Geo-Electrical Study for Groundwater Potential of Gude and Environs, Adamawa State, Nigeria

C. K. Mbah and A. Nur

ABSTRACT

Eighteen Vertical Electrical Sounding (VES) were carried out to evaluate groundwater potential and aquifer protective capacity of the overburden units in Gude and environs. The Schlumberger configuration with maximum current electrode of 100 m was used and H type curve accounted for 94.4%. Geo-electro stratigraphic sections revealed that the geologic sequence beneath the area is composed of topsoil and highly Weathered/Fracture basement. The first layer is topsoil and has resistivity values between 15 Ωm to 462 Ωm with thickness ranging from 0.82 m to 4.78 m. The second layer which is referred to as weathered/fractured has resistivity values between 23 Ωm to 119 Ωm and thickness value ranging from 15 m to 43 m. The third layer representing a weathered basement and has an average resistivity value of 316.10 Ωm. The Dar-Zarrouk parameter in Gude area showed that the transvers resistance varies from 140.83 to 4763.02 Ohm-m^2 with average value of 1422.32 Ohm-m^2. While the Hydraulic conductivity values determined from geoelectrical technique range from 7.028 to 48.554 m/day with average value of 17.145 m/day.

Keywords: Gude and Environs, Hydro-geophysics survey, Protective Capacity and Groundwater Potential.

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I. INTRODUCTION

The resistivity method is most widely used in groundwater exploration, and it is relatively cheap when compared with the seismic refraction method. Water is a highly mobile and variable resource that exists on the surface of the earth and within the subsurface in the pore spaces of geologic materials of the earth. Water beneath the subsurface generally occurs within water bearing porous and permeable rocks called aquifers. Examples of such rocks include sedimentary rocks like sandstone. However, fractured basement rocks and weathered basement rocks can also be classified as aquifers. Water is an indispensable resource and the concern of many earth scientists and researchers has been on the acquisition of a reliable source [1]. The study area is located between latitudes 10° 11′ N - 10° 16′ N and longitudes 13° 17′ E - 13° 21′ E (Fig. 1). The area has an undulating topography, and the elevation varies between 610 m to 1000 m or more above sea level (Fig. 1). The climatic condition varies from dry to rainy season; the dry season is popularly known as the harmattan and begins from November to March while the rainy season is from April to October [2]; thus, categorizing the vegetation type to that of Savannah vegetation. According to [3] the surface water resources of Adamawa State are enormous as shown by the mean annual rainfall (100 to over 1050 mm), mean annual onset dates and mean cessation dates of rains and the mean length of rainy season.

In the Basement Complex of Nigeria, extensive application of geo-electrical method for groundwater investigation has been reported by [4]-[8]. Electrical resistivity therefore is often preferred because of the resistivity contrast obtained when ground water zone is reached. Lateral changes in the stratigraphic sequence and electrical properties brought about by fractures and fault zones or variable thickness of weathered beds makes interpretation of vertical electrical sounding difficult. Therefore the ability of the layer to conduct electricity and its resistant depends on the type and nature of the materials within the subsurface. Thus most rocks conduct electricity by electrolytic rather than electronic processes. It therefore follows that porosity of rocks is the major control of resistivity of rocks and that resistivity generally increases as porosity decreases.

Basement complex environment, fractured basement columns have been identified as a very important lithological unit which contributes significantly to the productiveness and yields of boreholes [9]. However, to image this important hydrogeological unit in the subsurface. High hill basement complex rocks reduce the conductivity of groundwater in the adjacent valleys rendering such valleys non aquiferous [8]. Groundwater development in water scare basement complex area is a challenging task since the water occur mainly in a media with secondary porosity which are highly variable and vary sharply within very short distances, contributing to near-surface inhomogeneity. The Vertical Electrical Sounding (VES) technique of the electrical resistivity method utilizing the Schlumberger electrode configuration has been highly preferred because of its field procedure advantages.
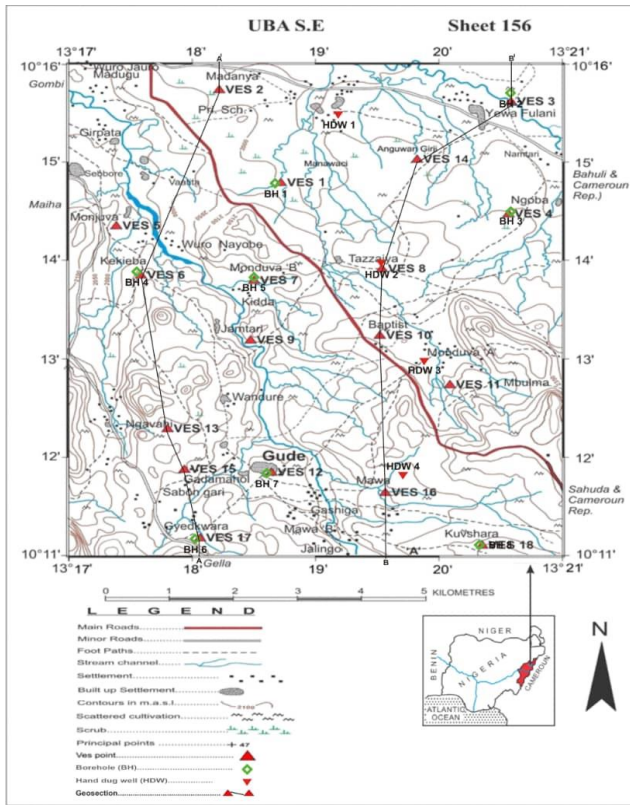
Fig. 1. Topographic map of the study area and environs (Modified from GSN 1969).

Fig. 2. Geological Map of Study Area (Modified from GSN 1969).

II. GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The rocks in the area are granite, migmatite gneisses, and the older granites series (granitoids) which evolved during the Pan African Orogeny. The hill in the vicinity appears to be composed of biotite granite [8]. Minor pegmatite and dolerite dykes also exist in the bedrock area surrounding the hills. The crystalline basement rocks are overlain by weathered profile of variable thickness, [10]. Outcropping in some parts of the study area and overlapping the basement rocks are alluvium deposits [11].

The Older Granite series include rocks intruded during the Pan African Orogenic cycle. These rocks are divided into three (3) main groups: basic and intermediate intrusive, migmatite and syntectonic to late tectonic granite [11]. The river course alluvium is the Quaternary deposits and they occur along the flood plains. The alluvial deposits are products of alteration caused by chemical and physical weathering of the basement rocks; they consist of sands, clays and laterite soil (Fig. 2).

The aquifer unit in the study area is mainly in the weathered/fractured basement, and poor infiltration of the surface water during the rainy season results in shallow water table conditions because of the low permeability characteristics of these rocks. Accurate geoelectrical data acquisition, subsequent analysis and interpretation of the data are valuable contributions in locating boreholes. These are exploited through drilling and digging of shallow and deep boreholes and wells into the thick alluvium and the fractured basement. According to [12], the fractured aquifer in the basement complex areas has low to moderate hydraulic conductivity and transmissivity values, which give rise to low and moderate yields and specific capacities in boreholes tapping these aquifer systems.
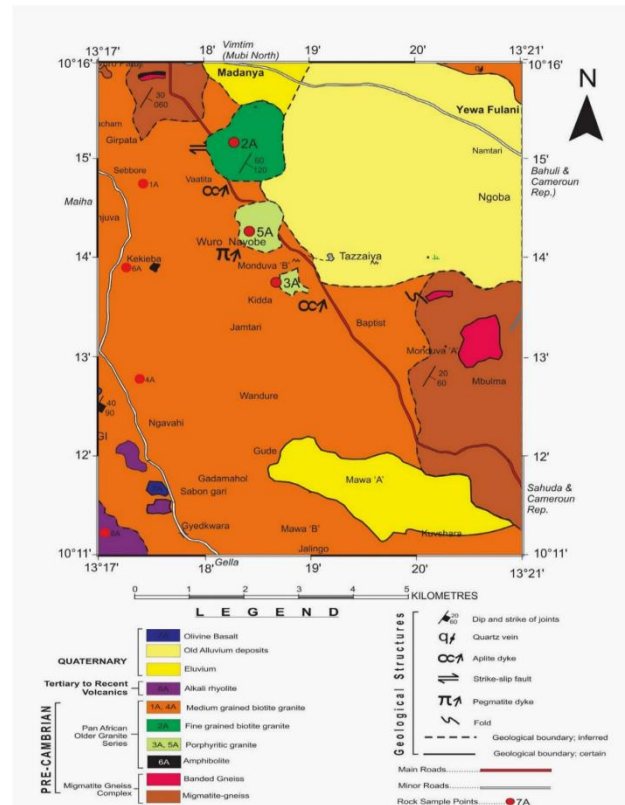
III. DATA COLLECTION AND ANALYSIS

Eighteen Vertical Electrical Sounding (VES) were carried out within the study area using Schlumberger array using Abem SAS 4000 terrameter. These stations were chosen at different locations within the study area (Fig. 1). The sounding curve for each point was obtained by plotting the apparent resistivity on the ordinate against half electrode spacing on a log-log graph paper. Partial curve matching technique was used in the initial stage of the analysis to obtain the resistivities and thicknesses, which were used as the initial input into a computer program IX1-D software used for computer modelling. The results obtained were used as initial input into computer program, (IX1-D); where it was unsatisfactory the parameters were modified until a smooth layered model with a minimum percentage error is obtained.

The computer output of the eighteen VES in the study area is presented in Table I. This result shows the details of the measured parameters such as thickness of layers, resistivity of layers, transverse resistance, longitudinal conductance and fitting error for all the sounded points.

Dar Zarrouk parameters (Longitudinal conductance and Transversal resistance) were used to define target areas of groundwater potential and also used in aquifer protection studies. The total longitudinal conductance values were then utilized in evaluating the overburden protective capacity of the study area. This is because the earth medium acts as a natural filter to percolating fluids, [13]. Surfer 12.0 was used to produce Iso-resistivity contour map and Geo-electro stratigraphic sections, protective capacity contour map, transmissivity, and hydraulic conductivity map of Gude and environs.

TABLE I: SUMMARY OF RESULTS OBTAINED FROM THE 18 VES IN THE STUDY AREA

S/N	Ves point	Layer thickness (m)		Layer resistivity (ohm-m)			Tranversal resistance (ohm-m^2)		Longitudinal conductance (siemen)		Fitting error (%)	Curve type
		h_1	h_2	ρ_1	ρ_2	ρ_3	T_1	T_2	S_1	S_2		
1	VES 1	0.92	12.44	47.31	10.10	106.70	43.53	125.64	0.02	1.23	0.63	H
2	VES 2	2.32	42.39	303.98	54.41	326.77	705.23	2306.44	0.01	0.78	0.41	H
3	VES 3	4.87	49.75	462.35	50.48	119.10	2251.64	2511.38	0.01	1.00	0.53	H
4	VES 4	1.31	21.50	135.34	69.32	224.34	177.30	1490.38	0.01	0.31	0.39	H
5	VES 5	1.00	13.70	57.69	18.95	86.32	57.69	259.62	0.02	0.72	0.35	H
6	VES 6	1.30	19.50	162.54	57.20	659.54	211.30	1115.40	0.01	0.34	0.93	H
7	VES 7	1.23	22.53	41.15	19.37	55.40	50.61	466.41	0.03	1.16	0.55	H
8	VES 8	1.20	34.24	174.85	55.41	498.72	209.82	1897.24	0.01	0.62	0.46	H
9	VES 9	1.26	18.52	116.02	48.82	204.07	146.20	904.15	0.01	0.38	0.33	H
10	VES 10	1.14	14.64	48.97	27.48	129.83	55.83	402.30	0.02	0.53	0.40	H
11	VES 11	1.10	6.30	53.11	17.18	624.16	58.42	108.23	0.02	0.37	0.53	H
12	VES 12	1.00	10.12	47.32	9.24	203.71	47.32	93.51	0.02	1.10	0.36	H
13	VES 13	1.30	14.92	131.72	32.38	307.00	171.24	483.11	0.01	0.46	0.50	H
14	VES 14	1.12	15.91	219.77	59.00	230.00	246.14	938.70	0.01	0.27	0.44	H
15	VES 15	1.06	33.50	67.36	22.91	178.86	71.40	767.50	0.02	1.46	0.58	H
16	VES 16	2.09	46.25	313.20	73.36	131.11	654.60	3392.50	0.01	0.50	0.50	H
17	VES 17	1.12	30.03	14.91	85.95	450.90	14.91	2581.10	0.08	0.35	0.60	A
18	VES 18	0.82	9.25	70.05	57.04	1152.50	57.44	527.62	0.01	0.16	0.45	H
	MEAN	1.45	23.08	137.10	42.70	316.10	290.60	1131.76	0.02	0.65	0.50	

IV. RESULT AND DISCUSSIONS

The eighteen Vertical Electrical Soundings (VES) were interpreted qualitatively and quantitatively. The results show details of the measured parameters such as thickness of layers, conductance, fitting errors and curve-types for all the sounded points (Table I). The computer modelling of the soundings in Gude and environs revealed H and A curve types. The interpretation of the data has helped in delineating aquifer zones in the study area. From the overall assessment of the quantitative analysis, the average thickness of the first layer is 1.45 m with a mean resistivity of 137 Ωm which represents topsoil and sand at some points. The second layer has average thickness of 23.08 m and resistivity of 42.70 Ωm which depicts an unconsolidated and highly weathered/fractured basement.

The third layer represents a weathered basement with average resistivity value of 316.10 Ωm.

A. Iso-Resistivity Maps

For a better understanding of the subsurface situation of the area, iso-resistivity maps for AB/2 = 40 m and AB/2 = 100 m were produced and presented in Fig. 3a and 3b. Iso-resistivity contour map Fig. 3a there is a distinct anomaly identified at the southern part of the study area. This anomaly at Gude area has the lowest resistivity value of 30 Ωm, the resistivity values increase outwards and it reaches up to 165 Ωm at the southeast of the study area. There are other minor anomalies at the centre and north of the area where the resistivity values are 85 Ωm at VES 6 near Kekieba and at Monduva and Manawaci area. At the northeast there are two smaller anomalies at VES 14 and VES 3, the resistivity values are 65 Ωm.

In Fig. 3b there are two major anomalies in the south of the study are. At Gude (VES 12) the resistivity value is 60 Ωm and increases outwards. At the southeast of the study are near Kuvashare (VES 18) the highest resistivity value of 290 Ωm was obtained.
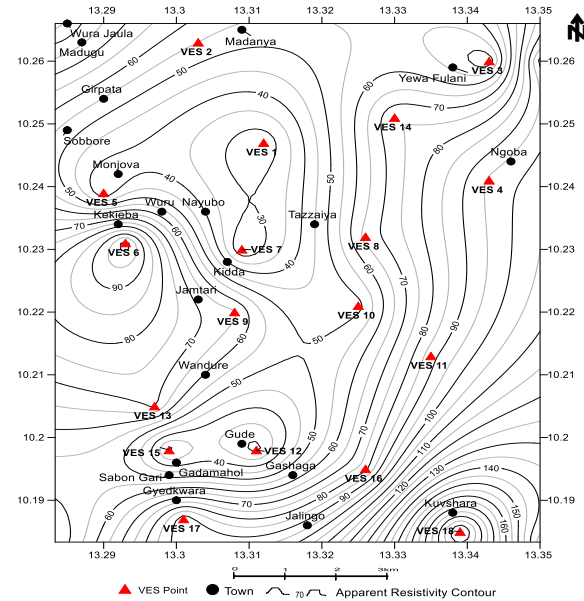

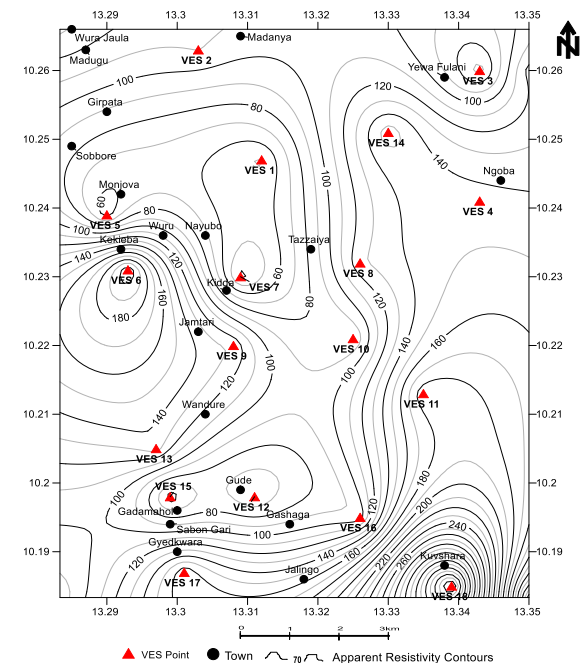Fig. 3a. Iso-contour map for AB/2 = 40 m. Contour interval = 5 Ωm.

Fig. 3b. Iso-contour map for AB/2 = 100 m. Contour interval = 10 Ωm.

B. Geoelectro-Stratigraphic Sections

Profile A-A' through the VES 17, VES 15, VES 13, VES 6 VES 2 and Profile B-B' through the VES 16, VES 10, VES 8, VES 14 and VES 3 were traced and both revealed three Geo-electrostratigraphic and layers comprise of topsoil, highly weathered/fractured basement and weathered / fractured basement (Fig. 4a).

The Geoelectro-stratigraphic Section A-A' (Fig. 4a) has three layers and the length is 17.5 km long with a total of five Vertical Electrical Soundings. The first layer of this profile is considered overburden topsoil and sandy soil with resistivity value ranging from 15 Ωm to 163 Ωm and thickness from 0.98-4.3 m with thinnest layer is found at VES 17 and thickest at VES 2, therefore has no potential for groundwater because sandy soil has no retention capability for water. It is however, observed from the geo-electric section that VES 17 is characterized with low resistivity value of 15 Ωm suggesting that the topsoil in these areas is possibly high moisture content. The second layer at VES 17, VES 15, VES 13, VES 6 and VES 2 are unconsolidated highly weathered basement with resistivity value ranging from 23 Ωm to 86 Ωm and thickness value of 19 m to 34 m, respectively, while the third layer at VES 17, VES 15, VES 13, VES 6 and VES 2 are weathered/fractured basement with resistivity value of 451 Ωm, 131 Ωm, 307 Ωm, 660 Ωm and 107 Ωm (107 Ωm to 660 Ωm range) and thickness of about 31m at VES 6 which is good for sitting a borehole. Generally, therefore area that is good for sitting boreholes.
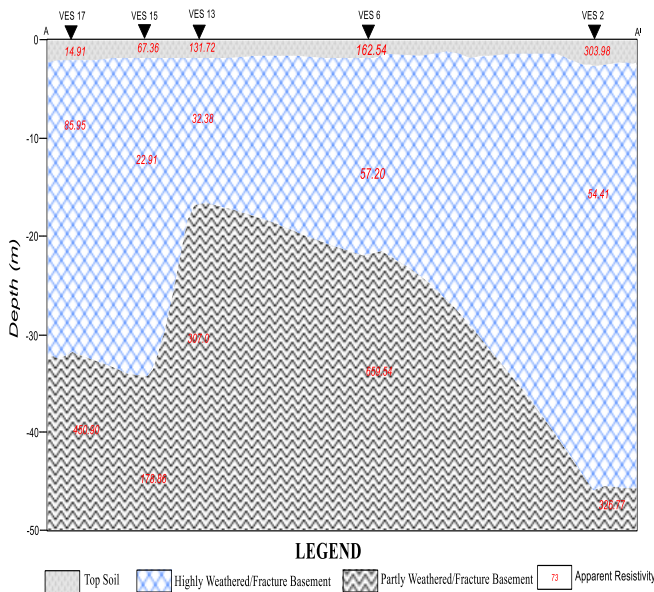

Fig. 4a. Geoelectro-stratigraphic section profile A-A'.

Geo-electrostratigraphic section B-B' presented in figure 4b consists of five Vertical Electrical Soundings. The profile has three layers with length of about 17.4 km long. The first layer is considered to be topsoil and sandy soil and has its lowest resistivity value of 50 Ωm at VES 10 and highest at VES 1 with a resistivity value of 462 Ωm. The thickness of this layer ranges from 0.98 m to about 4.8 m. The second layer is the unconsolidated highly weathered basement with a lowest resistivity value of 27 Ωm at VES 10 and highest with resistivity value of 73 Ωm at VES 16 and thickness is between 18 m to 48 m. The third layer represents the

weathered/fractured basement with a resistivity value of 119 Ωm at VES 15 and 499 Ωm at VES8. The thickness of this highly weathered basement is between 12 m to 42 m.
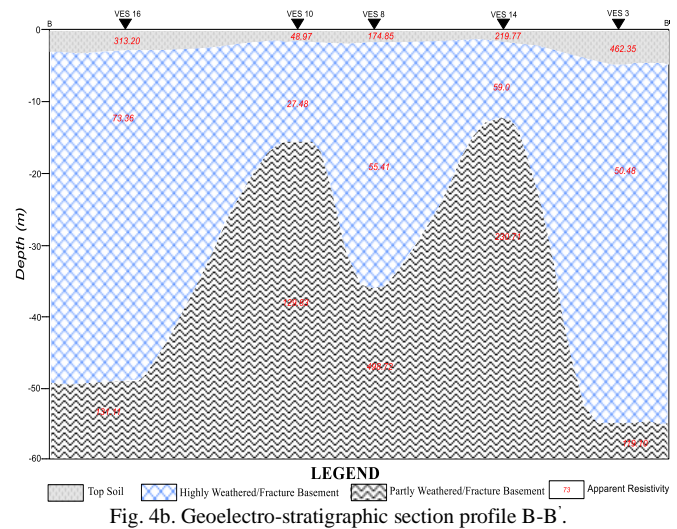

Fig. 4b. Geoelectro-stratigraphic section profile B-B'.

C. Aquifer Protective Capacity

The Dar-Zarrouk Parameters S and T could be of direct use in aquifer protection studies and evaluation of hydrologic properties of aquifer. On the aquifer protection studies, the protective capacity of a clayey aquifer overburden is proportional to its longitudinal conductance (S) which, in terms of aquifer protection, gets a dimension of time (e.g., Infiltration time). A typical example of the use of the parameters for the evaluation of hydrologic properties of aquifers was demonstrated by [13]. The longitudinal conductance is the geoelectrical parameter used to define target areas of groundwater potential. High longitudinal conductance values usually indicate relatively thick succession and should be accorded the highest priority in terms of groundwater potential. The transverse resistance (T) is one of the parameters used to define target areas of good groundwater potential. It has a direct relation with transmissivity and the highest T values reflect most likely the highest transmissivity values of the aquifers or aquiferous zones. Details of the formulae used for the calculation of the Dar Zarrouk Parameters can readily be found in [13].

[14] modified aquifer protection capacity rating to suite a crystalline Precambrian basement complex environment and adopted it in evaluating the protective capacity, according to them "an aquifer protection capacity rating can be classified on the basis of the total longitudinal unit conductance (ΣS) as excellent (S > 10), very good (5 ≤ S ≤ 10), good (0.7 ≤ S <5), moderate (0.2 ≤ S < 0.7), weak (0.1 ≤S < 0.2) and poor (S < 0.1) protective capacity" (p.41).

The Dar- Zarrouk Parameters of the potential aquifer zones were calculated as shown in Table II while the Longitudinal Conductance/Protective Capacity Rating of the eighteen vertical electrical sounding are presented in Table III.

From the calculated total longitudinal unit conductance (ΣS) in Table II shows that the layers overlying the aquifer zone range from weak to good capability in terms of aquifer protection. The total overburden thickness provides

protection from the overlying materials. Moreover, the second overburden layer will also impede fluid movement through it. VES 1, 2, 3, 5, 7, 12 and 15 showed good protective capacity with 39% over the study area. This in-turn decreases the infiltration time of contaminant fluids moving from the ground surface into the aquifer. 55.5% have moderate capacity which comprises of VES 4, 6, 8, 9, 10, 11, 13, 14, 16 and 17 while VES 18 showed weak protective capacity of the overburden materials. Areas that are classified as poor and weak are clearly indicated in Fig. 5, and thus are vulnerable to infiltration of leachate and and surface contaminations.

TABLE II: CALCULATED DAR-ZARROUK PARAMETER OF THE STUDY AREA

S/N	VES POINT	$\sum (S = h/\rho)$	$\sum (T = h.\rho)$
1	VES 1	1.25	169.17
2	VES 2	0.79	3011.67
3	VES 3	1.01	4763.02
4	VES 4	0.32	1667.68
5	VES 5	0.74	317.31
6	VES 6	0.35	1326.7
7	VES 7	1.19	517.02
8	VES 8	0.63	2107.06
9	VES 9	0.39	1050.35
10	VES 10	0.55	458.13
11	VES 11	0.39	166.65
12	VES 12	1.12	140.83
13	VES 13	0.47	654.35
14	VES 14	0.28	1184.84
15	VES 15	1.48	838.9
16	VES 16	0.51	4047.1
17	VES 17	0.43	2596.01
18	VES 18	0.17	585.06

TABLE III: LONGITUDINAL CONDUCTANCE/PROTECTIVE CAPACITY RATING

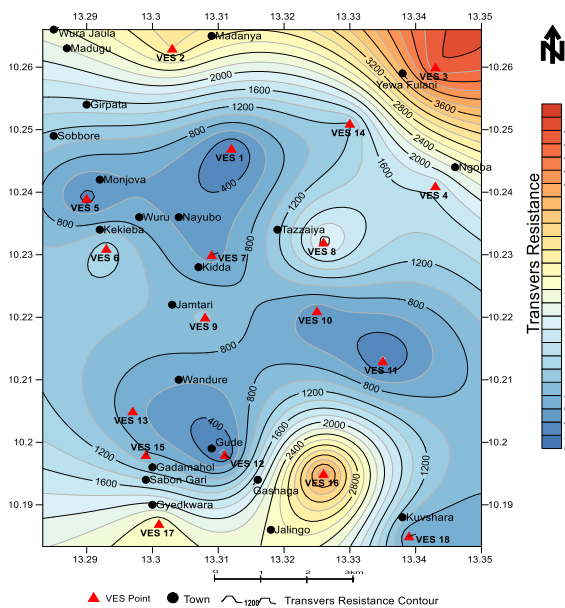| Longitudinal Conductance (Ω-1)	Protective Capacity Rating	VES POINT	%
>10	Excellent	–	0
5 – 10	Very good	–	0
0.7 – 4.9	Good	1, 2, 3, 5, 7, 12 and 15.	39
0.2 – 0.69	Moderate	4, 6, 8, 9, 10, 11, 13, 14, 16, and 17.	55.5
0.1 – 0.19	Weak	18.	5.5
<0.1	Poor		0

Fig. 5. Protective capacity contour map of the study area (Contour interval 0.05 Seimens).

Transverse resistance is also used to define areas of groundwater potentials. A resistance layer can be determined by transverse resistance. The transvers resistance within the study area ranges from 140.83 to 4763.02 ohms-m^2 with average value of 1422.32 ohms-m^2. High transvers resistance value is found at the North-eastern part of the map (Fig 6).
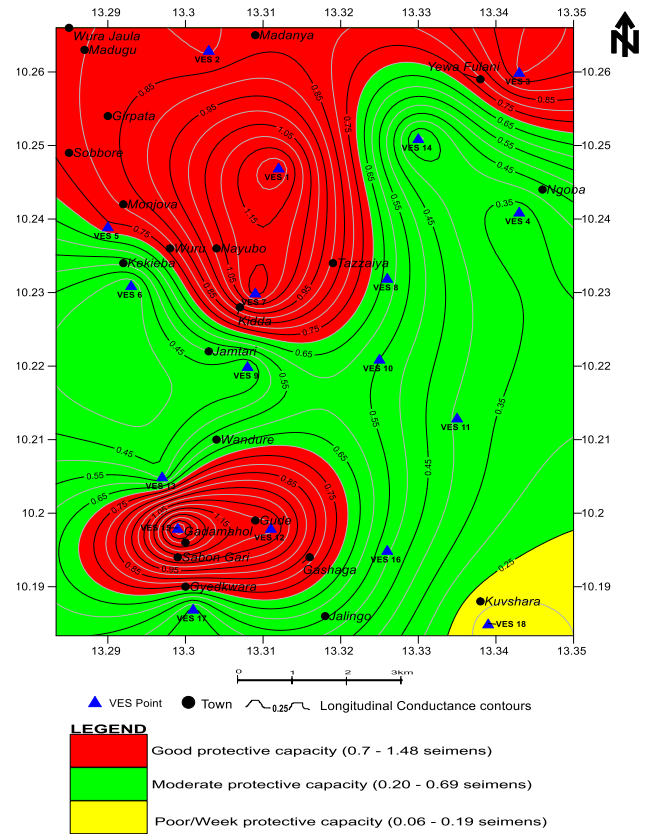

Fig. 6. Transvers resistance contour map. (Contour interval 200 Ωm^2).

D. Hydraulic Conductivity and Transmissivity

The pumping test technique is used to determine the aquifer properties and potentials. However, this technique is very expensive. The vertical electrical sounding method can be used to determine the aquifer parameters. The values of transmissivity and hydraulic conductivity were calculated from the geophysical data. Details of the formulae used for this study can be readily available in [13].

Table IV shows the calculated Aquifer Parameters Estimated from Geophysical Data; the hydraulic conductivity values determined from geoelectrical technique range between 7.028 to 48.554 m/day with average value of 17.145 m/day. Hydraulic conductivity is proportional to permeability. High permeability can be observed in aquifer zone with high hydraulic conductivity and also contaminants will be easily circulated. The hydraulic conductivity estimated from the electrical resistivity sounding data was contoured as shown in Fig. 7.

Transmissivity values obtained from VES method for potential aquifers range between 82.21 to 697.26 m^2/day with average of 318.75 m^2/day. VES 1, 7 and 15 has high transmissivity value indicating the large amount of groundwater in this zone while the remaining shows moderate potential. Fig. 8 shows contour map of Transmissivity values of Gude and environs.

TABLE IV: AQUIFER PARAMETERS ESTIMATED FROM GEOPHYSICAL DATA

S/N	Ves Point	Aquifer Thickness (m)	Aquifer Resistivity (Ωm)	Transvere Resistance (ohm-m^2)	Longitudinal Conductance (Seimens)	K_c (m/day)	T_c (m^2/day)	Groundwater Potential
1	VES 1	12.44	10.10	125.64	1.23	44.686	555.89	High
2	VES 2	42.39	54.41	2306.44	0.78	9.288	393.71	Moderate
3	VES 3	49.75	50.48	2511.38	1.00	9.961	495.55	Moderate
4	VES 4	21.50	69.32	1490.38	0.31	7.410	159.31	Moderate
5	VES 5	13.70	18.95	259.62	0.72	24.845	340.37	Moderate
6	VES 6	19.50	57.20	1115.40	0.34	8.865	172.86	Moderate
7	VES 7	22.53	19.37	466.41	1.16	24.34	548.38	High
8	VES 8	34.24	55.41	1897.24	0.62	9.131	312.64	Moderate
9	VES 9	18.52	48.82	904.15	0.38	10.276	190.31	Moderate
10	VES 10	14.64	27.48	402.30	0.53	17.566	257.16	Moderate
11	VES 11	6.30	17.18	108.23	0.37	27.225	171.51	Moderate
12	VES 12	10.12	9.24	93.51	1.10	48.554	491.36	Moderate
13	VES 13	14.92	32.38	483.11	0.46	15.073	224.88	Moderate
14	VES 14	15.91	59.00	938.70	0.27	8.612	137.01	Moderate
15	VES 15	33.50	22.91	767.50	1.46	20.814	697.26	High
16	VES 16	46.25	73.36	3392.50	0.50	7.028	325.04	Moderate
17	VES 17	30.03	85.95	2581.10	0.35	6.063	182.07	Moderate
18	VES 18	9.25	57.04	527.62	0.16	8.888	82.21	Moderate

K_c = Hydraulic conductivity. T_c = Transmissivity.
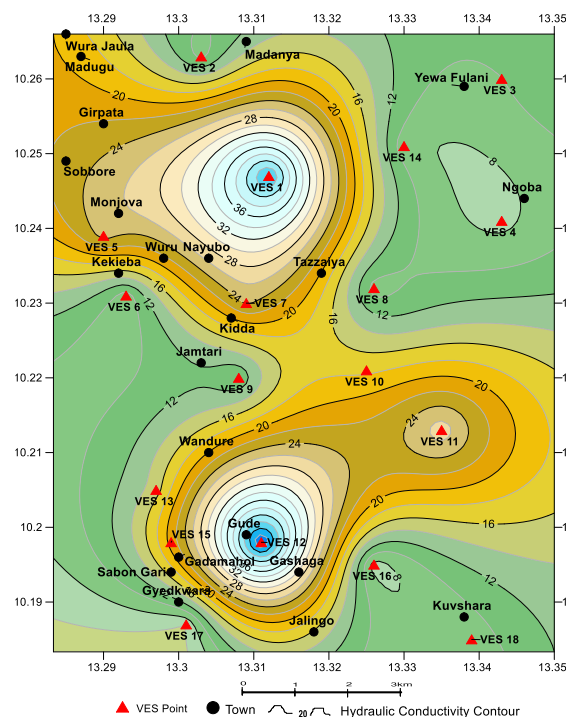>500 High potential, 60-500 Moderate potential, 6-59 Low potential, 0.5-5 Very low potential.

Fig. 7. Hydraulic conductivity contour map (contour interval 2m/day).
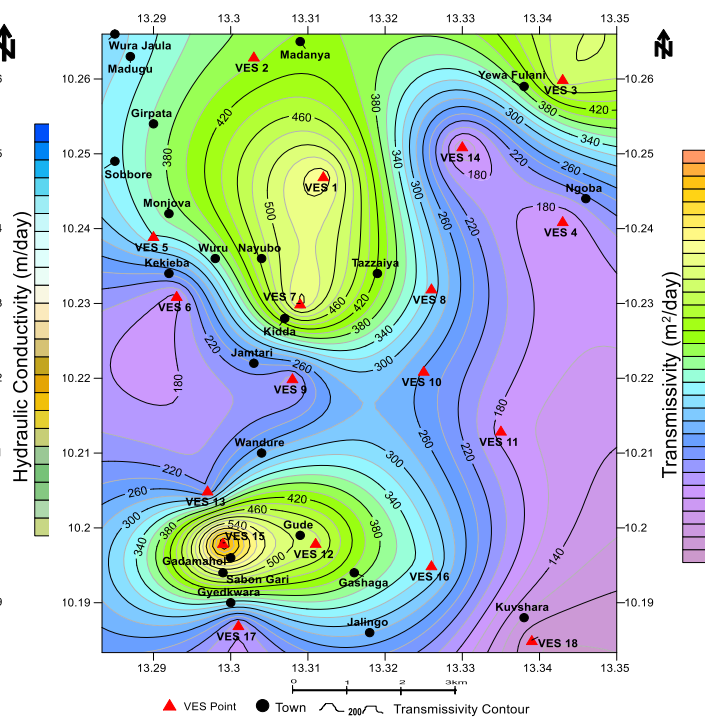

Fig. 8. Aquifer transmissivity contour map (contour interval 20 m^2/day).

V. CONCLUSION

The information gathered from the qualitative and quantitative interpretation of the eighteen Vertical Electrical Soundings in the study area revealed that most of the curves in the study area are of H-type. The quantitative and qualitative interpretation of the Soundings has helped in delineating the depth to the basement in the study area.

The Groundwater potentials of the area from analysis and interpretation of the resistivity data found that the third layer is the weathered/fractured basement and as such they are potentially viable zones for Groundwater development and suitable for drilling borehole. Based on Dar-Zarrouk parameters and Longitudinal Conductance/Protective Capacity Ratings; 39 % showed good protective capacity, 55.5% as moderate capacity, while 5.5% showed weak protective capacity of the overburden materials. Hydraulic conductivity values determined range from 6.06 to 48.55 m/day with an average value of 17.15 m/day. Transmissivity values obtained from VES method for potential aquifers range between 82.21 to 697.26 m^2/day with an average of 318.75 m^2/day. Therefore, the high transmissivity values observed in the south and northern parts of the area indicates high groundwater potential zones.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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