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GROUNDWATER POTENTIAL AND OVERBURDEN PROTECTIVE CAPACITY IN MAGAMA GUMAU, TORO NORTHEASTERN NIGERIA

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ABSTRACT

The study area is underlain by crystalline rocks of the north-eastern part of Nigerian Basement Complex. A geophysical study of electrical resistivity was carried out with the aim of assessing the groundwater potential for alternate water source due to insufficient surface water and low yield boreholes in the area. Thirty-two (32) Vertical Electrical Soundings (VES) were obtained from Magama Gumau and its environs using Schlumberger electrode configuration with current electrode separation (AB) varying from 1.5 to 125 m. The acquired field data were interpreted and iterated using "IX1D" software. The total transverse resistance value (194.75 - 143014 Ωm^2) was adopted in the classification of the area into poor, weak, moderate and very good transmissivity zones. The groundwater potential of Magama Gumau is classified into low, medium and high groundwater potential zones based on the integration of geo-electric and Dar-Zarrouk parameters. The VES data indicate three (3) to four (4) geo-electric layers namely: topsoil, clayey soil, fractured basement and fresh basement. The Overburden comprises topsoil, clay/laterite, and fractured basement with thickness ranging from 1.2 to 41.6 m. The zones with overburden thickness of 20 m and above are feasible for groundwater abstraction and constitute about 34.38 % of the area. The aquifer protective capacity of the area was classified into good (> 0.7 mhos), moderate (0.2 – 0.69 mhos), weak (0.1 – 0.19 mhos), and poor (< 0.1 mhos), based on the longitudinal conductance value (0.009036 - 3.771312 mhos). Hence, the result of this work will form the tools for groundwater development, management and infrastructural/structural development planning of Magama Gumau, Toro northeastern Nigeria.

Keywords: Basement Complex, Electrical resistivity, Geoelectric sections, Groundwater potential, Magama Gumau.

INTRODUCTION

Groundwater is referred to as the waters found in the subsurface (Ariyo and Adeyemi, 2009). High proportion of water users in the world depend significantly on groundwater (Reilly et al., 2008). Groundwater is a very important natural resource for socio-economic development of a nation. Groundwater contributes substantially to meet the water needs for most domestic, municipal and industrial purposes worldwide, due to its availability in almost all parts of the world. Groundwater is being replenished by rain that infiltrated the soil naturally or through secondary pores of the subsurface rocks (Nampak *et al.* 2014). It is the only feasible safe source of water in many remote areas where development of surface water is not economically viable. Crystalline basement rocks of the Basement Complex are generally impervious and have no substantial water storage capacity, nevertheless, groundwater wells have been effectively developed in basement areas in different parts of Nigeria and the world (Foster, 1984). The accessibility of groundwater in these aforementioned rocks is mainly due to the development of secondary porosity and permeability resulting from weathering and fracturing. The occurrence and distribution of groundwater in an area can be influenced by climatic condition, geology, the structural features of the subsurface rock, geomorphological features, land use type and their interaction with the hydrological features (Edet et al., 1998, Jaturon et al., 2014, Kumar et al., 2007). The urge to sustain groundwater need by people has supported the application of appropriate geophysical and hydrogeologic search to detect areas of high and reliable groundwater prospect or characterize seasonal variations in the near surface aquifer (Lashkaripour, 2003; Batayneh, 2010; Omosuyi, 2010; Anudu *et al*., 2011; Webb *et al*., 2011).

The geoelectric sounding (VES) technique of electric resistivity method has been successfully and widely used for groundwater exploration in the basement terrains (Omosuyi, 2000), because it is capable of defining the significant contrast in the geoelectric parameters of the topsoil and in-situ weathered material, fractured zone and the fresh basement rock (Bayode *et al*, 2005). The geoelectric sounding using the Schlumberger array has proved useful especially for delineation of weathered and fractured zones which are aquifers in the basement rocks (Anudu *et al*, 2008). According to (Aina et al., 1996; Olayinka et al., 2000), the geoelectric succession in the basement terrains of Nigeria usually consists: a thin highly resistive topsoil a highly conductive weathered basement and a highly resistive crystalline basement whose resistivity surpasses 1000 ohm-m. Any basement rock resistivty above 3000 ohm-m can be thought of as representing fresh basement containing little or no water (Olayinka et al., 2000), Drilling programmes for groundwater development in areas of basement terrain are usually preceded by detailed geophysical investigation. The study area is underlain by Precambrian Basement Complex rocks. These rocks are naturally distinguished by low porosity and almost insignificant permeability. The maximum groundwater yield in basement terrains is located in areas where thick overburden overlays fractured zones. These zones are often characterized by relatively low resistivity values. (Olorunfemi and Fasuyi, 1993). The most likely use of the electrical resistivity survey is in hydrogeological investigation in relation to aquifer delineation, lithologic boundaries and geological structures to give subsurface evidence (Bose *et al*., 1973). Though, groundwater occurs either in the weathered mantle or in the joints and fractured system in the un-weathered rocks (Olorunfemi and Olorunniwo, 1985; Ako and Olorunfemi, 1989; Olayinka and Olorunfemi, 1992).

The population of Magama Gumau has increased immensely in the last decade. This is due to its new status of not only the sole junction to Gumau Town but also a business hub in Toro Local Government Area of Bauchi State. It has witnessed an influx of people from far and near for business transaction. For any community to grow and become an urban center there must be an unlimited supply of good water quality. Thus, there has been an increase in water demand by the people in the area for both domestic and industrial usage. The present study intends to determine the geoelectric parameters (resistivities and thicknesses) of subsurface layers and their hydrogeologic properties. The study in addition is intended to evaluate the groundwater potential of the area and established the aquifer protective capacity (insulation from pollution) of the overlying formations.

Location and Geology of the Study Area

The study area is located between latitudes 10° 07' 12"N and 10° 07' 32"N and longitudes 09° 07' 00"E and 09° 07' 20"E (Figure 1).

Information on the local geology of the area was sourced mainly from the various rock outcrops observable in the area. It falls within the setting of the geology of the Basement Complex of northeastern Nigeria, (Rahaman, 1988). The major rock units distinguished are the undifferentiated migmatite and granite gneiss (Figure 2). The Precambrian Basement Complex of northeastern Nigeria underlies the area with local geology essentially granite gneiss and migmatite. It is about 800 m above mean sea level, with some dome shaped hills at the outskirt. The hills are of granite and metamorphic gneiss and quartzite forming residual hills. The topography is gently undulating, consisting of lateritic soil, clay, sandy clay, and top soil and low-lying outcrops at the lowland area. Rivers, seasonal streams and springs, dominate the drainage system.

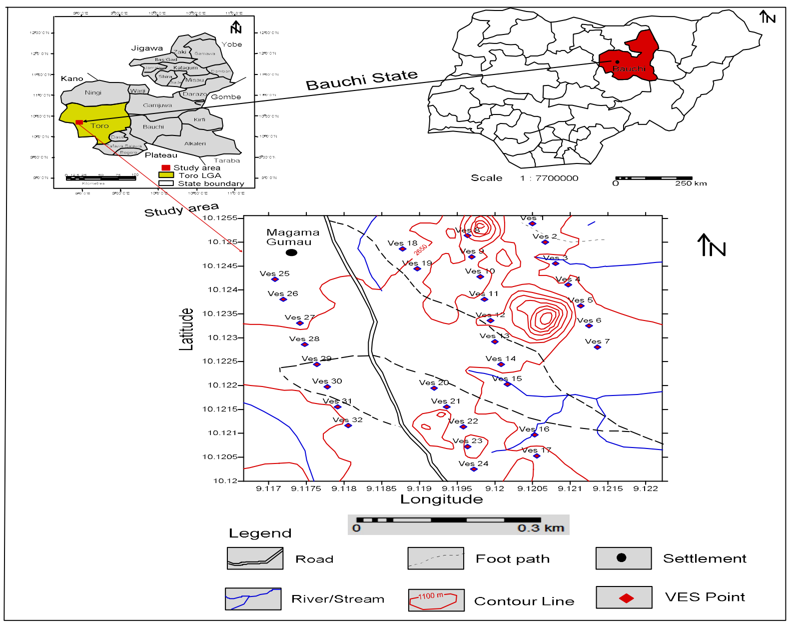


Figure 1: Location map of the study area showing the distribution of VES stations

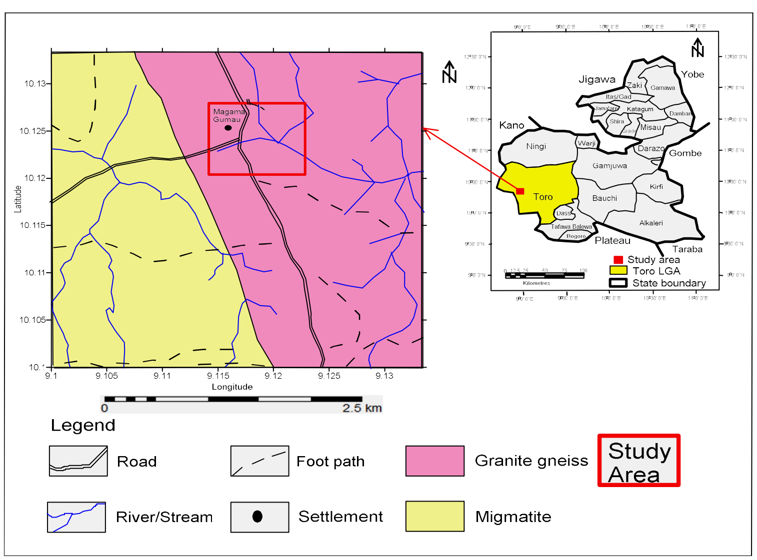


Figure 2: Geology map of the study area northeastern Nigeria (Source: NGSA, 2009)

MATERIALS AND METHOD

The geophysical resistivity data was obtained with the R-50 d.c resistivity meter which includes both the transmitter unit, through which current enters the ground and the receiver unit, through which the resulting potential difference is recorded. Other materials include: a pair of metallic current and a pair of potential electrodes, two red coloured connecting cable for current and two black coloured cable for potential electrodes, two reels of calibrated rope, hammer for driving the electrodes in the ground, GPS for finding the coordinates with elevation, compass for finding the orientation of the traverses, cutlass for cutting traverses and data sheet for recording the field data. The Schlumberger array method was applied. The electrode spread of AB/2 was varied from 1 to a maximum of 125 m. The expected depth of investigation was (D) = 0.125 L, where L = AB/2 where AB is the current electrode separation. Sounding data were presented as sounding curves, by plotting apparent resistivity against AB/2 on a log-log paper. Ground resistance (R) measurements were recorded with the R–50 d.c resistivity meter. The electrical resistances obtained were multiplied by the corresponding geometric factor (k) for each electrode separation to obtain the apparent resistivity (ρ = kR) in ohm-meter. The models obtained from the calculations above were used for computer iteration to obtain the true resistivity and thickness of the layers. Computer-generated curves were compared with corresponding field curves by using a computer program “IX1D”. The software was further used for both computer iteration and modeling. Computer iterations were carried out to reduce errors to a desired limit and to improve the goodness of fit.

The Dar-Zarrouk parameters (Table 1) 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 numerous layers (Zhody *et al.,* 1974). For n layers, the total longitudinal unit conductance is:

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

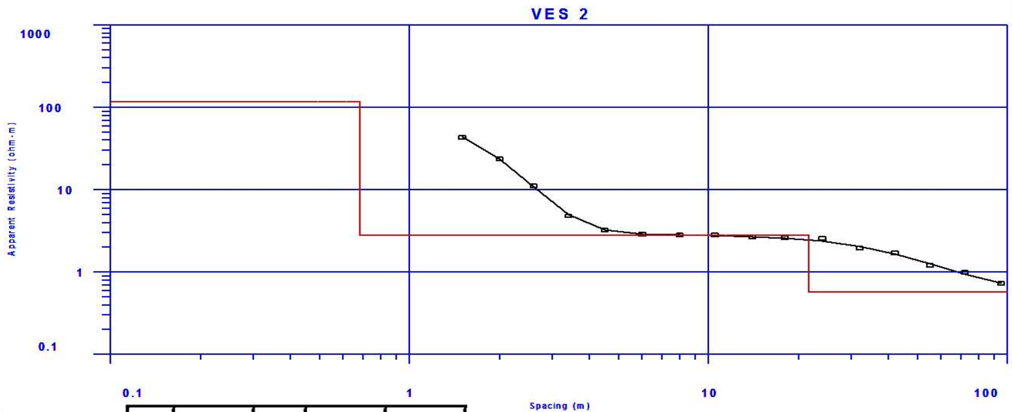
$$\mathbf{T} = \sum_{i=1}^{n} \rho i h i \quad \text{.................................... (2)}$$

$$\boldsymbol{\lambda} = \left(\frac{\rho T}{\rho L}\right)^{\frac{1}{2}} \quad \text{.................................... (3)}$$

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).

RESULTS

The summary of the thirty-two (32) VES stations data, curve types and overburden thickness obtained are shown in Table 1 while Figures 3a - c show a summary of the interpretations of representative curves of the VES points of the area. The true resistivity for each layer (*P*), true thickness for each layer (h), Total Longitudinal Conductance Unit (S), Total Transverse Resistance Unit (T) and Electric Anisotropy (I) are also presented in Table 1. The resistivity sounding curves obtained from the study area varied from the 3-layer (A, K, Q and H types) to 4-layer (HA, HK and QQ) and 5-layer (HKH, KHK and KQH) with the HK type being the dominant (Figure 4).

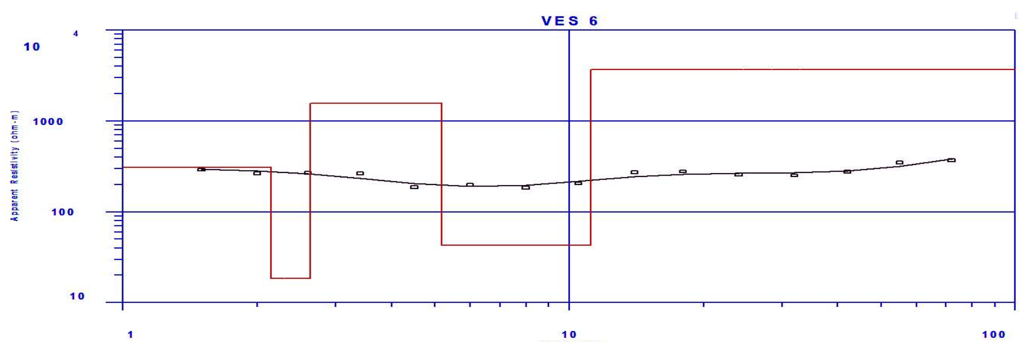


#	Rho	Fix?	Thick	Depth
1	116.92		0.68088	0.68088
2	2.7876		20.962	21.643
3	0.57734			
4				

Figure 3a: Typical Q-type curve for 3 layered earth model of the study area northeastern Nigeria.

#	Rho	Fix?	Thick	Depth
1	312.77		0.40472	0.40472
2	8.0140		0.82952	1.2342
3	34.433		7.3398	8.5741
4	19465.			
5				

Figure 3b: Typical HA-type curve for 4 layered earth model of the study area northeastern Nigeria.



#	Rho	Fix?	Thick	Depth
1	307.68		2.1484	2.1484
2	18.360		0.48560	2.6340
3	1573.8		2.5488	5.1829
4	43.131		6.0071	11.190
5	3665.5			
6				

Figure 3c: Typical HKH-type curve for 5 layered earth model of the study area northeastern Nigeria.

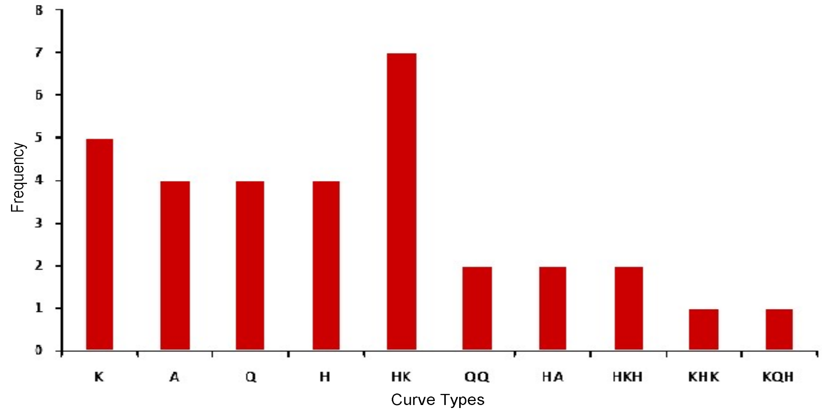


Figure 4: Frequency distribution of observed curve types of the study area northeastern Nigeria.

DISCUSSION

The Weathered Layer Thickness

The weathered layer underlay the topsoil unit and as well overlay the basement rock. The thickness of the weathered layer ranges from 0.4 to 39.2 m with an average thickness of 10.27 m (Figure 5). The variations in weathered basement thicknesses across the study area is shown in Figure 5. The study area underlying by areas showing thickness values less than the average aquifer unit thickness (10.27 m) and is dominated by aquifer unit thickness of less than 10 m which constitutes more than 62.50 % of the study area (Figure 5). Thick aquifer unit which is 22 m and above is found in the red and pink colour zones of the study area while the intermediate thickness which is between 15 to 22 m is found at the cyan colour part of the area with the yellow and green colour areas are dominated by the lowest aquifer unit thickness. The aquifer unit shows the degree of weathering that has affected the basement around the study area. The basement around the study area has not been affected by the weathering agent using the weathered basement thickness as a benchmark.

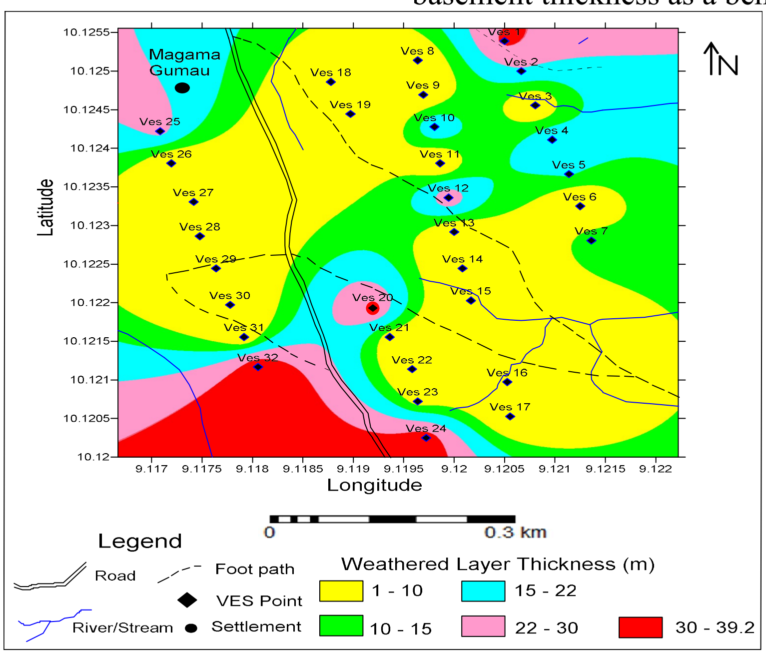


Figure 5: Weathered layer thickness map of the study area northeastern Nigeria.

Table 1: Summary of interpreted results and inferred lithologies for the study area northeastern Nigeria

VES Stations	Resistivity (Ohm-m)					Thickness (m)				Curve Type	Overburden thickness	Dar-Zarrouk Parameters		
	P_1	P_2	P_3	P_4	P_5	H_1	H_2	H_3	H_4			S (mhos)	T(Ωm^2)	I
1	63.72	3799.0	11.66			3.5	32			K	35.5	0.063351	223.02	0.10
2	116.92	12.79	0.58			0.7	21			Q	21.7	1.702625	350.43	1.11
3	76.57	8.60	12.30	0.18		0.7	1.9	38.4		HK	41.1	3.352023	542.259	1.04
4	89.93	12.63				0.7	21.9			Q	22.6	1.741751	339.54	1.01
5	32.43	421	54548			2.5	15.9			A	18.4	0.114856	6774.9	1.52
6	307.68	18.36	1573.80	43.13	3665.5	2.1	0.5	2.5	6	HKH	11.2	0.174761	4589.8	2.55
7	356.44	2487.20	832.02			1.2	14.1			K	15.3	0.009036	35497.	1.17
8	109.54	18.01	4766.20			1.6	1.6			H	3.2	0.103446	204.08	1.44
9	188.33	9.48	63558	27.09		1.0	2.0	20.9		HK	23.9	0.216609	132856	4.50
10	120.10	1426.70	13150			1.9	22			K	23.8	0.03124	31615.	1.31
11	302.1	72.59	3796.90	0.18		1.8	1.2	37.5		HK	40.5	0.032366	143014.	1.68
12	88.20	8.24	9.28			2.8	28.9			H	31.6	3.539028	485.09	1.31
13	159.00	15.98	239.14	0.12		0.8	1.0	1.7		HK	3.5	0.074718	549.718	1.83
14	3934.7	42.06	252.31	0.14		0.4	0.4	13.6		HK	14.4	0.063514	5022.12	1.24
15	49.83	1493.20	31.84	941.06	0.18	0.2	0.6	1.5	1.9	KHK	4.1	0.053545	953.64	1.70
16	56.58	1161.30	43573			5.7	1.5			A	7.2	0.102034	322.506	0.79
17	776.72	13.15	244.87	6.23		0.4	1.8	5.5		HK	7.7	0.159858	1681.14	2.13
18	132.60	69.99	0.45			4.7	3.1			Q	7.9	0.079737	840.189	1.05
19	561.96	15.22	0.20			0.5	0.7			Q	1.2	0.046882	291.634	3.08
20	1396.2	2978.30	0.15			9.00	31.4			K	40.4	0.016989	106084.	1.05
21	160.26	33.38	17.07	0.13		0.4	5.6	3.1		QQ	9.1	0.351866	303.949	1.14
22	66.69	74.42	0.26			3.7	1.6			K	5.3	0.07698	365.825	1.00
23	312.77	8.01	34.43	19465		0.4	0.8	7.3		HA	8.6	0.313178	382.855	1.29
24	15.06	10.38	12.86			5.0	35.7			H	40.7	3.771312	445.866	1.01
25	65.68	10.59	12.90			15.6	24.9			H	40.4	2.58879	1288.29	1.43
26	275.49	21.12	147.18	20441		0.6	0.7	15.9		HA	17.2	0.143353	2520.24	1.11
27	331.87	22.70	15.59	0.19		0.5	1.6	1.7		QQ	3.8	0.181035	228.758	1.69
28	96.16	12.31	47.60	9.52	10.35	1.0	1.7	1.4	24	HKH	28.3	2.719927	318.566	0.90
29	158.84	54.36	28.85	8.12	9.43	1.7	1.2	2.3	24	KQH	28.9	3.013862	577.692	1.21
30	61.89	16.22	38.68	0.19		2.3	1.8	0.6		HK	4.7	0.163649	194.751	1.20
31	59.42	237.99	381.07			1.3	2.8			A	4.1	0.033643	743.618	1.22
32	108.73	483.42	50446			2.4	39.2			A	41.6	0.103162	19211.0	1.07

P_1 = True Resistivity for Each Layer I,
h_1 = True Thickness for Each Layer,
S = Total Longitudinal Conductance Unit
T = Total Transvance Resistance Unit,
I = Electric Anisotropy (Dimensionless)

Weathered Layer Resistivity

The weathered basement resistivity values obtained from the study area range from 8.24 to 3799 Ωm (Figure 6) with average resistivity of 279.82 Ωm and the variations in the weathered layer resistivity across the study area are shown in Figure 6. The material composition of the weathered basement comprises clayey soil, sandy clay and clayey sand. The aquifer resistivity map (Figure 6) indicates that VES points that fall between the layer resistivity values of 8.24 to 100 Ωm have higher groundwater potential because the basements have been weathered into sandy clay or clay layer which allows percolation and storage. The rock type, clayey contents and climatic conditions continuously influence the resistivity of the aquifer unit. Weathered layer resistivity only cannot be used to infer groundwater potential; other factors such as Overburden thickness, bedrock relief and basement resistivity are also considered (Table 1). The yellow, cyan and pink colour areas are characterized by low resistivity weathered basement (Figure 6) and this with other geoelectric parameters could be a pointer to good groundwater yield. The existence of clay within the regolith will decrease the resistivity of the weathered layer to less than 100 Ωm and thus, reduce the permeability and also lower the aquifer potential (Olayinka *et al.*, 1997).

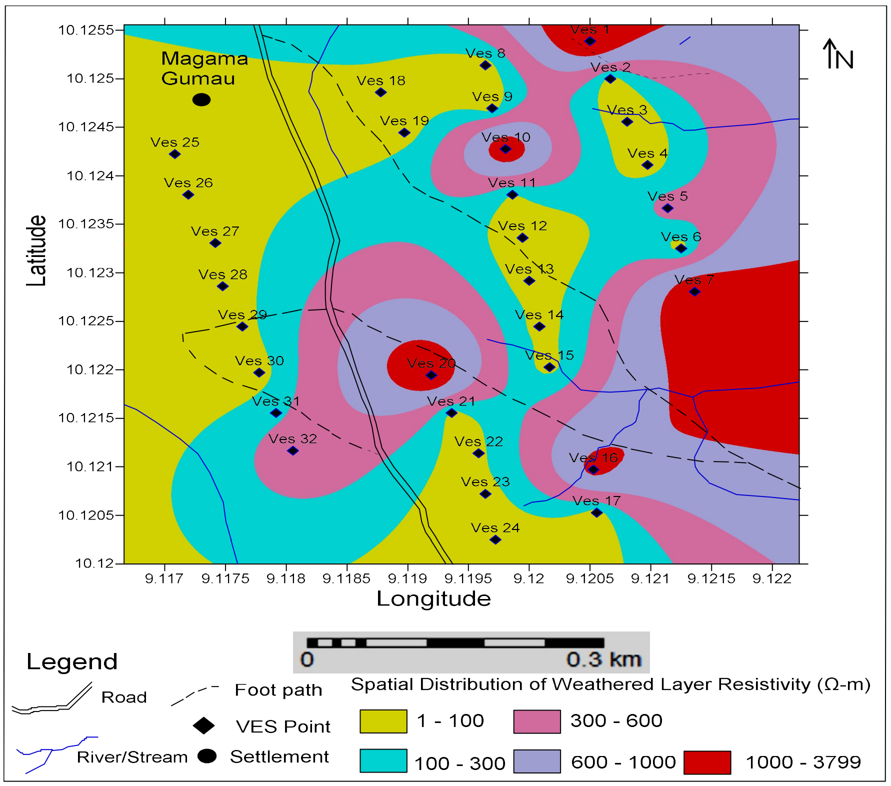


Figure 6: Isoresistivity map of the weathered layer of the study area northeastern Nigeria.

Overburden Thickness of the Area

The overburden thickness map (Figure 7) shows that the overburden thickness of the area varies from 1.2 to 41.6 m, with a mean value of 19.0 m. The overburden thickness map shows zones of relatively thick overburden with values greater than 20 m and zone of relatively thin overburden with values less than 20 m (Figure 7). Significant overburden thickness regions are possible groundwater collecting zones; thus, unconsolidated material could contain reliable aquifer if thick and sandy (Olayinka *et al.*, 2004).

Geophysical studies in southwestern Basement Complex of Nigeria have recognized thick overburden as regions of high groundwater potentials (Oladapo *et al*, 2004; and Oyedele and Olayinka, 2012). This is similar with the present study where the overburden is fairly thick (15 to 20 m) and occurs in the green colour portions of the study area (Figure 7). These zones are indicative of probable groundwater potential zones and cover about 6.25 % of Magama Gumau area.

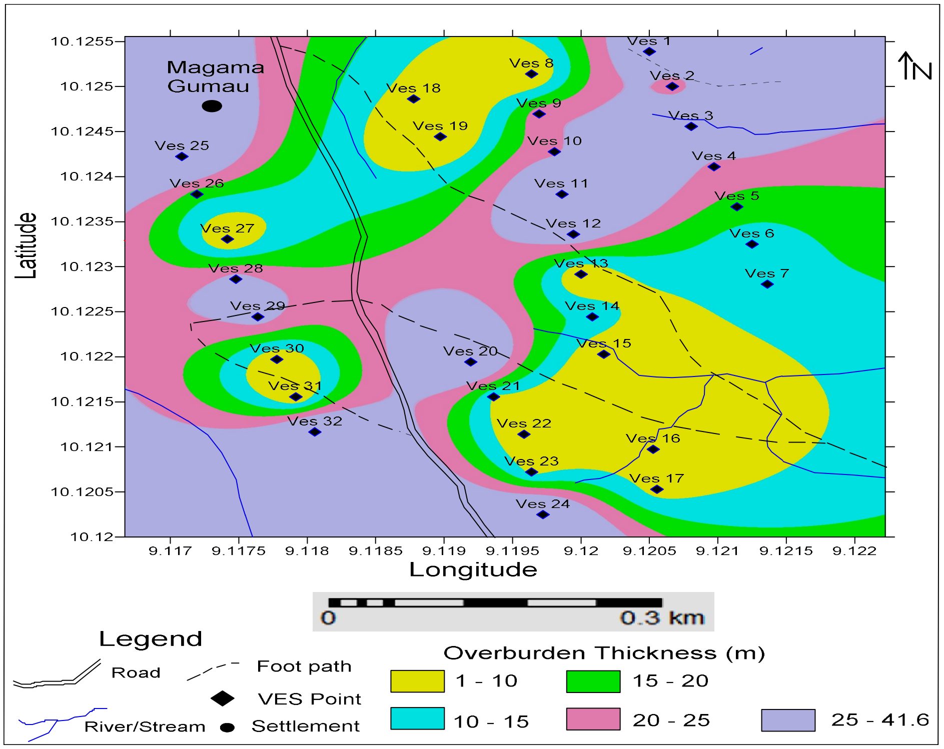


Figure 7: Overburden thickness map of the study area northeastern Nigeria.

Aquifer Protective Capacity Evaluation

The values of longitudinal unit conductance (S) obtained from the study area, ranges from 0.009036 to 3.771312 mhos (Table 1) with a mean value of 0.785598 mhos. The values obtained from the longitudinal unit conductance of the study area were categorize into poor, weak, moderate and good protective capacity zones according to the classification of Oladapo and Akintorinwa (2007). The longitudinal unit conductance map (Figure 8) was derived from equation 1 above for all the thirty-two (32) VES locations and was used for the overburden protective capacity rating of the study area. Where the longitudinal unit conductance is greater than 0.7 mhos, the areas are considered zones of good protective capacity. The section with conductance values ranging from 0.2 to 0.69 mhos was classified as zone of moderate protective capacity; and area with values ranging from 0.1 to 0.19 mhos was classified as exhibiting weak protective capacity while the zones where the value of conductance is less than 0.1 mhos were considered to have poor protective capacity. This research work shows that the overburden materials in the study area around the pink and powder blue colours (Figure 8) have good to moderate protective capacity and consist of relatively thick overburden within the range of 20 to 41.6 m as observed in Figure 7.

The green and yellow colour areas as shown in Figure 8 exhibit weak to poor overburden protective capacity with thin overburden thickness in the range of 1 to 20 m (Figure 7). Thus, figure 8 further indicates that about 60 % of the area falls within the poor to weak overburden protective capacity, while about

40 % constitutes the moderate to good protective capacity rating. The nature of the overburden materials that overlain the aquifers were estimated using the layer parameters (i.e. resistivity and thickness), the longitudinal unit conductance (S), the transverse unit resistance (T) and the coefficient of anisotropy in order to determine its capacity to prevent the infiltration of fluids contaminant into the aquifer. The geologic materials covering an aquifer might act as a seal in preventing the fluid from percolating into it. The earth materials act as a natural filter to infiltrating fluids; therefore, its ability to retard and filter percolating ground surface fluids pollutant is a measure of its protective capacity (Olorunfemi *et al.,* 1999). The clayey overburden is impervious and is characterized by relatively high longitudinal conductance, which in turn offers protection to the underlying aquifer (Abiola *et al.,* 2009).

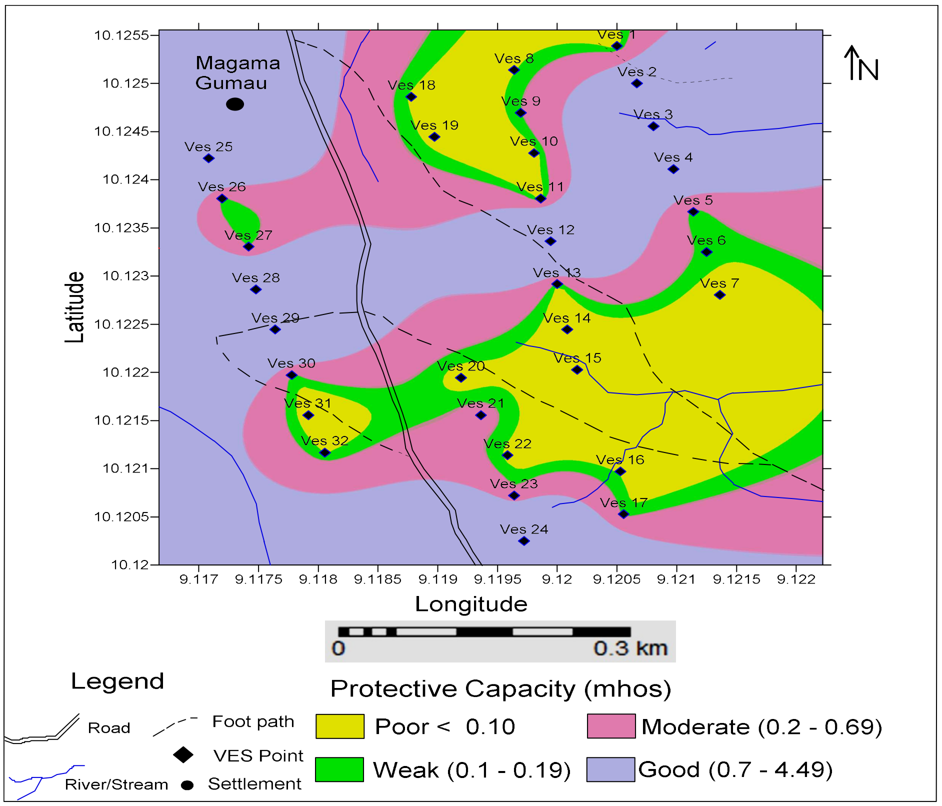


Figure 8: Overburden protective capacity map of the study area northeastern Nigeria

Geo-electric (Dar-Zarrouk) Parameters:

Geoelectric parameters such as total longitudinal conductance (S) and total transverse resistance (T) which were described by Maillet (1947) as Dar-Zarrouk parameters were derived from the fundamental parameters where Resistivity (ρi) and thickness (hi) are the basic parameters that describe the geoelectric layer derived from electrical sounding in an area. The subscript 'i' indicates the position of the layer in the section (Zohdy, *et al*., 1974). The following parameters are based on the consideration of a column of unit square cross-section area (m^2) cut out of a group of layers of infinite lateral extent (Khalil, 2009).

They are mathematically derived as:

Total Longitudinal Conductance (S) = $\frac{h1}{\rho 1} + \frac{h2}{\rho 2} + \frac{h3}{\rho 3} + \ldots\ldots + \frac{hn}{\rho n}$ (Ω^{-1})

Total Transverse Resistance (T) = h1*ρ1 + h2*ρ2 + h3*ρ3 + ……+ hn*ρn ($\Omega\ m^2$)

Where i = 1, 2, 3 … nth layer.

They are defined for individual layers or as a summation for a multi-layer section (Khalil, 2009).

Average Longitudinal Resistivity (ρ_L) = $\frac{H}{S} = S\ hi \Big/ \left(\frac{S\ hi}{\rho i}\right)$ (Ωm)

Where H = h1 + h2 + h3 + …hn (Ωm)

Average Transverse Resistivity (ρ_t) = $\frac{T}{H} = \frac{(S\ hi*\rho i)}{S\ hi}$ (Ωm)

Electric Anisotropy (I) = $\left(\frac{\rho L}{\rho t}\right)^{1/2} = \left(\frac{T*S}{H}\right)^{1/2}$ is a dimensionless entity,

These parameters are calculated to the bottom of the last layer of local aquifers made up of clay, weathered and fractured rocks above the basement in the study area. The total longitudinal conductance (S) map (Figure 8) gives information about the variation of the highly resistive fresh basement topography since depth to the basement relates to the total longitudinal conductance (S). Murali and Patangay (2006) noted that in a region where geoelectric conditions are uniform resistivity will not vary much.

Thus, the total longitudinal conductance (S) is proportional to the total thickness, which means that large total longitudinal conductance (S) values are indicative of deeper basement and vice versa. In this study, the total longitudinal conductance (S) values range from 0.009036 to 3.771312 mhos (Table 1) with a mean value of 0.785598 mhos. A marked increase in the total longitudinal conductance (S) value may correspond to a typical increase in the clay content and consequently a decrease in the transmissivity of the aquifer (Oteri, 1981; and Khali, 2009).

In the present study, low values of the total longitudinal conductance (S) correspond with aquifer units made of clay only and were depicted in VES 11, VES 13, VES 14, VES 19 and VES 22. This relates to differences in geologic terrain since this study was being carried out in hard rock terrain and is at variance to the report of Oteri (1981) in sedimentary environment. Meanwhile, the study also reveals that the values greater than the mean value of the total longitudinal conductance (0.785598 mhos) as shown in Table 1 are associated with clay aquifer as depicted in VES 2, VES 3, VES 4, VES 12, VES 24, VES 25, VES 28 and VES 29, where the aquifer is not fractured basement but rather clay.

The total transverse resistance (T) map (Figure 9) of the study area shows *T* value ranges from 194.75 to 143014 Ωm^2 with a mean value of 15588.1 $\Omega\ m^2$ (Table 1). Transverse resistance unit map was used by Nafez *et al*. (2010) for the determination of zones with high groundwater potential. High values of total transverse resistance (T*)* can be associated with the zones of high transmissivity and an indication of an unconfined aquifer (Braga *et al.* 2006). Hence, the pink, powder blue and orange colour zones (Figure 9) are suitable for groundwater exploitation.

The coefficient of anisotropy (I) map (Figure 10) of the study area is characterized by the transverse and longitudinal resistivities (Maillet, 1947). This parameter is also calculated to the top of basement rock and its value ranges from 0.1 to 4.5 (Table 1) with a mean value of 1.43 in the study area. Singh and Singh (1970) pointed out that lower coefficient of anisotropy (I) value corresponds to high aquifer potential zones. Thus, VES 2, VES 5, VES 6, VES 8 and VES 18 are expected to have higher groundwater potential with thick aquifer but were not observable in the area. However, the electric anisotropy (I) map (Figure 10) reveals that coefficient of anisotropy (I) value cannot be solitarily used to characterize aquifer potential without recourse to the aquifer thickness. VES 16, VES 18 and VES 22 have low values of coefficient of anisotropy (I) of 0.79, 1.05 and 1.00 respectively and they are expected to have higher aquifer thickness but their aquifer thickness are 7.2 m, 7.9 m and 5.3 m respectively. This thickness cannot make reasonable yield as we know that aquifer with water column of 7.9 m would be unreasonable to rely on for borehole production.

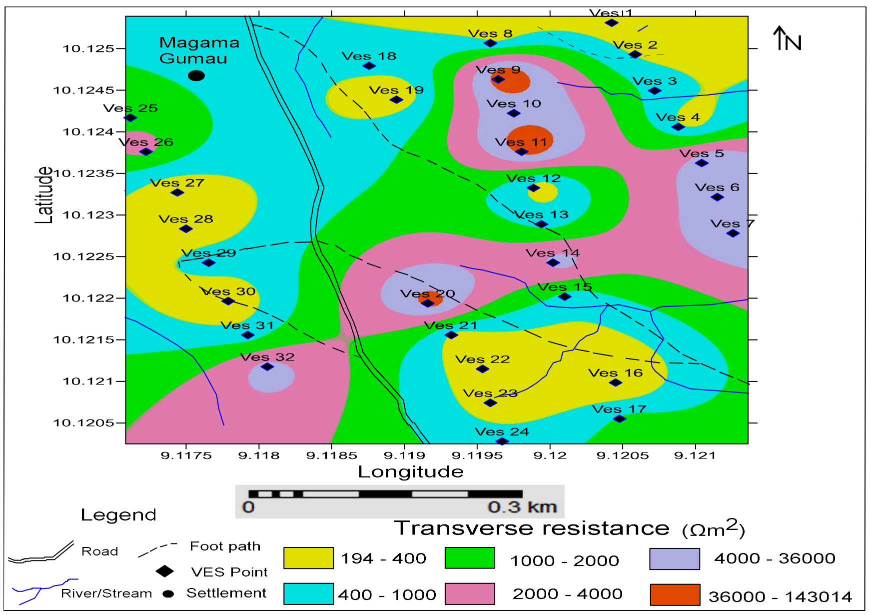


Figure 9: Total transverse resistance map of the study area northeastern Nigeria

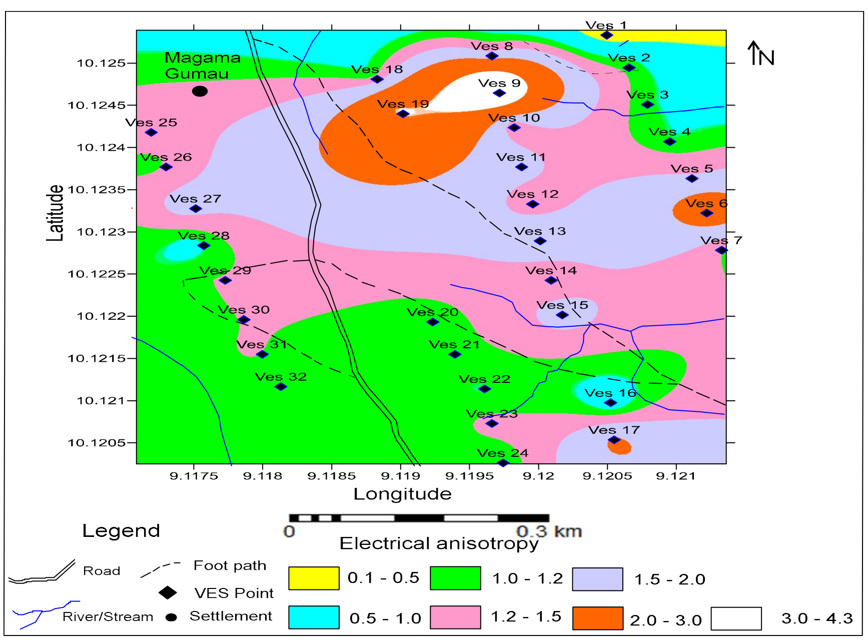


Figure 10: Electrical anisotropy map of the study area northeastern Nigeria

Geoelectric Sections

The summary of the results of the thirty-two (32) Vertical Electrical Soundings (VES) carried out in the study area is presented in Table 1. Figure 11a shows the Profile ‘A-A’ section and has four (4) distinct geologic layers. The topsoil has resistivities values of 15.06 to 1396.2 Ω-m and thickness ranging from 0.4 to 9 m. The second layer consists of fresh basement at VES 20, with clayey layer at the other VES points that directly underlying the topsoil having resistivities of 8.01 to 2978.3 Ω-m and thickness of 0.7 to 35.7 m. The third layer consists of fractured basement having resistivities of 0.15 to 34.43 Ω-m and thickness of 3.1 to 7.3 m. The fourth layer of an infinite depth with resistivity value of 2978.30 Ω-m is the fresh basement (Figure 11a). Aquifer at VES 21 and VES 24 are protected from surface fluid contaminants due to thick clay layer overlying the aquifer and the entire profile is good for borehole drilling as a result of very thick aquifer and deeper basement rock with the exception of VES 23 (Figure 11a).

The Profile B-B’ section is shown in Figure 11b and has four (4) distinct geologic layers. The topsoil resistivities range from 59.42 to 331.87 Ω-m with thickness of about 0.5 to 15.6 m. The second layer has clayey unit at VES 25, VES 26, VES 27, VES 28, VES 29 and VES 30 underlying the topsoil with resistivities of 10.59 to 237.99 Ω-m and thickness of 0.7 to 24.9 m. The fracture basement with resistivities value ranges from12.9 to 381.07 Ω-m and thickness ranging from 0.6 to 39.2 m was identified at the third layer. The fourth layer has fresh basement at VES 26 and VES 32 with resistivities values ranging from 20441 to 50446 Ω-m and an infinite thickness. The clay layer underlying the topsoil was located at VES 25, VES 26, VES 27, VES 28, VES 29 and VES 30 which serves as a seal for the aquifer (Figure 11b). VES 26 has thin overburden thickness and will not be favourable for groundwater production while VES 31 and VES 32 are vulnerable to fluid contamination as they are devoid of protective sealed above their aquifer

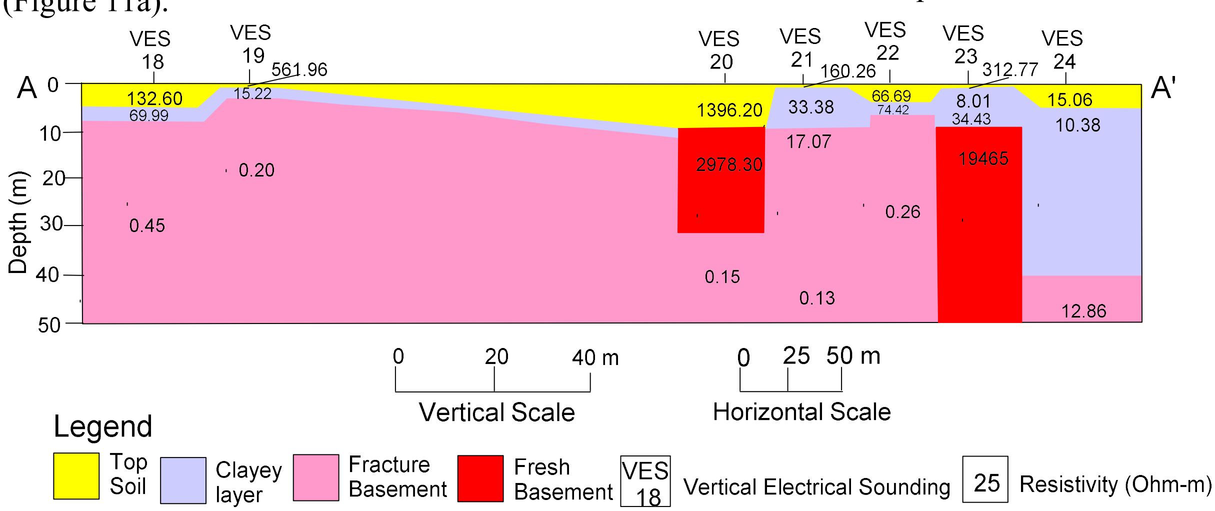


Figure 11a: 2-D Geoelectric sections along profile AA’ of the study area northeastern Nigeria.

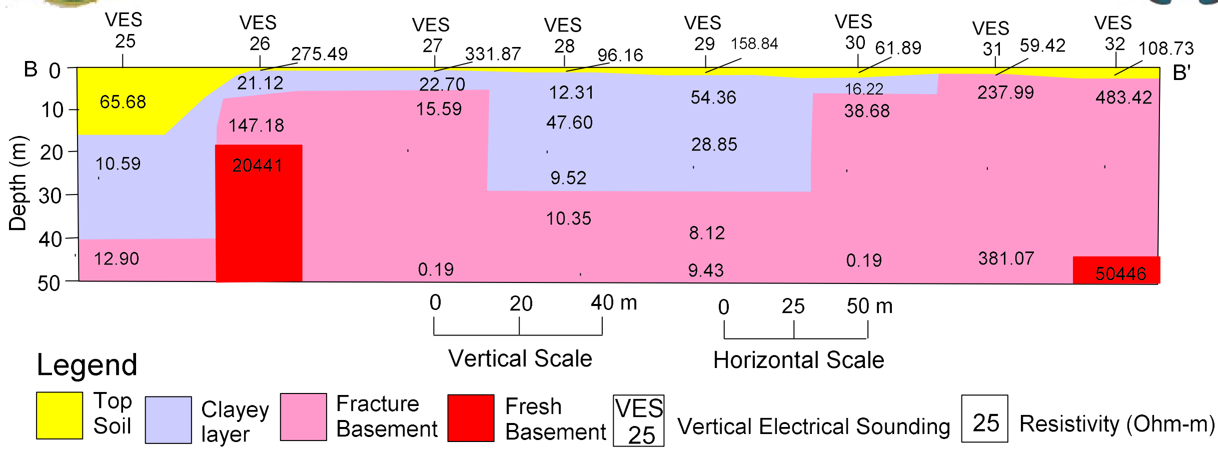


Figure 11b: 2-D Geoelectric sections along profile BB' of the study area northeastern Nigeria.

Groundwater potential evaluation

Figure 12 is the groundwater potential map of the study area. The above overburden thickness and nature of the weathered layer are main parameters in the groundwater potential appraisal of a Basement Complex terrain (Bala and Ike, 2001). Shemang, 1993; Bala and Ike 2001 reported that the horizon is also regarded as a significant water-bearing layer especially if significantly thick and the resistivity parameters suggest saturated conditions. The groundwater prospects of the study area are zoned into high, medium and low potentials. In this study, zones where thickness of the aquifer is greater than 25 m and of low clay content (average resistivity values between 100 and 300 ohm-m) are considered zones of high groundwater potentials. The powder blue colour parts of the study area constitute the high potential zones. The pink colour parts (Figure 12), have aquifer thickness ranging from 10 – 25 m and are of moderate clay contents (average resistivity values lie between 80 - 100 ohm-m), are classified under medium groundwater potential. The yellow colour parts of the study area fall within the low groundwater potential rating where the thickness of aquifer is below 10 m and with average resistivity value less than 80 ohm-m (Abiola *et al*., 2009; Oladapo and Akintorinwa, 2007). This constituted a sizeable portion of the segmentation. From the isoresistivity maps of the topsoil and weathered layer, Figures 5 and 6, it was observed that the clay content of the overburden was relatively high, which informed the relatively low groundwater potential rating of the study area owing to low permeability usually associated with clay. It was observed that about 65.62% of the area falls within the low/medium groundwater potential rating while only about 34.38% constitutes the high potential rating. This suggests generally an average groundwater prospect for the study area.

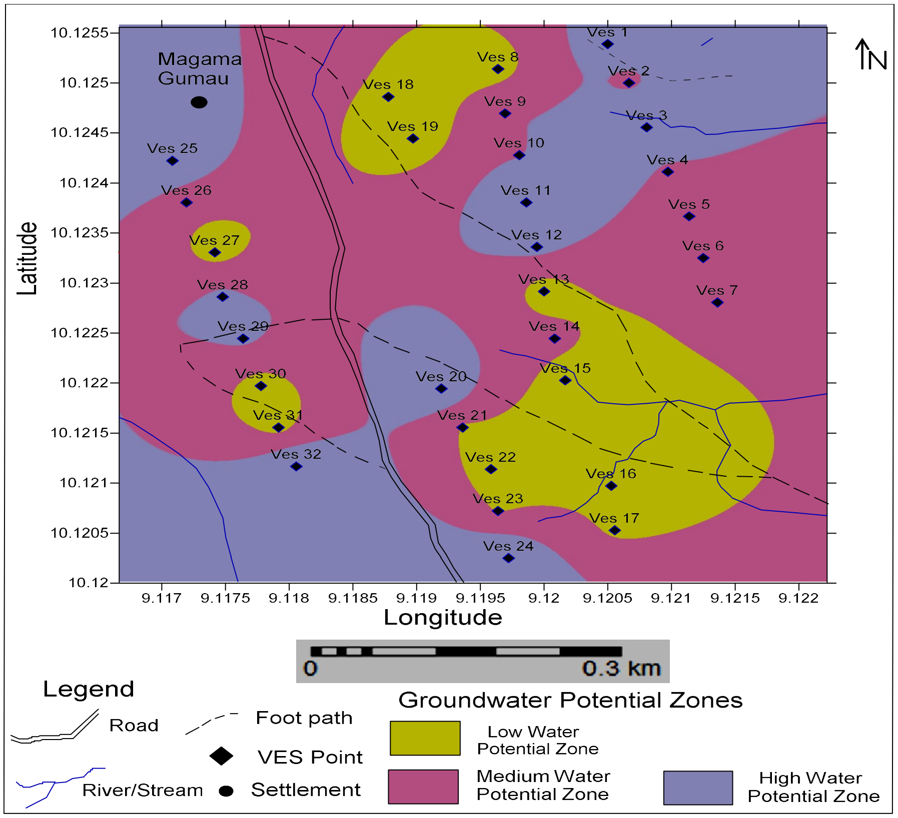


Figure 12: Groundwater potential map of the study area northeastern Nigeria.

CONCLUSION

In this study, the groundwater potential and protective capacity evaluation of the rock units around Magama Gumau, Toro, northeastern Nigeria was undertaken using 32 Schlumberger vertical electrical soundings (VES). The curve type varied from simple three-layer A, K, Q and H-types to the complex QQ, HA, HK, HKH, KHK and KQH-types. The computer assisted sounding interpretation revealed subsurface sequence composing topsoil with limited hydrologic significance, weathered layer, fractured basement and the fresh basement. The high variability of the thickness of the top soil appeared responsible for the observed overlapping resistivities across the study area. The weathered layer constituted the sole aquifer unit in the area; the yield being dependent on degree of the clay content. The higher the clay content, the lower the groundwater yield. The characteristic geoelectrical parameters of the delineated aquifer at each sounding station were used to produce the groundwater potential map of the area. About 65.62% of the study area falls within the low/medium rated groundwater potential zone while the remaining 34.38% constituted the high groundwater potential zone. Hence, the groundwater potential rating of the area is considered generally moderate. The study also revealed that most parts of the area are underlain by materials of poor to weak protective capacity. The pink and powder blue colours portions of the area are underlain by materials of moderate to good protective capacity. Not most of these areas coincide with zones of appreciable overburden thickness with clayey columns thick enough to protect the aquifer in the area from the surface polluting fluid. The groundwater in the area of weak protective capacity is therefore vulnerable to pollution if, for example, there is leakage of buried underground storage tanks; a source of serious environmental hazard. Susceptible zones comprise yellow and green colour parts. The results of this study have presented reliable information for a detailed groundwater abstraction and environmental factors needed for planning and development of residential and industrial estates by the urban planning authorities. For successful groundwater development programmes in the study area, it is recommended that pre-drilling geophysical investigations be carefully carried out for economic and environmental purposes. Future groundwater development in the study area by government should be concentrated within the high/medium groundwater potential zones with good/moderate aquifer protective capacity. Also, an assessment of licenses for siting of underground petroleum storage tanks in the town is very important. Areas for situating such facilities should be restricted to zones of moderate/good ground water protective capacity.

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