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Full Length Research Article

EVALUATION OF GROUNDWATER RESOURCES AND GEOELECTRIC PROPERTIES USING ELECTRICAL RESISTIVITY METHOD AT BARAKIN RAFIN GORA AREA, JOS-PLATEAU, NORTHCENTRAL NIGERIA

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ABSTRACT

The evaluation of groundwater resources and geoelectric properties at Barakin Rafin Gora area, Jos-Plateau was carried out using electrical resistivity method. Forty (40) Vertical Electrical Soundings (VES) were carried out using the Schlumberger electrode array configuration, with half-current electrode separation (AB/2) varying from 1 to 125 m using Allied Ohmega terrameter and its accessories. The resistivity sounding curves obtained from the study area varied from the 3-layer (A and H types) to 4-layer (AK, KH, HK, QH, HA, AA and QK) and 5-layer (HKH and KHK) with the H type being the predominant. The geoelectric sections indicate that the subsurface is characterized into five (5) geologic layers namely: topsoil, weathered layer (laterite, clayey), fractured basement and fresh basement. The thickness of overburden ranges from 0 to 40m and is classified into three zones rating basically as low aquifer potential (0-5m), intermediate aquifer potential (20-30m) and higher aquifer potential (30-40m). The groundwater prospects of the study area are zoned into high (red colour), medium (pink colour) and low potentials (yellow colour). The zones where thickness of the aquifer is greater than 25m are considered zones of high groundwater potentials at VES points, 3, 9, 15, 25, 28 and 38 while the low groundwater potential rating occurs where the aquifer thickness is below 20m at VES points 13, 19, 20, 24, 28, 31, 33 and 34.

Keywords: *Aquifer, Groundwater, Geoelectric, Basement and Depth*

INTRODUCTION

The geophysical method of groundwater exploration is inexpensive and had been used for so many years in solving numerous problems of groundwater search. This method is used to determine depth, thickness and boundary of an aquifer (Adeniji et al., 2014). An aquifer is an underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials. Groundwater can be extracted using water well or borehole. Aquifers are sometimes categorized according to the types of rock or sediments of which they are composed (Miller, 2006).

Geoelectric method is used for both groundwater resource investigation and water quality evaluations and has increased intensely over the years due to the rapid advances in microprocessors and associated numerical modeling solutions (Baeckmann and Schwenk, 1975). Geoelectric method is also suitable for mapping the thickness and delineating the extent of aquiferous overburden and in the resolve and mapping of groundwater quality (Ajibade and Ogungbesan, 2013).

Searching for viable aquifers has over the years been carried out through numerous means ranging from physical observations to surface and subsurface geophysical procedures (Todd and Mays, 2005). An aquifer is an underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials while groundwater is one of the most precious freely given natural resources and is referred to as the waters found in the subsurface (Bear and Verruijt, 1987). Groundwater is being refilled by rain that infiltrated the soil naturally or through secondary pores of the subsurface rocks (Jaturon *et al*., 2014; Kumar *et al*., 2007). Groundwater resources contribute to meet the water needs for most domestic, municipal and industrial purposes (Nampak *et al*., 2014).

The Barakin Rafi Gora village is located in Jos on latitudes 9⁰ 56ˡ 00ˡˡ to 9⁰ 57ˡ 00ˡˡ N and longitudes 8⁰ 50ˡ 30ˡˡ to 8⁰ 51ˡ 00ˡˡ E (Figure 1). As a result of increasing population along Zaria Road in Jos, more domestic and industrial wastes were being produced, which are possible groundwater contaminants. The study area is underlain by aplo-pegmatitic granite gneiss (figure 2). The present study focuses on the evaluation of ground water resources of Barakin Rafi Gora area using electrical resistivity method

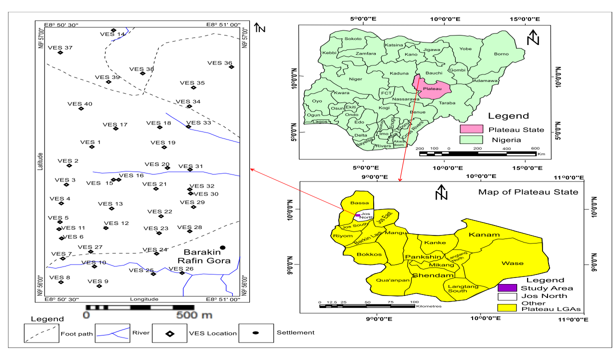

Figure 1: Location map of Barakin Rafin Gora area showing VES points

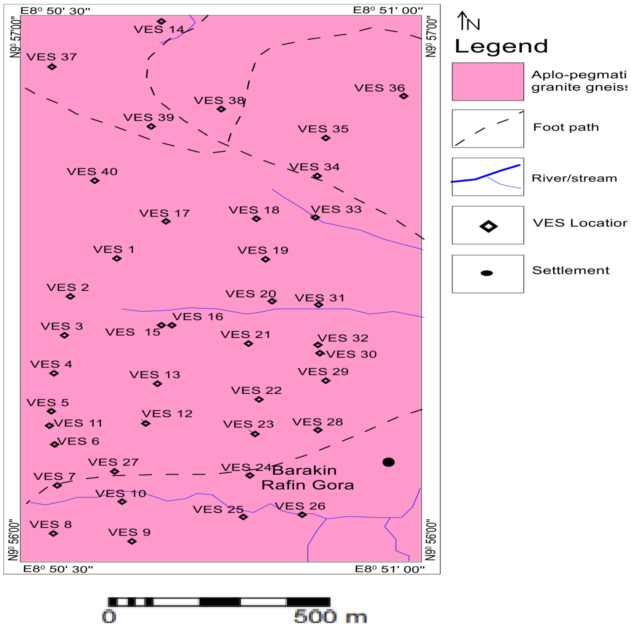

Figure 2: Geological map of study area (NGSA, 2009)

MATERIALS AND METHODS

The geophysical data were acquired with a D.C SAS 2000 Terrameter that contains a transmitter unit, through which current enters the ground and the receiver unit through which the resultant potential difference was recorded. Other materials used for the geophysical survey include two metallic current electrodes and two potential electrodes .Two reels of calibrated rope, hammer for driving the electrodes into the ground, compass for finding the orientation of the transverse , cutlass for cutting transverses and data sheet for recording the field data, Schlumberger configuration was employed in the data acquisition known as vertical Electrical soundings (VES) as described by Ariyo and Adeyemi (2009).

This present study adopted the use of an electrical resistivity survey method where forty (40) Vertical Electrical Soundings (VES) stations were occupied and VES readings were carried out with the used of SAS 2000 Terrameter and its accessories. The conventional Schlumberger array pattern (Figure 3), with half electrode spacing (AB/2) varying from 1 m to a maximum of 125 m was adopted. The apparent resistivity was computed using the equation:

$$\rho a = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right)\frac{\Delta V}{I}, \quad (1)$$

Where ρa is apparent resistivity

π is $\frac{22}{7}$,

G = $\pi\left(\frac{a^2}{b} - \frac{b}{4}\right)$ is geometrical factor, and $\frac{\Delta V}{I}$ = R is the resistance

The apparent resistivity values gotten from equation (1) were plotted on log-log graph against the half current electrode separation spacing (AB/2). From these plots, qualitative deductions, such as the resistivity, thickness and depth of each layer were made with the curve types gotten from the primary electrical parameters. The resistivities and thicknesses of the various layers were enhanced by employing an automatic iterative computer program following the main concepts of Zohdy and Martin (1993). The WINRESIST computer software was employed for carrying out the iteration and inversion processes. The root mean square (RMS) error of lower than 5% was obtained through the iteration process conducted for each sounding station in order to get a goodness of fit for the Computer-generated curves with the corresponding field curves data.

The Dar-Zarrouk parameters were obtained from the first order geoelectric parameters (layer resistivities and thicknesses) and these include the Total longitudinal unit conductance (**S**), Total transverse unit resistance (**T**) and coefficient of anisotropy (**λ**). These secondary geoelectric parameters are mainly significant when they are used to define a geoelectric section comprising of numerous layers (Zhody *et al.,* 1974). For n layers, the total longitudinal unit conductance is:

$$\mathbf{S} = \sum_{i=1}^{n}\left(\frac{hi}{\rho i}\right) \quad (2)$$

$$\mathbf{T} = \sum_{i=1}^{n} \rho i h i \quad (3)$$

$$\boldsymbol{\lambda} = \left(\frac{\rho T}{\rho L}\right)^{\frac{1}{2}} \quad (4)$$

where ***hi*** is the layer thickness, ***Pi*** is layer resistivity while the number of layers from the surface to the top of aquifer, (*i*) varies from 1 to n. Electrical anisotropy is a measure of the degree of inhomogeneity in a basement terrain; which increases the near surface effects, variable degree of weathering and structural features such as faults, fractures, joints, foliations and beddings (Billings, 1972; Maliek *et al.,* 1973). These in turn are responsible for producing secondary porosity (Φs) and hence effective porosity (Φe).

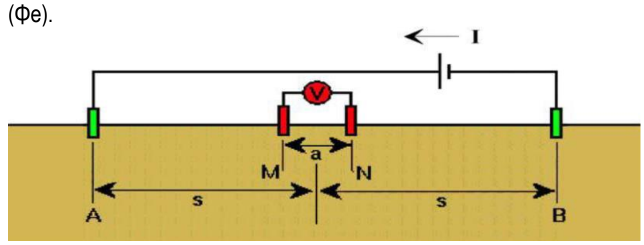

Figure 3: Schematic diagram of Schlumberger array

The total longitudinal unit conductance (s) is particularly important which is used to describe a Geoelectric section consisting of several layers. The total longitudinal conductance (s) of the overburden unit at every vertical sounding location was obtained from the mathematical equation according to Zhody et al. (1974) in equation 4.

RESULTS

The result of resistivity values, thickness of each of the layers, depths of each of the layers and curve types from the forty (40) VES points is presented in Table 1. The resistivity value ranges from 12.86 to 6498.4 ohm-m, thickness of the layer ranges from 0.2 to 31.1 m while the depth varies from 0.2 to 40 m and the curve types include: A, H, KH, AK, HK QH, HA, AA, KQ, HKH and KHK. The p1 (layer resistivity) ranges from 12.86 to 6498.4 ohm-m. The resistivity sounding curves obtained from the study area varied from the 3-layer (A and H types) to 4-layer (AK, KH, HK, QH, HA, AA and QK) and 5-layer (HKH and KHK) with the H type being the predominant.

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Table 1: The results of resistivity values, thickness of the layers, depths of the aquifer and curve types from the forty (40) VES points

	RESISTIVITY (Ohm-m)					THICKNESS (m)				DEPTH (m)				Curve Type
VES	P1	P2	P3	P4	P5	H1	H2	H3	H4	D1	D2	D3	D4	
1	346.33	167.18	645.17			1.1	15.8			1.1	16.9			H
2	288.52	220.44	469.53			0.6	28.6			0.6	29.2			H
3	649.46	259.21	568.74			5.2	29.6			5.2	34.8			H
4	178.57	903.62	104.65	342.25		2.8	2.6	11.2		2.8	5.5	16.7		KH
5	449.68	1247.2	77.61	796.92		0.6	3.4	17.7		0.6	4	21.7		KH
6	260.29	87.91	1143.2			2.7	18.1			2.7	20.8			H
7	243.31	121.26	255.54			1.1	11.1			1.1	12.2			H
8	214.09	109.85	511.63			0.6	29.9			0.6	30.5			H
9	1453.4	394.47	7115.3	922.44		1.5	12.5	17.8		1.5	14	31.8		HK
10	873.80	111.98	780.90	246.96		0.8	0.9	11.2		0.8	1.7	12.9		HK
11	339.43	126.66	745.49	173.78		1.9	4.6	3.4		1.9	6.5	9.9		HK
12	22.46	86.07	775.70	232.71		0.3	6.6	8.6		0.3	6.9	15.5		AK
13	108.77	788.94	152.65	407.53		2.1	0.8	2.5		2.1	2.9	5.5		KH
14	74.13	134.66	20.53	7164.3	139.27	1.3	2.1	3.8	15.8	1.3	3.4	7.2	22.9	KHK
15	325.99	222.98	4610.8	424.49		1.2	15	23.8		1.2	16.3	40		HK
16	214.73	53.24	1674.80	83.64	2393	1.5	4.8	6.4	21.4	1.5	6.3	12.7	34	HKH
17	512.56	204.37	52.24	66790		0.8	7.5	6.1		0.8	8.3	14.4		QH
18	269.12	127.45	51.13	241.10		1.4	6.9	6		1.4	8.2	14.3		QH
19	354.21	84.75	3943	1342.60		2.6	1.7	2.4		2.6	4.2	6.6		HK
20	443.35	55.08	768.76	315.71		2.8	3.8	0.6		2.8	6.6	7.2		HK
21	670.31	135.43	19352	129.65		2	9.4	7.6		2	11.4	20		HK
22	1006.7	476.88	551.31	1275.30		1.9	2	22.6		1.9	3.9	26.5		HA
23	395.80	60.50	15056	104.30		2.5	3.8	10.3		2.5	6.3	16.6		HK
24	396.54	262.98	43.52	504.23		0.6	6.1	3.2		0.6	6.7	9.9		QH
25	61.74	161.49	215.53	13964		0.4	2.8	30.6		0.4	3.1	33.7		AA
26	205.72	207.55	15064			1.2	31.3			1.2	32.4			A
27	78.68	150.86	23922			5.9	22.2			5.9	28.2			A
28	539.30	94.13	4672.2	20.81		1.8	13.1	9		1.8	13.1	9.1		HK
29	711.65	111.47	51823			7.5	11.2			7.5	18.7			H
30	458.38	206.52	283.12	432.87		1.1	0.6	8.5		1.1	1.7	10.2		HA
31	100.79	556.49	136.79	246.44		0.8	0.8	8.1		0.8	1.6	9.7		KH
32	283.02	119.78	315.90			2.5	11.8			2.5	14.3			H
33	1031.1	338.83	736.66			0.9	4.1			0.9	5			H
34	383.82	31403	595.01	581.49		1.7	0.1	5.9		1.7	1.8	7.7		KQ
35	41.91	19952	88.47	1979.60	12.86	0.2	0.2	5.6	12.4	0.2	0.4	5.9	18.3	KHK
36	457.07	185.66	502.33	129.99		1.2	2.7	23.2		1.2	3.9	27.2		HK
37	186.64	518.39	59.38	486.46		2.7	5.1	7		2.7	7.8	14.8		KH
38	335.78	125.21	1588.9	159.15		1.3	18.2	21.5		1.3	19.5	41		HK
39	367.57	26.10	8038.8	43.66	6498.4	1.6	1.2	5.7	7.4	1.6	2.9	8.5	15.9	HKH
40	916.75	140.55	1465.3	347.86		1.2	1.3	18		1.2	2.5	20.5		HK

DISCUSSION

Overburden thickness

The nature of the materials that overlain the mapped aquifers were evaluated using primary electrical parameters such as layer resistivities and thickness. The longitudinal unit conductance (s) used to determine the capacity to prevent infiltration of unwanted fluids into the aquifers was derived from Dar-Zarrouk equation. The p1 (layer resistivity) ranges from 12.86 to 6498.4 ohm-m.

The thickness of overburden is shown in Figure 4 and ranges from 0 to 40m. According to the classification of Henriet (1976) and Oladapo et al. (2004), the study area is classified into three zones of aquifers rating basically as low aquifer potential (0-5m), intermediate aquifer potential (20-30m) and higher aquifer potential (30-40m) in ground water potential (figure 4).

Furthermore, result based on the research indicates zones that are overburden in other words overburden materials in the area around zones rating are classified distinctively and characterised into colours to show zones that are low, weak, intermediate and higher protective capacity (figure 4). The zones of overburden thickness are rated as yellow (low) with overburden thickness of 0.5 to 12 m; pink (weak) with overburden thickness of 12 to 20 m; Blue (intermediate) with overburden thickness of 20 to 30 m; and red (higher) with overburden thickness of 30 to 40m (figure 4).

The areas covered by poor and weak aquifer protective capacity

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are regions that are vulnerable to be affected by surface contamination sources such as the infiltration of leachates, from the decomposition of open refuse dumps, leakages from underground petroleum storage tanks and diffuse pollutions from agricultural activities. The Red higher aquifer potential and intermediate aquifer potential (pink) are zones having aquifer protective properties and capabilities that prevent the contamination.

Of fluids infiltration into aquifer, so that in the face of scenarios of contamination such zones are extremely safe. Naturally seen and observed based on research scientifically the earth materials act as natural filters to infiltrate liquid therefore it serves functions to preclude and filter percolating ground surface polluting fluids these serves as protective capacity (Adeniji et al., 2014; Olorunfemi et al., 1999). Normally the overlaying materials in aquifers act as protection in preventing fluids from infiltrating into it.

Geoelectric sections

Five (5) distinctive geoelectric layers were identified in A-A profile section as shown in Figure 5. The topsoil has resistivities of 186.64 to 649.46 ohm-m and thickness in values of 0.3 to 5.0m. The second layer consists of laterite with resistivities value of 903.67 to 1247.2 ohm-m and thickness of 0.3 to 0.8 m. The third layer is clay with resistivity value of 78.91 ohm-m and thickness of 0.4 to 20m. The fourth layer is fractured basement with resistivity value of 59.36 to 568.74 ohm-m and thickness of 0.5 to 40 m. The fresh basement directly underlies the top soil and fractured basement at VES 40 while at VES 5 and 6, it has an infinite thickness. This A-A' profile has very thick aquifer at VES 2, 3 and 37 (Figure 5) and is good for groundwater production

Five (5) distinctive geoelectric layers were identified in B-B profile section as shown in Figure 6. The topsoil has resistivities of 22.64 to 1453.4 ohm-m and thickness in values of 0.2 to 0.5m. The second layer consists of laterite with resistivity value of 788.94 ohm-m and thickness of 0.3 to 0.6m. The third layer is clay with resistivity value of 86.07 ohm-m and thickness of 0.2 to 0.7m. The fourth layer is fractured basement with resistivity value of 43.66 to 780.90 ohm-m and thickness of 0.3 to 43m. The fresh basement directly underlies the top soil and lateritic layer at VES 39 and 12 while at VES 9, 17 and 27, it has an infinite thickness. This B-B' profile has very thick aquifer at VES 1 and 13 (Figure 6) and is good for groundwater production with exception of VES 39, 17, 15, 27 and 9 because according to Bala and Ike, (2001) an area with basement topographic ridges corresponds with thin overburden and high basement resistivity and is said to have poor groundwater prospect.

Four (4) distinctive geoelectric layers were identified in C-C profile section as shown in Figure 7. The topsoil has resistivities of 61.74 to 1006.7 ohm-m and thickness in values of 0.1 to 0.4m. The second layer consists of clay with resistivities value of 55.08 to 84.75 ohm-m and thickness of 0.3 to 0.8m. The third layer is fractured basement with resistivity value of 20.53 to 551.31 ohm-m and thickness of 0.2 to 43m. The fresh basement directly underlies the top soil and clay layer at VES 19, 20 and 23 while at VES 19 and 22, it has an infinite thickness. This C-C' profile has very thick aquifer at VES 18 and 24 (Figure 7) and is good for groundwater production with exception of VES 14, 19, and 38 because according to Bala and Ike, (2001) an area with basement topographic ridges corresponds with thin overburden and high basement resistivity and is said to have poor groundwater prospect

Five (5) distinctive geoelectric layers were identified in D-D profile section as shown in Figure 8. The topsoil has resistivities of 41.91 to 539.30 ohm-m and thickness in values of 0.1 to 0.8m. The second layer consists of laterite with resistivity value of 19953 to 31403 ohm-m and thickness of 0.2 to 0.3m. The third layer is clay with resistivity value of 88.47 to 94.13 ohm-m and thickness of 0.3 to 1.7m. The fourth layer is fractured basement with resistivity value of 12.86 to 595.01 ohm-m and thickness of 0.3 to 43m. The fresh basement directly underlies the top soil and clay layer at VES 28 and 35 while at VES 29 and 26, it has an infinite thickness. This B-B' profile has very thick aquifer at VES 30, 31, 32, 33, 34 and 36 (Figure 8) and is good for groundwater production with exception of VES 29 because according to Bala and Ike, (2001) an area with basement topographic ridges corresponds with thin overburden and high basement resistivity and is said to have poor groundwater prospect.

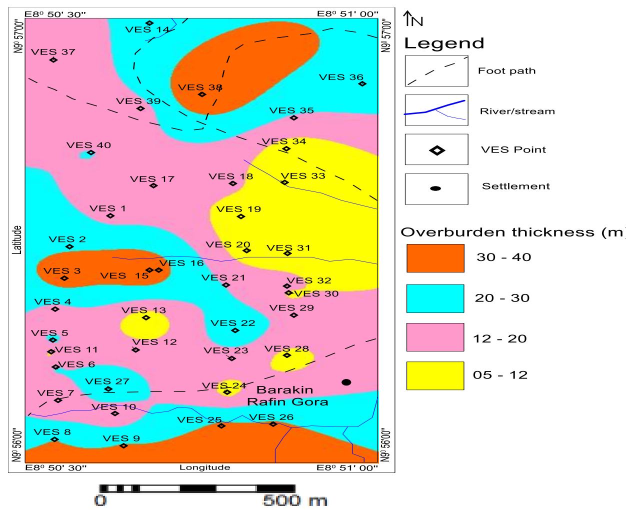

Figure 4: showing overburden thickness

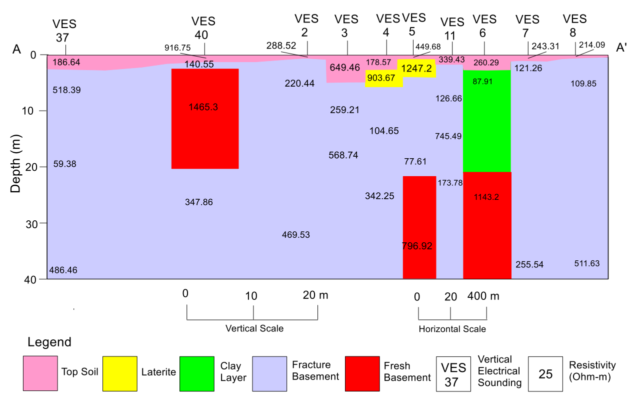

Figure 5: Geoelectric section of profile A-A

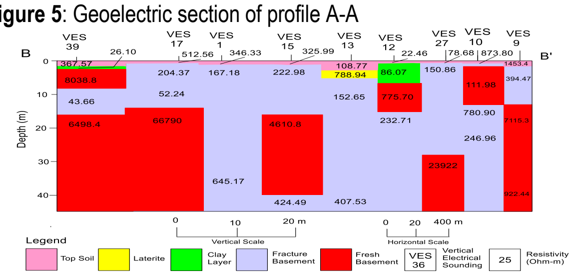

Figure 6: Geoelectric section of profile B-B

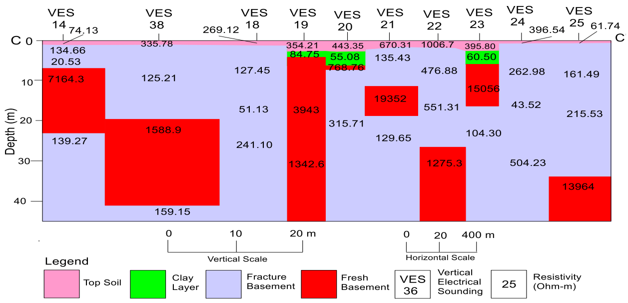

Figure 7: Geoelectric section of profile C-C

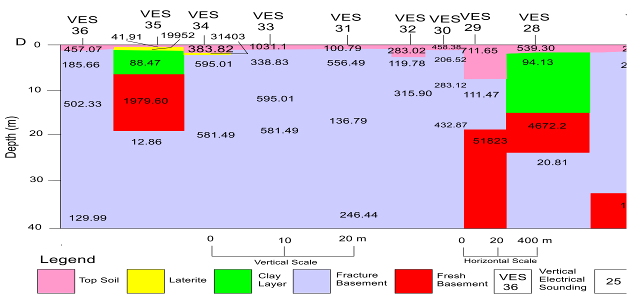

Figure 8: Geoelectric section of profile D-D

The Depth to basement

The depth to basement map of the study area (Figure 9) shows the bedrock elevation morphology at each VES point which helps to predict the area suspected to have good groundwater prospect. The importance of basement topography for hydrogeological studies have been identified by Dan-Hassan and Olorunfemi (1999); Bala and Ike (2001). The best zones of groundwater prospect can be projected from the basement relief map, this is possible because area with basement topographic depression (basement trough) corresponds with thick overburden and low basement resistivity can be observed to have good groundwater prospect likewise, area with basement topographic ridges corresponds with thin overburden and high basement resistivity and is said to have poor groundwater prospect. The basement relief map is shown in figure 9. The basement ridge ranges from 20 to 40 m and basement depression ranges from 5 to 20m

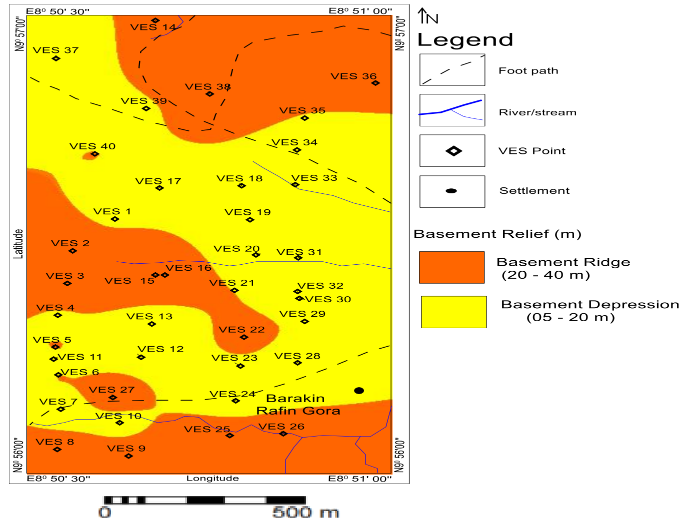

Figure 9: Basement relief

Groundwater Flow Direction

The groundwater flow direction of the area as shown in Figure 10 was produced using elevation height of each VES location and subtracting it from the overburden thickness in meters (i.e., is VES elevation – overburden thickness = Hydraulic head). These hydraulic head values are used on a topographic map, relating the hydraulic value to be borehole's location. Piezometric lines are drawn at right angles to indicate the groundwater flow direction of the area as observed in Figure 10. The flow directions are located at the points where the arrows are pointing away from each other. The yellow and pink colour areas represent basement depression and serve as water collection regions while the red and ash colour areas represent water revitalize regions (Figure 10). As a rule of thumb, groundwater flow from regions of higher to lower elevation.

Groundwater Potential Evaluation

The groundwater potential map of the study area as shown in Figure 11 was obtained by combination of the results of overburden thickness, depth to basement, longitudinal conductance and groundwater flow direction maps. The groundwater potential map (Figure 11) was produced from the integration of geo-electric and Dar-Zarrouk parameters and was used to assess the groundwater potential of the study area. The groundwater potential zones of the study area are classified into low, intermediate and high groundwater potential zones (Figure 11). The high groundwater potential zone must have overburden greater than 10 m; the basement must show an indication of fracture from the basement resistivity value which should be less or equal to 800 Ωm and the aquifer unit (weathered basement) resistivity should be between 50 to 300 Ωm (Olayinka *et al*., 2004; and Barker *et al*. 1992).

The groundwater prospects of the study area are zoned into high (red colour), medium (pink colour) and low potentials (yellow colour) as shown in Figure 11. In this study, zones where thickness of the aquifer is greater than 25m are considered zones of high groundwater potentials. The red colour part of the study area falls within the high potential zones. The medium groundwater potential zones are located at the pink colour region of the study area. The low groundwater potential rating where the thickness of overburden is below 20m are located at VES 13, 19, 20, 24, 28, 31, 33 and 34. These portions constitute a diminutive segment of the study area.

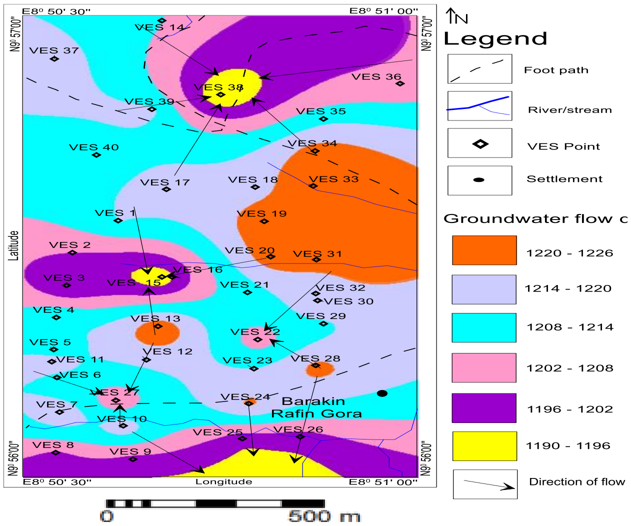

Figure 10: Groundwater flow direction

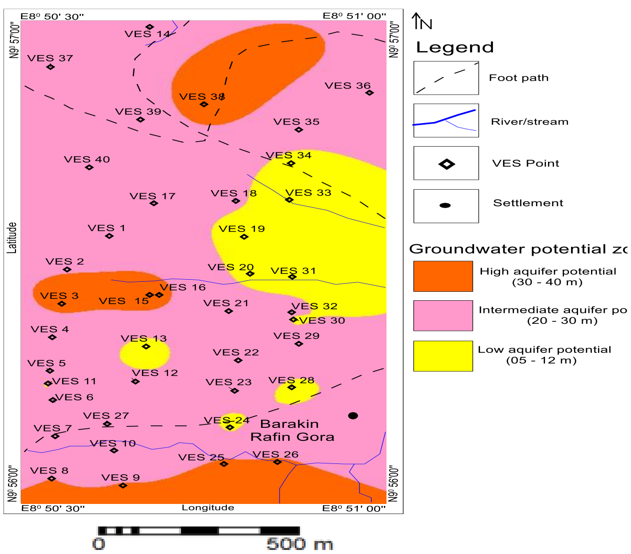

Figure 11: showing groundwater potential zones

CONCLUSION

The resistivity sounding curves obtained from the study area varied from the 3-layer (A and H types) to 4-layer (AK, KH, HK, QH, HA, AA and QK) and 5-layer (HKH and KHK) with the H type being the predominant. The geoelectric sections indicate that the subsurface is characterized into five (5) geoelectric layers namely: topsoil, laterite, clayey layer, fractured basement and fresh basement.
The thickness of overburden ranges from 0 to 40m and was classified into three zones rating basically as low aquifer potential (0-5m), intermediate aquifer potential (20-30m) and higher aquifer potential (30-40m) in ground water potential.

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