International Journal Of Latest Technology In Engineering & Management (IJLTEM)
Volume 8 - Issue 3 {May-Jun. 2023} {Page: 36-47}

SPATIAL VARIATION OF GROUNDWATER POTENTIAL AT ERUSU-ARIGIDI IN ONDO STATE

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Contributions of the Authors
Onifade YS worked on the Data got by Egbejule KA from the field work. Analytics of the Data and graphical representation were done by the two Authors.

ABSTRACT: *An investigation has been made of the groundwater potentials of Erusu-Arigidi, Ondo State, Nigerian and using electrical resistivity survey. This study was motivated to determine the electrical resistivity parameters of the area. This work aims to use the electrical resistivity method to explore the groundwater potentials of the study area. A total of ten vertical electrical soundings (VES) were conducted with a maximum electrode spacing of 150 m. The data was acquired using ABEM SAS 1000 Terrameter and processed using WINRESIST. The interpreted and analyzed results reveal four to six geoelectric layers. The VES curves obtained were QH, H, AAA, HKH, and HA. Findings from the study revealed that geoelectric layer ranges from 3 to 5 layers. From the result, the Dar Zarrouk parameters longitudinal conductance (S) and transverse resistance (Tr), average longitudinal resistance (ρ_L), transverse resistivity (ρ_t), coefficient of anisotropy (λ), and reflection coefficient ranges from 0.22 to 1.45mhos, 67.12 to 4262.91 Ω/m^2, 8.81 to 76.12 Ω-m, 12.0 to 243.5 Ωm2, 1.01 to 1.78, and 0.72 to 0.99 respectively. Deduction from S suggested that groundwater tends to be slightly vulnerable to surface contamination. Further findings from Dar Zarrouk parameters revealed that southwest parts of the study area tends to high in groundwater potential when compared to other parts of the study area. While hydraulic conductivity, and transmissivity ranges from 0.003 to 0.051m/day, and 11.16 to 158.30m^2/day, results obtained from H, and T revealed northwest parts of the study area is considered to be aquiferous when compared to other parts of the research area.*

Keywords: Groundwater, Spatial Variation, Vertical Electrical Sounding, Logitudinal Conductance

INTRODUCTION

One of the primary requirements that sustain life is considered to be water. It is found above and below the earth's surface as surface water and groundwater. Due to its less contaminated nature than surface water, groundwater is always preferable over it (Rilwanu, 2014). According to Eyankware et al. (2022a), groundwater has several advantages over surface water, including the fact that it naturally occurs, is frequently of potable quality, and doesn't need to be treated. More specifically, one of the most vital resources for community development is water. Planning and development of groundwater systems require a thorough understanding of an area's hydrogeological and hydrochemical properties.

The research area struggles with severe water shortage issues, particularly during the dry season when certain communities' surface water resources run out. The prevalence of water-borne infections is a result of this issue. Ponds and a few nearby streams are the only sources of household water available to the area's residents (Mogaji et al., 2011).Prior attempts to distribute water in the area by state governments, non-governmental organizations, and individuals resulted in the creation of numerous unsuccessful boreholes (Ebong, et al., 2014). Lack of understanding of the subsurface geology, aquifer geometry, and features could be the cause of such failures (Mogaji et al., 2011). Therefore, to raise the standard of life of the populace, there is currently an increasing demand for accurate understanding, describing, and mapping of the spatial distribution of water-bearing units at Erusu-Arigidi area. In Nigeria, groundwater availability varies according to the local geology. Groundwater is found in both fissures in the recently formed crystalline rocks and weathered regolith in the terrain of the Basement Complex. Wells and boreholes use the groundwater beneath thick weathered zones or fissures in young rocks to produce water (Obasi,et al., 2020). Determining the depth of the water table and other hydrogeophysical issues can be investigated using the electrical resistivity approach (Akinalu et al., 2017a; Akinalu, et al., 2017b; Alaa et al., 2017; Hani, 2010; John et al., 2015; Sultan et al., 2017 and Yadav et al., 2010), determination of aquifer characteristics and distribution (Mele, et al., 2010) and aquifer protective capacity (Okiongbo and Akpofure, 2012; Braga, et al.,2006). Similar to this, Bayode et al. (2006) characterized the aquifer in the Basement Complex area at a few locations throughout Osun State, Nigeria, using the resistivity method with Schlumberger configuration.

Location of Study

The study region is located in Ondo State's basement complex area in southwest Nigeria between latitudes 7°33' and 7°37' N and longitudes 5°40' and 5°52' E as shown in Fig. 1. The drainage system in the area is characterized by the development of many minor river channels. The vegetation is abundant and composed primarily of evergreen broad-leaved trees. . The lithologic units include Schist, Quartzite, gneiss and Migmatite. These types of rock units are usually characterized by poor hydraulic properties due low porosity and hydraulic conductivity. However these properties can be improved by fracturing, faulting, jointing etc. The primary permeability in this unit is low due to clay which results from the weathering of schist and migmatite that contain ferromagnesian minerals. Although areas underlain by schist are usually characterised by thick weathering depths, the ability of this thick overburden to transmit groundwater could be hindered by the low permeability of the clayey aquifer.

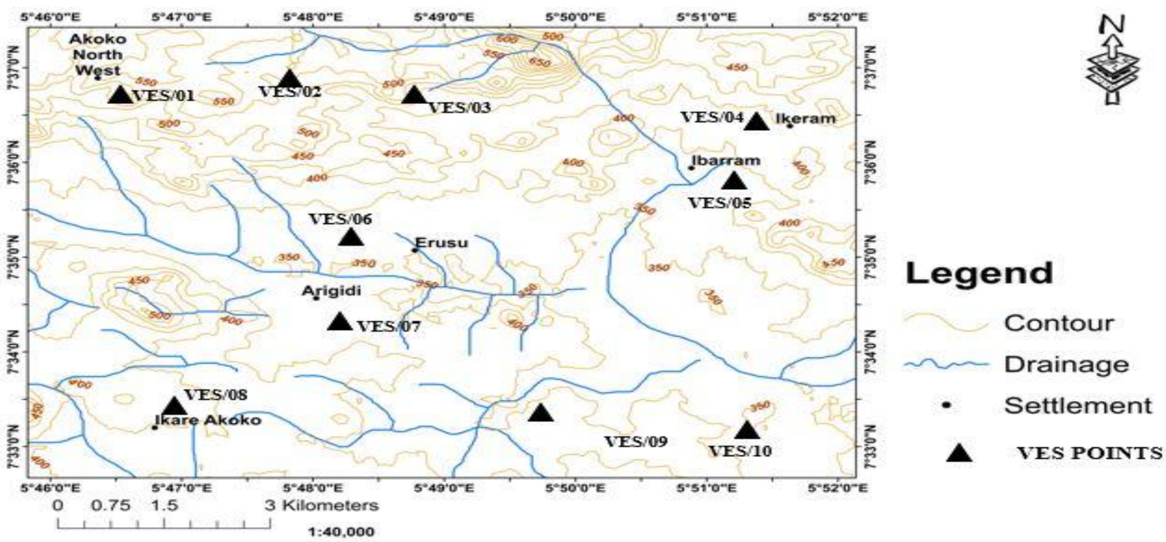

Figure 1: Topographic Map of the study area.

MATERIALS AND METHODS

Materials used for this research are: Abem Terrameter SAS 1000, Laptop, Camera, Brunton compass, Measuring Tape, Global position system (GPS), Field note book, Topographic map and ranging pole.

In each sounding point, four (4) electrodes are hammered in to the ground via which the electric current will be transmitted into the ground and the potential difference will be detected and measured by the Terrameter. The schlumberger electrodes array will be employed to generate the field data. The two (inner) potential electrodes (P_1 and P_2) will initially be placed at 0.2m from the central reference point. Similarly, the two current electrodes (C_1 and C_2) will be placed at 2m from the reference point, all lying symmetrical to each other as shown in figure 2.

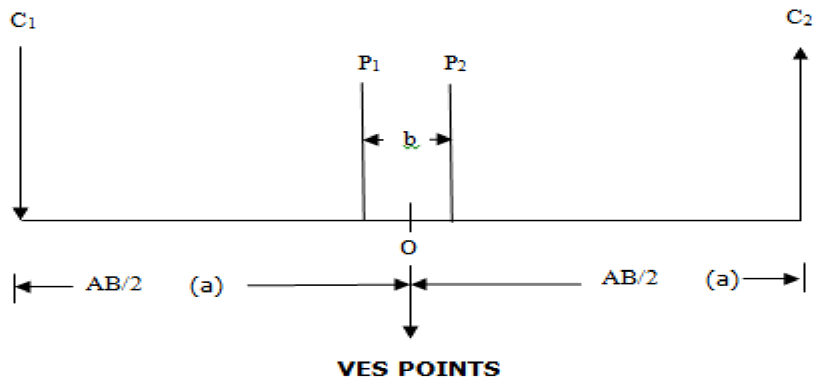

Figure 2: Sketch Diagram of Schlumberger Array.

The Terrameter was connected to the electrodes via conducting wires. After making all the necessary connections, the readings will be displayed on the LCD screen of the terrameter. This technique will be repeated for the rest of the VES stations in the study area. A total number of 10 Schlumberger VES points were sound in the survey area with AB/2 of 150m. The VES was adopted using the Schlumberger configuration. The VES allows for a fixed depth to be probed to a deeper depth while the current electrodes are being moved symmetrically about the Centre of spread.

The Vertical Electrical sounding (VES) data were interpreted qualitatively and quantitatively. The VES data were plotted on a bi-log graph, in which the apparent resistivity data were plotted against electrode spacing which is AB/2 for VES. Results are presented as sounding curves, tables and maps. The qualitative interpretation involved the visual inspection of plots obtained from the resistivity data in terms of variation of resistivity with depth. In the profile data, the areas of high and low resistivity were noted and described, and attributed to the presence of resistive/conductive bodies below the surface at the point of observation of generated anomalies.

The quantitative interpretation involved the observation of resistivity sounding curves, there by identifying the layers number base on the curve type. This quantitative interpretation of VES data involved partial curve matching of obtained data to obtain layer resistivity values and thicknesses. This process compares the obtained field curves with a set of theoretical matching curves. The scaled bi-logs graphs of both the field curve and the theoretical matching curves were kept at the same on both axes, following the law of parallelism on overlaying the field curves on the theoretical curves. Layers parameters were obtained from fitted curves. The obtained layer parameters were then fed into WINRESIST interpretation software and iterated. The layers parameters were automatically adjusted until a best fit is obtained with a minimum Root Mean Square (RMS) error less than 10%

The Dar Zarrouk Parameters such as longitudinal conductance (S), transverse resistance (T), longitudinal resistivity (L), transverse resistivity, and coefficient of anisotropy (l) are secondary resistivity parameters introduced by Maillet (1947) that are derived from primary resistivity parameters as shown in equation1 to5. These parameters reduce ambiguity in the interpretation of the subsurface geology.

a. The Total Longitudinal unit conductance (S) was calculated using Henriet (1976). For 'n' layers, the total longitudinal conductance is

$$\mathbf{S} = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_i}{\rho_i} + \frac{h_2}{\rho_2} + \cdots + \frac{h_n}{\rho_n} \qquad 1$$

Where h = thickness and ρ = resistivity.

b. Transverse unit resistance was calculated using Niwas and Singhai, (1981)

$$T = \sum_{i=1}^{n} h_i\rho_i = h_i\rho_i + h_2\rho_2 + \cdots + h_n\rho_n 2$$

Where h = thickness and ρ = resistivity

c. Longitudinal Resistivity was calculated using Maillet, (1947) equation.

$$\rho_L = \frac{H}{S} = \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} \frac{h_i}{\rho_i}} \qquad 3$$

Where h = thickness and ρ = resistivity

d. The Transverse Resistivity was calculated using Maillet, (1947) equation.

Transverse resistivity is

$$\rho_t = \frac{T}{H} = \frac{\sum_{i=1}^{n} h_i \rho_i}{\sum_{i=1}^{n} h_I} \qquad 4$$

Where ρt = Transverse resistivity, h = thickness and ρ = resistivity.

e. Coefficient of Anisotropy (λ) was calculated for using Zohdy, et al., (1974) equation

$$\lambda = \sqrt{\frac{\rho_t}{\rho_L}} = \frac{\sqrt{ST}}{H} \qquad 5$$

f. Transmissivity (T) is the product of the hydraulic conductivity (k) and the aquifer layer thickness.

$$T = K \times h \qquad 6$$

g. Hydraulic Conductivity

$$K = 0.0538E^{0.0072P} \qquad 7$$

Where P is the aquifer layer resistivity

RESULTS AND INTERPRETATION

From literatures, field study, and geoelectric method the following summary and conclusion was assumed: Findings from VES revealed geoelectric layers range from three to six layers with different intra-facies and inter-facies changes as shown in Table 1.The following curve types were deduced from modeling of VES data obtained from the field curve (Fig 3)

Table 1: Summary of the Aquifer formation of layer parameters

VES NO.	Layer No.	Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Curve Type	RMS % ERROR
1	1	181.3	1.3	1.3	$\rho_1 > \rho_2$	2.5
	2	17.6	2.5	3.8	$> \rho_3 < \rho_4$	
	3	7.8	5.9	9.6	QH	
	4	235.1	-	-		
2	1	75.7	0.9	0.9	$\rho_1 > \rho_2$	3.5
	2	12.8	11	11.9	$< \rho_3$	
	3	312.9	-	-	H	
3	1	48.5	1	1	$\rho_1 > \rho_2$	4.1
	2	22.7	13	14	$< \rho_3$	
	3	1368.8	-	-	H	
4	1	29.3	1.2	1.2	$\rho_1 > \rho_2$	5.1
	2	7.4	3.2	4.4	$< \rho_3$	
	3	2168.8	-	-	H	
5	1	73.4	1.2	1.2	$\rho_1 > \rho_2$	7.9
	2	14.2	3.2	4.4	$> \rho_3 < \rho_4$	
	3	10.8	2.7	7.2	QH	
	4	2101.8	-	-		
6	1	150.6	0.8	0.8	$\rho_1 > \rho_2$	6.4
	2	19.7	2.8	3.6	$> \rho_3 < \rho_4$	
	3	9.4	4.5	8	QH	
	4	3148.6	-	-		
7	1	15.2	1.6	1.6	$\rho_1 < \rho_2$	13.4

	2	35.4	1.2	2.9	$< \rho_3 < \rho_4$	
	3	241.8	2.4	5.3	$< \rho_5$ AAA	
	4	370.7	2.4	7.7		
	5	7072.7	-	-		
8	1	115.6	0.8	0.8	$\rho_1 > \rho_2$	9.5
	2	11.4	1.4	2.2	$< \rho_3 > \rho_4$	
	3	54.4	6.1	8.3	$< \rho_5$ HKH	
	4	22.2	4.2	12.6		
	5	481.5	-	-		
9	1	211.4	0.9	0.9	$\rho_1 > \rho_2$	11.7
	2	20.4	3.1	4.0	$< \rho_3 < \rho_4$ HA	
	3	46.2	16.8	20.9		
	4	289.3	-	-		
10	1	57.7	1.3	1.3	$\rho_1 > \rho_2$	9.0
	2	16.7	5.0	6.3	$< \rho_3 < \rho_4$ HA	
	3	54.7	4.8	11.1		
	4	2327.2	-	-		

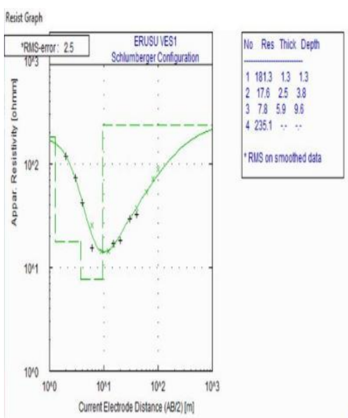

Fig. 3 Graph of VES 1

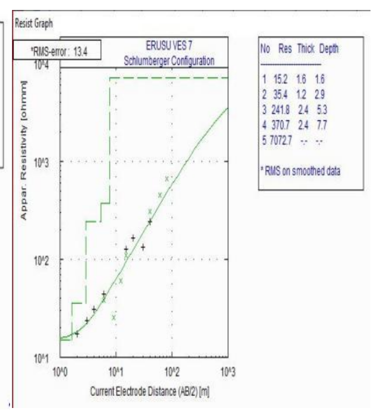

Fig. 4. Graph of VES 7

Ten (10) vertical electrical soundings was used to evaluate the subsurface hydrogeological condition at electrode spacing of AB/2 = 150 m. The sounding curves were classified according to resistivity contrasts between layers as multiples of QH, HA, H, AAA, HKH, and four major types, (types 1- IV) representing major lithostratigraphic units have been inferred from the analysis of the sounding curves. It was observed that curve HK was the dominant curve type that cut across study area.Deductions from Fig.5, revealed that VES 2, and 3 has a total of three layer, with the first layer having resistivity value of 29.3 Ωm to 48.5 Ωm, with depth range of 1.0 m to 1.2m, while the second layer has 7.4 Ωm to 22.7 Ωm, with depth range of 4.4 m to 14.0 m as shown in Fig. 5. The third layer has resistivity value of 1368.8 Ωm to 2168.8 Ωm, with depth considered to infinity see Fig. 5.

From Fig. 6, it was observed that VES 1, 2, 3, 4, 5, 6, 9, and10 has a total of four layers, the first layer was interpreted as topsoil, with depth ranging from 0.8 to 1.3m depth. With resistivity value ranging from 12.8 Ωm to 20.4 Ωm for second layer with depth range of 3.6 m to 11.9 m as shown in Fig. 6. As for the third layer the resistivity value ranges from 7.8 Ωm to 54.7 Ωm, with depth range of 7.2 m to 11 m. The fourth layer has resistivity value range of 235.1 Ωm at VES 1 to 2327.2 Ωm at VES 10, with depth considered to be infinity see Fig. 6.Observation from Fig. 7, showed that VES 7, and 8 has a total of five layers, with the first layer having depth range of 0.8 m to 1.6m, and resistivity value of 15.2 Ωm at VES 7to 115.6 Ωm see Fig. 7. The second layer has resistivity value of 11.4 Ωm to 35.4 Ωm, with depth range of 2.2 m to 2.9 m, the third layer has depth range of 5.3 m to 8.3 m, with resistivity value of 54.4 Ωm to 241.8 Ωm as shown in Fig.7. The fourth layer has resistivity value of 22.2 Ωm to 370.7 Ωm, with depth range of 7.7 m to 12.6 m, the fifth layer has resistivity value of 481.5 Ωm to 7072. 7 Ωm see Fig.7.

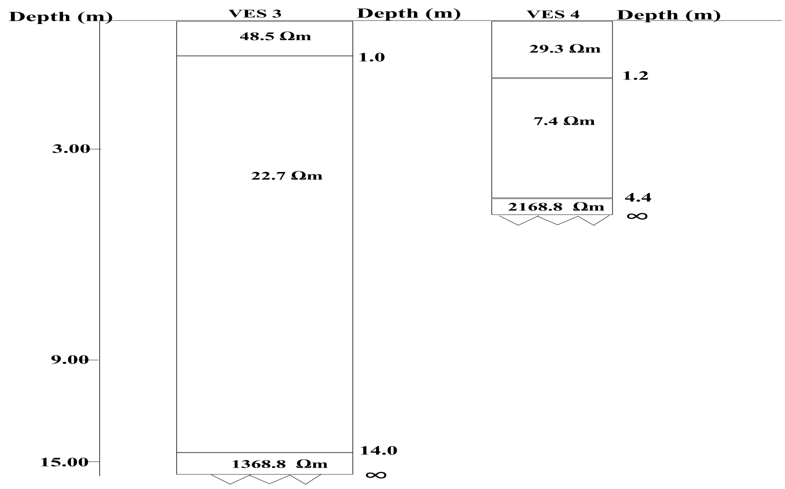

Figure 5: showing Vertical Electrical Sounding from VES 3 and 4

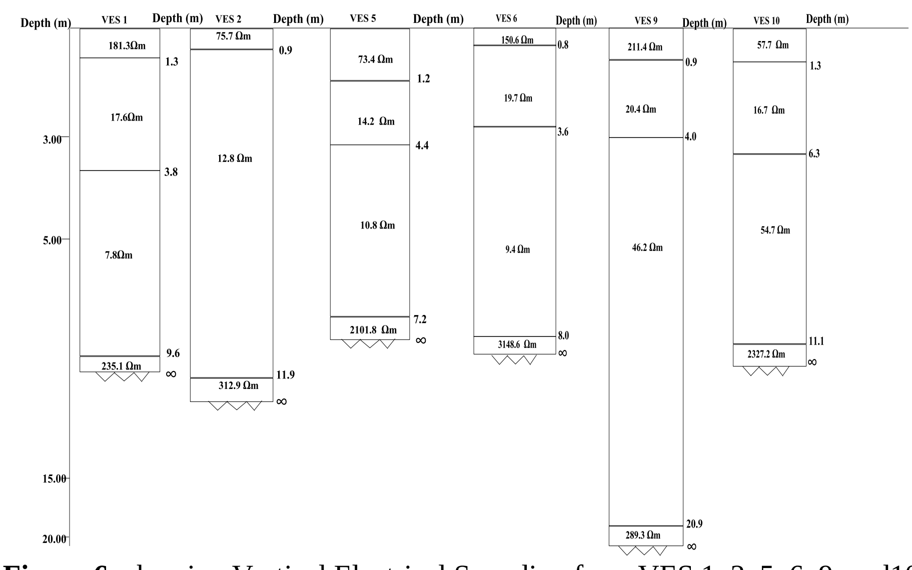

Figure 6: showing Vertical Electrical Sounding from VES 1, 2, 5, 6, 9, and10.

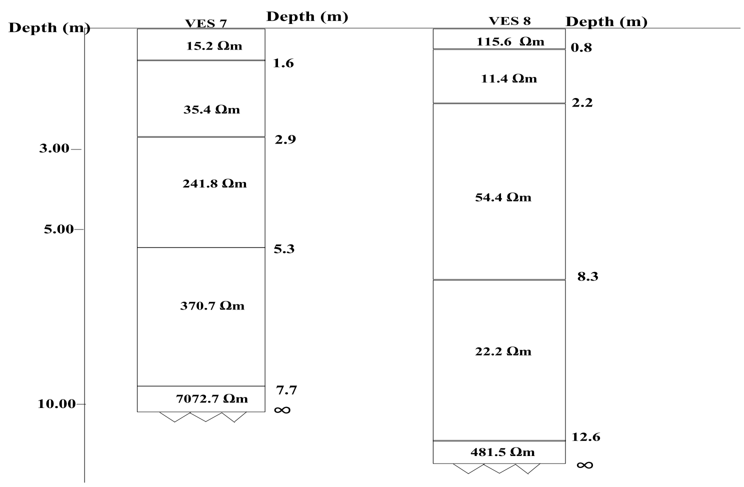

Figure 7: showing Vertical Electrical Sounding from VES 7 and 8 respectively

The aquifer protective capacity for the study area was computed as shown in equations 2 to 7 and results of the estimated were presented in Table 1. Table 2 showed aquifer protective capacity rating. The longitudinal conductance (S) is one of the geoelectrical parameters used to determine target areas of the protective capacity of aquifer of the study area.

Table 2: Results of Dar-Zarrouks parameters

VES Points	Longitudinal Unit Conductance (S)	Transverse Unit Resistance (Tr)	Average longitudinal resistance (ρ_L)	Transverse Resistivity (ρ_t)	Coefficient of anisotropy (λ)	Reflection coefficient	Hydraulic Conductivity (m/day)	Transmissivity (m^2/day)	Aquifer Conductivity
VES/1	1.453849	377.45	10.11109	25.67687	1.593573	0.935776	0.050862	11.95762	0.008234
VES/2	0.941577	220.45	13.59422	17.22266	1.125571	0.9214	0.049063	15.35194	0.006141
VES/3	0.637359	366.3	23.53463	24.42	1.018636	0.967373	0.045688	62.5376	0.001437
VES/4	0.63555	67.72	8.811263	12.09286	1.171508	0.993199	0.051009	110.6274	0.000919
VES/5	0.992875	228.32	12.89186	17.8375	1.176276	0.989776	0.049775	104.6172	0.000947
VES/6	1.039117	266.6	11.93321	21.5	1.342272	0.994047	0.050279	158.3094	0.000633
VES/7	0.229875	4262.91	76.12849	243.5949	1.788794	0.900395	0.003729	26.37656	0.003265
VES/8	0.920044	848.8	25.97702	35.51464	1.169255	0.911852	0.045853	22.07806	0.02611
VES/9	0.652717	1237.44	39.5271	47.96279	1.101551	0.72459	0.038576	11.16007	0.005961
VES/10	0.602701	787.39	31.027	42.10642	1.164942	0.95407	0.036286	84.4449	0.00084
Min	0.229875	67.72	8.811263	12.09286	1.018636	0.72459	0.003729	11.16007	0.000633

Max	1.453849	4262.91	76.12849	243.5949	1.788794	0.994047	0.051009	158.3094	0.02611
Aver.	0.815782	1082.834	28.2063	61.96803	1.288317	0.917593	0.039655	64.74419	0.006769

From Fig. 8, it was observed that area around Akoko North West (VES/01, 02, 04, 05, and VES 06) has high *S*, while areas around VES/03, 07, 09, and 10 fell within low *S* value. Eyankware et al., (2020b) further stated that area with low *S* values signify poor and weak aquifer protective zone and considered to be susceptible to contamination, while the area with high S value signify high protective zone. High Tr values correspond to high transmissivity values and vice versa (Henriet 1976; Ward 1990; Harb et al, 2010). Fig. 9 revealed that southwest part of the study area has high *Tr* value, this implies Arigidi, and Ikare Akoko is considered to be more aquiferous when compared to other parts of the research area. Fig.10 showed that the spatial variation of longitudinal resistance with contour interval demarcates the saline, brackish, and freshwater aquifers into three different regions based on their varying resistivity regimes (Gupta et al, 2015). Fig.10, showed that high value ρL was noticeable around VES/08, and 09 with red, green, and yellow colour. While VES/01, 02, 03, 04, 05, 06,and 09 fell within area with low ρL value. High ρt was observed around the southwest axis of the study area in blue, and yellow color as shown in Fig. 11. The high value of ρt was observed around Ikare Akoko, Arigidi axis of the study area. Further observation from Fig. 11, revealed that areas around VES/01, 02, 03, 04, 05, 06, 09, and selected parts of VES/10. Deduction from Fig.12, revealed that southwest, and northwest part of the study area with lemon, and yellow colour tends to be more fracture and believed to show more tendency of having groundwater potential when compared to other parts of the study area. Around around VES/08, 07, and slightly parts of VES 06, tends to be more aquiferous, while areas around VES/02, 03, 04, 05, 09, and 10 tends to less fracture. Hence considered to be low in terms of groundwater potential. From Fig. 13, it was noticed that southwest, and northeast part of the study area tends to be high in terms of fracture. Although results obtained from Rc contradict results obtained from λ in Fig.12. Obiora, et al. (2015) were of the believe that K controls the behaviour of groundwater flow within an aquifer. From Fig. 14, it was observed that high K was observed around northwest, and northeast parts of the study area around VES/01, 02, 04, 05. Hence, the aforementioned areas can be said to have high porosity. Fig. 15 revealed that northwest, and northwest parts of the study area tend to be aquiferous. Findings obtained from T is slightly similar to that obtained from K in Fig.14.

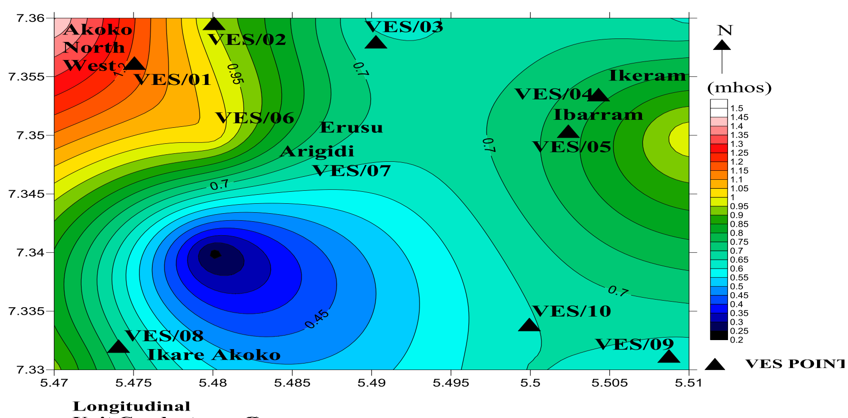

Fig. 8. Spatial Variation of longitudinal resistance

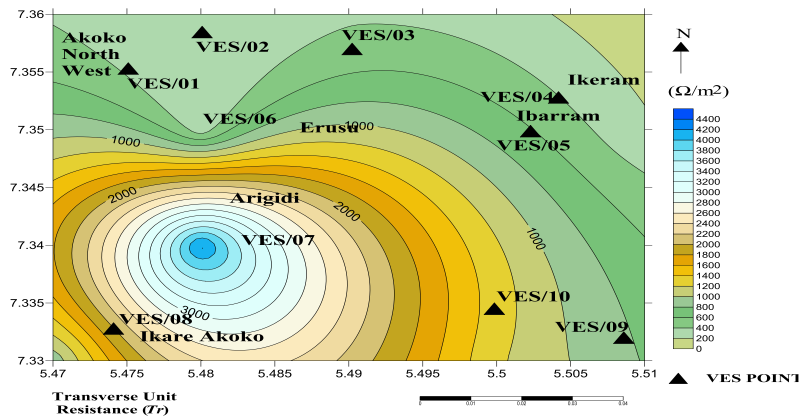

Figure 9: Spatial variation of transverse unit resistance

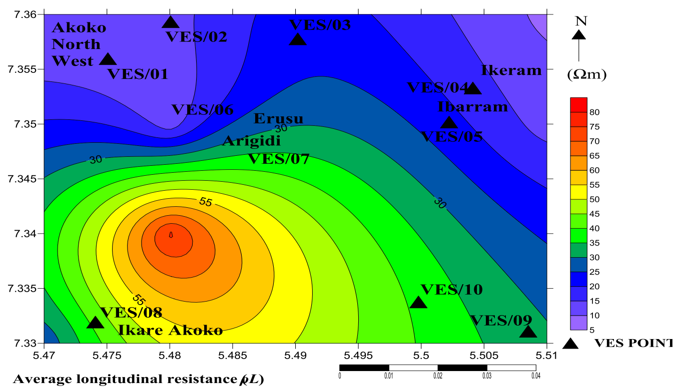

Figure 10: Spatial variation of average longitudinal resistance

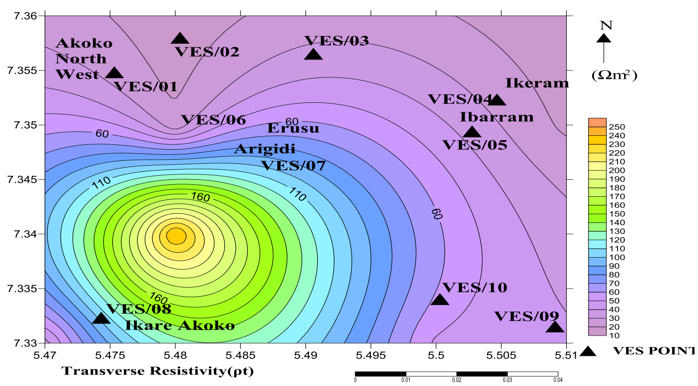

Figure 11: Spatial variation of transverse resistivity

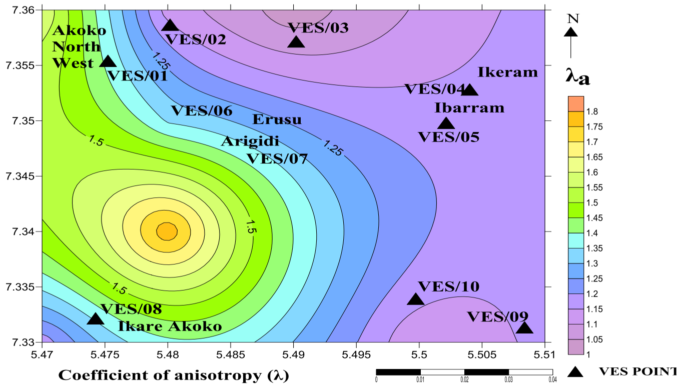

Figure 12: Spatial variation of anisotropy

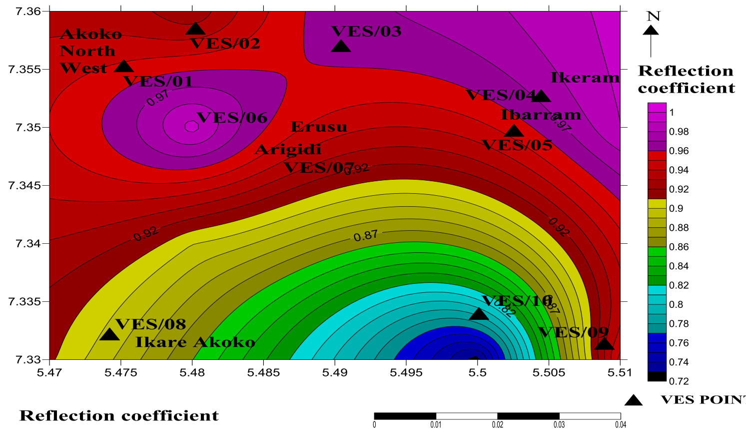

Figure 13: Spatial distribution of Reflection Coefficient within the study area.

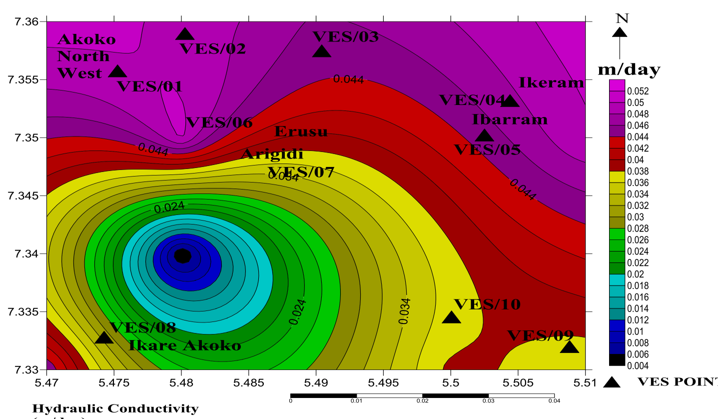

Figure 14: Spatial distribution of Hydraulic conductivity of the study area.

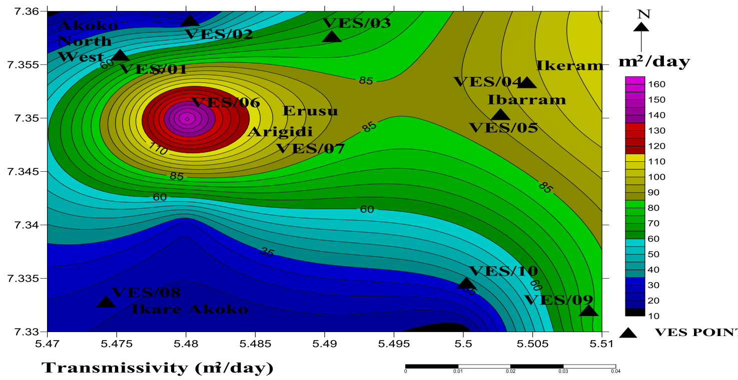

Figure 15: Spatial distribution of transmissivity within the study area.

CONCLUSION

The results from this research have contributed greatly in an improvising the existing knowledge on resistivity survey for groundwater not only that hydrogeologists could locate definite sites for drilling boreholes, but also data cheap or reduced cost. In addition, groundwater development at the proposed locations will help reduce the existing seasonal water scarcity, long distance trekking in search of water and overcrowding of few streams, rivers and ponds (which are prone to contaminations). The major reason for failed borehole is that the fracture rock exists at a shallow depth that cannot sustain groundwater exploration over a long period of time

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