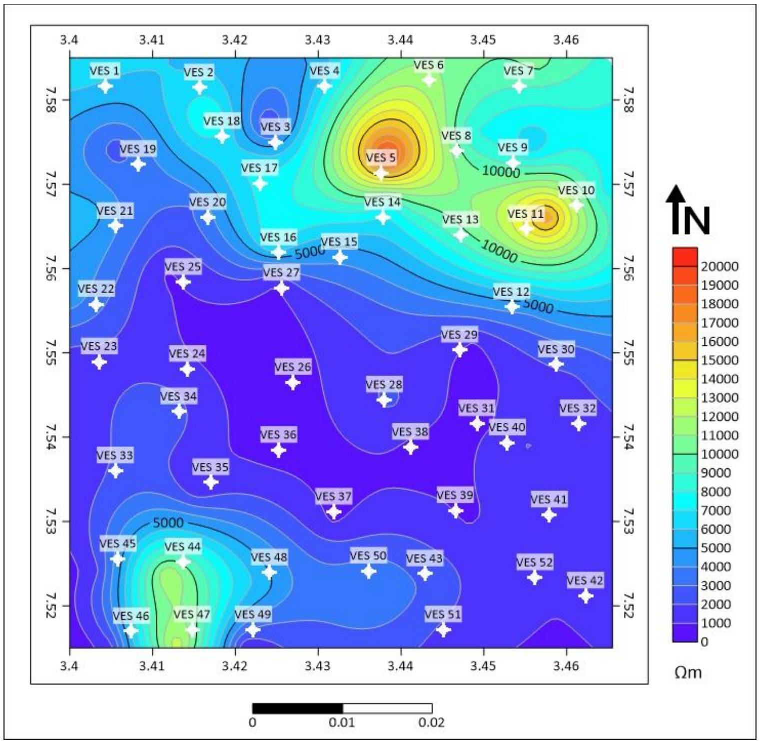


Figure 6:- Geospatial distribution of the Basement rock resistivity in the study area with incremental trending northward.

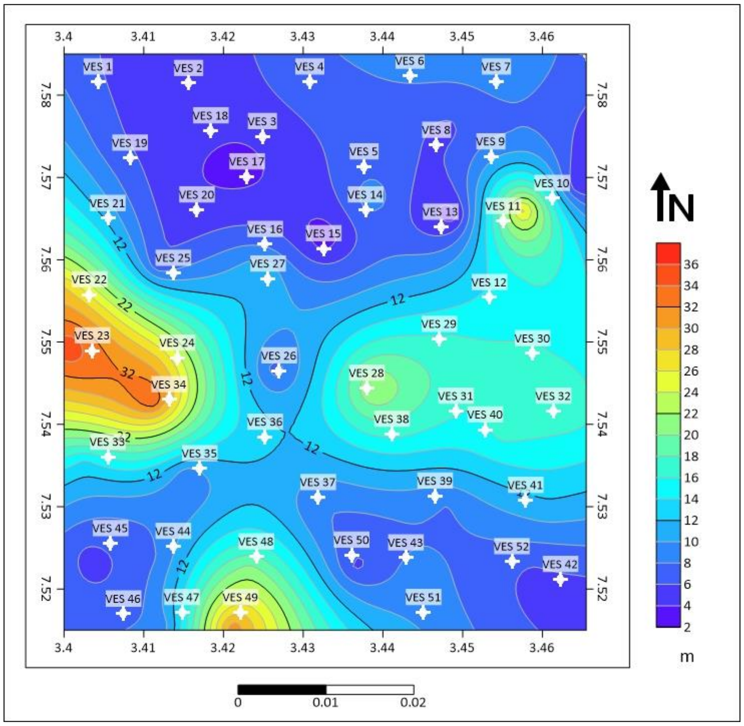


Figure 7:- Geospatial distribution of the Overburden thickness with increasing overburden to the East and West ward.

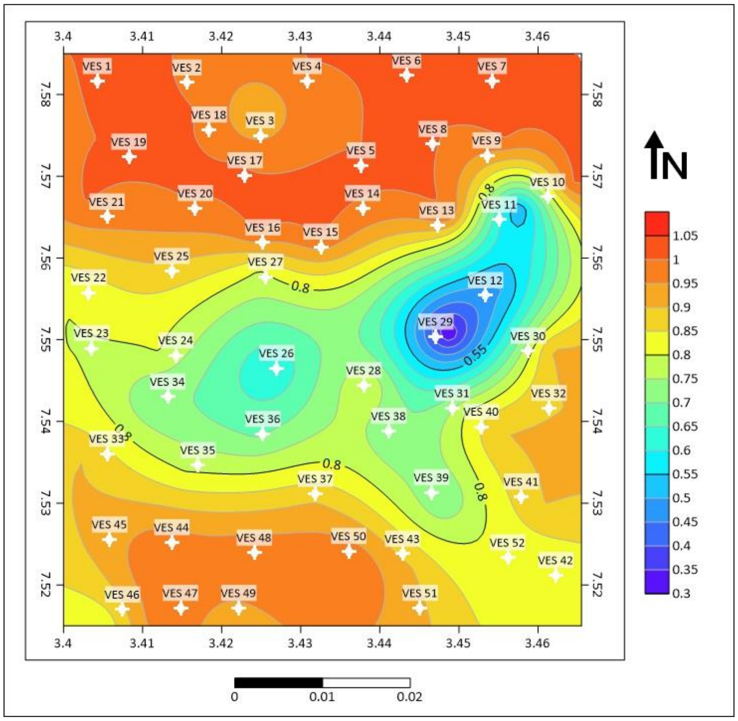


Figure 8:- Geospatial distribution of the Reflection coefficient with increment from the central part of the study area.

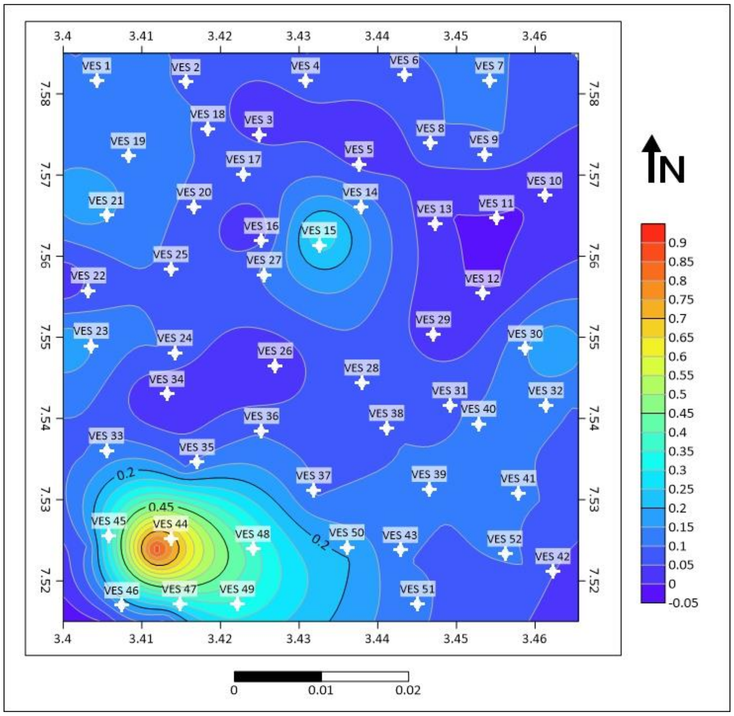


Figure 9:- Geospatial distribution of the Longitudinal conductance with incremental trend southward

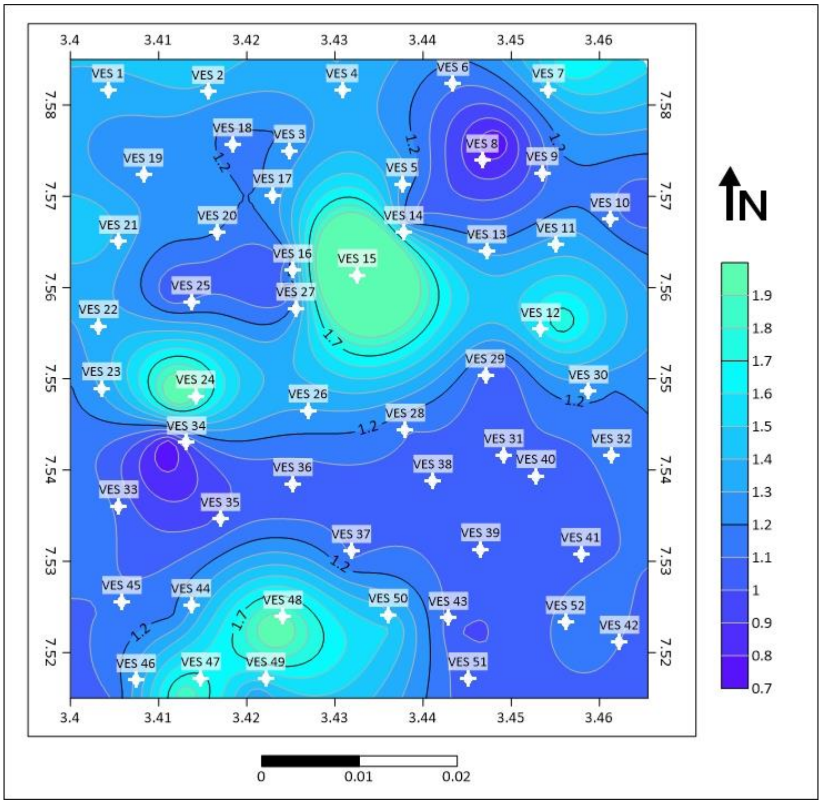


Figure 10:- Geospatial distribution of the Anisotropy coefficient

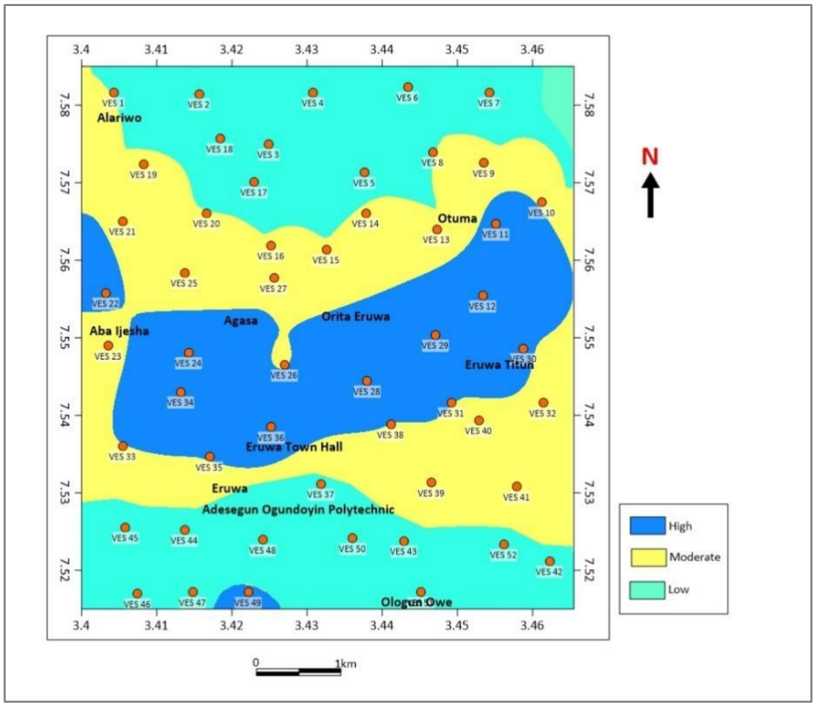


Figure 11:- Geospatial representation of Groundwater Potential of the study area

Table 2:- Groundwater Potential delineation of the established Point

VES No.	Overburden thickness	Reflection coefficient	Ground water Potential	VES No.	Overburden thickness	Reflection coefficient	Groundwater Potential
VES 1	6.9	1	Low	VES 27	11.9	0.8	Moderate
VES 2	4	1	Low	VES 28	22.3	0.8	High
VES 3	5.1	0.9	Low	VES 29	16.1	0.3	High
VES 4	7.7	1	Low	VES 30	15.9	0.9	Moderate
VES 5	6.9	1	Low	VES 31	15.8	0.8	Moderate
VES 6	9.4	1	Low	VES 32	16.8	0.9	Moderate
VES 7	9.6	1	Low	VES 33	13.5	0.9	Moderate
VES 8	5.6	1	Low	VES 34	34	0.7	High
VES 9	8.3	1	Low	VES 35	8.5	0.8	Moderate
VES 10	4	1	Low	VES 36	12.8	0.7	High
VES 11	27	0.5	High	VES 37	8.1	0.9	Low
VES 12	14.6	0.5	High	VES 38	16	0.7	Moderate
VES 13	2.9	1	Low	VES 39	8	0.7	Moderate
VES 14	9.3	1	Low	VES 40	16.7	0.9	Moderate
VES 15	2.6	1	Low	VES 41	11.4	0.9	Moderate
VES 16	6.6	1	Low	VES 42	5.2	0.8	Low
VES 17	3.3	1	Low	VES 43	8.9	0.9	Low
VES 18	5.2	1	Low	VES 44	8.1	1	Low
VES 19	6.8	1	Low	VES 45	5.5	0.9	Low
VES 20	4.5	1	Low	VES 46	7.6	0.8	Low
VES 21	12.9	1	Moderate	VES 47	9.7	1	Low
VES 22	28.1	0.8	High	VES 48	20.7	1	Low
VES 23	35.6	0.8	Low	VES 49	31.5	0.9	High
VES 24	27.1	0.8	High	VES 50	5.6	1	Low
VES 25	6.4	0.9	Low	VES 51	9.5	0.9	Low
VES 26	7.1	0.6	Moderate	VES 52	5.5	0.8	Low

CONCLUSION

This present research provides detailed exploration research in understanding the subsurface lithological and structural influence on groundwater aquiferous occurrence within the Precambrian Basement Complex of Nigeria. The derived and calculated geoelectric parameters, resistivity values, and geological curves indicated the presence of weathered lithological layers and unweathered basement rock layers. The absence of fractures within the study area is a result of limited structural deformation, thereby inhibiting the development of secondary porosity that could enhance groundwater flow. This limitation in the bedrock in the area makes the overburden lithological composition of the weathered layers emerge as a promising source for groundwater recovery in the study area. The findings have significant implications for decision-making for groundwater resource management and environmental conservation for sustainable groundwater exploitation.

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