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RESEARCH PAPER

Geoelectrical Investigation For Groundwater Potential and Aquifer Protective Capacity of Overburden Units at Unions Site, Gidankwano Campus, Federal University of Technology, Minna, North Central, Nigeria

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ABSTRACT

Evaluation of groundwater potential was carried out at Northern part of Gidan kwano campus, Federal University of Technology, Minna. Schlumberger electrode configuration was adopted with maximum current electrode spacing (AB/2) of 100 m. The profile separations of 100 m with inter vertical electrical soundings (VES) point spacing of 100 m. Total of sixty (60) vertical electrical soundings station were covered. The interpretation revealed three distinct geologic layers. These include topsoil with resistivity values between 11.41 and 1009 ohm-m and thickness is relatively thin and ranges between 1 and 6m, The weathered/fractured layer has resistivity values from 11 to 963ohm-m with thickness from1 to 45m indicate high degree of weathered/fracture and/or water saturation, The fresh basement has resistivity values that range between12 and 2983 ohm-m. All the soundings 3-layered and characterised by A, H and Q curve types. The area was categorised into high, medium and low groundwater potential zones. Twenty five (25) VES points were delineated as ground water zones having weathered/fractured resistivity varies between 100 and 963 Ωm and thickness ranging from 5 – 45m. The characteristic longitudinal unit conductance from 0.01 to 1.84 mhos. About 30% of the VES points fall within the good rating suggesting generally poor overburden protective capacity around the study area.

Keywords: overburden protective capacity, groundwater potential, vertical electrical sounding, longitudinal unit conductance

INTRODUCTION

The Federal University of Technology is located 14 km along Minna- Kataeregi - Bida Road with 10, 650 hectares of land, the study area is located between latitudes 09^0 27'N and 09^0 32'N and longitudes 06^0 23' and 06^0 27'E (Figure 1)

The successful exploration of basement terrain ground water requires a proper understanding of the characteristics of the aquifer units in relation to its environmental susceptibility. This is particularly important of the discontinuous (localized) nature of the basement aquifers, (Satpatty and Kanugo, 1976 & Abiola *et al*; 2009). The method has been extensively used in groundwater investigation in the basement complex terrains of Africa (Barongo and Palacky 1991; Olayinka and Olorunfemi, 1992; Olorufemi et al., 1993, & Abiola *et al*; 2009) and also in the sedimentary basins (DeBeer and Blume, 1985; Mbonu et al., 1991; Shemang, 1993, & Abiola *et al*; 2009).

The basement complex rocks are inherently characterized by low porosity and near negligible permeability. The highest groundwater yield in basement terrains is found in areas where thick overburden overlies fractured zones. These zones are often characterized by relatively low resistivity values. (Olorunfemi and Fasuyi, 1993). However, groundwater occurs either in the weathered mantle or in the joints and fractured system in the unweathered rocks (Olorunfemi and Olorunniwo, 1985; Olayinka and Olorunfemi, 1992).

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Ejepu and Olasehinde, (2014) evaluated groundwater potential in the Crystalline Basement of Gidan Kwano Campus, Federal University of Technology, Minna, North Central, Nigeria using Geoelectric Methods. The result show three geologic layers, the top soil (0.2 m to 7.4 m), weathered layer (0.3 m to 58,8 m) and fresh basement, the study area has been found to have a very high potential for groundwater development

Amadi *et al*., (2011) evaluated groundwater potential in Pompo Village, Gidan Kwano, Minna, using geoelectrical method. The result show four geologic layers, the top soil, the weathered layer, the fractured layer and fresh basement. They revealed two types of aquifers which are the weathered and fractured basement aquifer. The aquifer units may have significant groundwater potential.

The growth of any locality depends on the availability of basic infrastructures such as water, electricity, schools, hospital, road and industries among others. A general case of northern Nigeria where the amount of rainfall is limited to very few months of the year with annual rainfall of about 1000-1500 mm (Eduvie, 1998).

Geology of the Study Area

The Minna area falls within the larger north. The rocks of the area are mostly crystalline rocks consisting of Gneisses and Migmatites, and Meta-Sedimentary Schist (Mccury 1976). The area is thus under layed by two lithological units of Granites and Gneisses with Pegmatite's and quartz veins as minor intrusive. The Granites, which cover about 80% of the area, are mostly exposed on the western part of the town. They mostly form high batholiths, which are extensive in size. The Granitic outcrops are highly jointed, fractured, foliated and in some places appear as boulders (Adeniyi, 1985). The second lithological unit, the Gneiss, covers about 20% of the area and occurs to the east of the city.

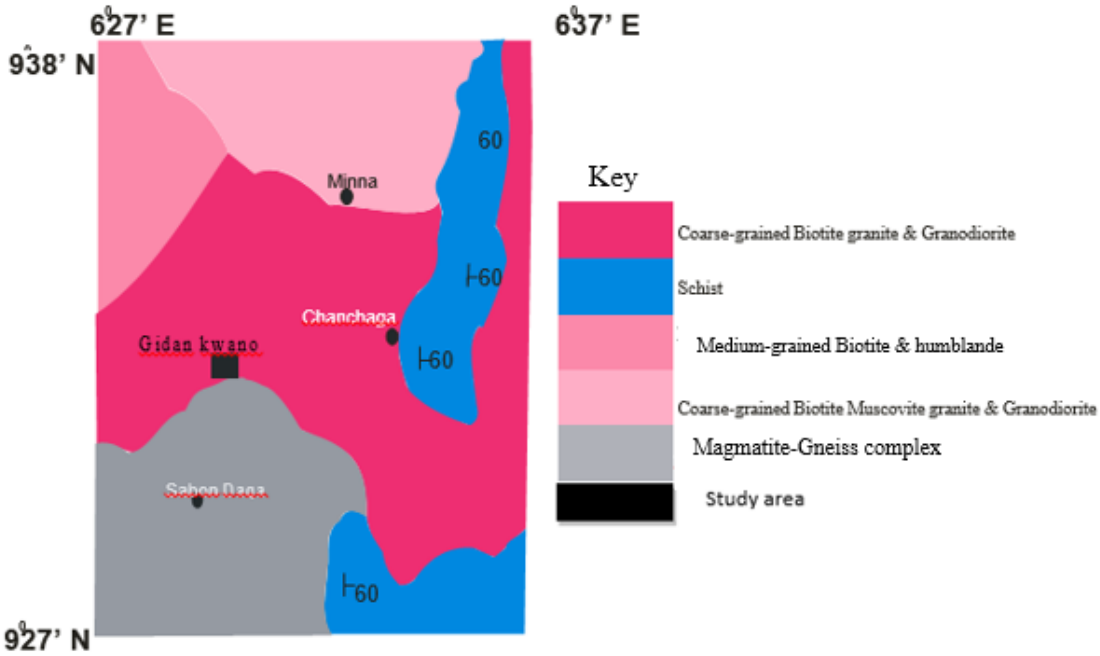


Figure 1: Geological map of the study area (Amadi *et al*. 2011

METHODOLOGY

The data was acquired with the Geosensor Terrameter (Model DDR1), Global Positioning System (GPS) for taking accurate coordinate of the VES points and elevations, Metal Electrodes, Measuring Tape, Labelled Tag (used in locating station position), Hammer (used in driving the electrodes into the ground), Connecting Cables. The Schlumberger array was adopted. The electrode spread of AB/2 was varied from1to a maximum of 100m. Sounding data were presented as sounding curves, by plotting apparent resistivity against AB/2. The electrical resistances obtained were multiplied by the corresponding geometric factor (k) for each electrode separation to obtain the apparent resistivity.

$$R = \frac{V}{I} \tag{1}$$

where R is the resistance and equation 1is written as

$$\rho = kR \tag{2}$$

$$k = \pi \frac{\left[\left(\frac{AB}{2}\right)^2\right] - \left[\left(\frac{MN}{2}\right)^2\right]}{2\left(\frac{MN}{2}\right)} \tag{3}$$

where AB is the current electrode spacing and MN is the potential electrode spacing. The apparent resistivity obtained was used for computer iteration to obtain the true resisitivity and thickness of the layers. Computer-generated curves were compared with corresponding field curves by using a computer program"IP2WIN" surfer 11 was used to produce the contour and longitudinal conductance maps.

The aquifer protective capacity characterisation is based on the values of the longitudinal unit conductance of the overburden rock units in the area. The longitudinal layer conductance (S) of the overburden at each station was obtained from the equation (4):

$$S = \sum_{i=1}^{n} \frac{hi}{\rho i} \tag{4}$$

Where hi is the layer thickness, ρi is the layer resistivity while the number of layers from the surface to the top of aquifer varies from I = n. Where the longitudinal unit conductance values is greater than 0.7 mhos, the layers are adjudged zones of good protective capacity. The portion where the conductance value ranges between 0.2 and 0.69 mhos is classified as zones of moderate protective capacity. The zones which have conductance value ranging from 0.1 and 0.19 mhos is classified as zones of weak protective capacity and where it is less than0.1 mhos is considered as poor aquifer protective capacity (Abiola*et al;* 2009).

Table 1: Longitudinal conductance/aquifer protective capacity rating (Abiola *et al*; 2009)

Longitudinal conductance (mhos)	Aquifer protective capacity rating
> 10	Excellent
5 – 10	Very good
0.7 - 4.49	Good
0.2 - 0.69	Moderate
0.1 - 0.19	Weak
< 0.1	Poor

According to Olorunfemi and Olorunniwo (1985), Idornigie and Olorunfemi (1992), Olayinka and Olorunfemi (1992) & Abiola *et al*; (2009), it is possible to classify the curve types into four distinct classes as follows: Class1type curve, represents a subsurface condition in which there is an increase in resistivity values from the top soil to the basement rock, example is the A-type curve. In class 2 curve types, the upper horizons when not leached are usually clayey and of low resistivity. Immediately underlying this usually low resistivity high porosity, low specific yield and low permeability aquiferous zone is the fresh basement. This classic architecture of the profile produces an H-type curve signature, which is found to be most preponderant in the area. Curve types of class 3 are typical of a succession of relatively low and high resistivity layers. The K type is found where a highly resistive lateritic layer underlies low resistivity clayey top soil and weathered zone in turn underlies the former. Or it may result from where the basement, fractured at depth, underlies the topsoil. In the curve type in class4, the succession of the subsurface layers starts with a highly low top soil followed by a more conductive horizon and then another less conductive layer underlies the latter example is the KH-type curve.

The observed thickness and nature of the weathered/fractured layer are important parameters in the groundwater potential evaluation of a basement complex terrain (Clerk, 1985; Bala and Ike, 2001 & Abiola *et al;* 2009). The horizon is also regarded as a significant water bearing layer (Shemang, 1993; Bala and Ike 2001, & Abiola *et al*; 2009) especially if significantly thick and the resistivity parameters suggest saturated conditions.

Curve Types

The (table 2) shows the relationship between Curvetype and Layers resistivity which was used to determine the curve types in the research.

Table 2: Modified Classification of Curve Ttypes/Curve type Layers Resistivity Relationship (Abiola*et al*; 2009)

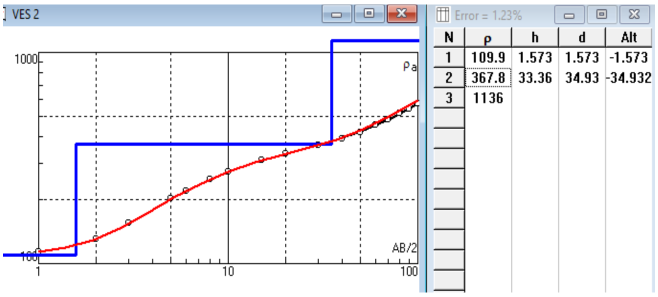
Classification of curve types.	Curve type Layer's resistivityrelationship
A	$\rho1 < \rho2 < \rho3$
H	$\rho1 > \rho2 < \rho3$
Q	$\rho1 > \rho2 > \rho3$
K	$\rho1 < \rho2 > \rho3$
QA	$\rho1 > \rho2 > \rho3 < \rho4$
HA	$\rho1 > \rho2 < \rho3 < \rho4$
HK	$\rho1 > \rho2 < \rho3 > \rho4$
KH	$\rho1 < \rho2 > \rho3 < \rho4$
AA	$\rho1 < \rho2 < \rho3 < \rho4$
HKH	$\rho1 > \rho2 < \rho3 > \rho4 < \rho5$
AKH	$\rho1 < \rho2 < \rho3 > \rho4 < \rho5$
AKHA	$\rho1 < \rho2 < \rho3 > \rho4 < \rho5 < \rho6$

ρ - Resistivity

RESULTS AND DISCUSSION

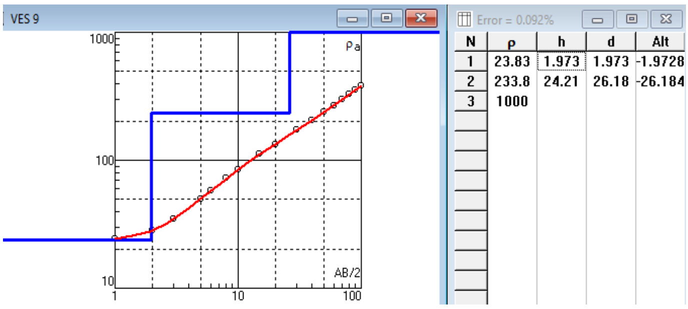
The result of 60 VES locations were summerised and presented in tables 3.

The interpretation assessed the prevalent curves in the study area, determined the geoelectric properties of the subsurface layers and delineated the aquifers in terms of the thickness, presence of suitable aquifer (weathered and fractured basement), and the conductivity of the subsurface. The nature of the overburden cap rock was also assessed. The results presented in form of tables, curves,and iso-resistivity maps.



N	ρ	h	d	Alt
1	109.9	1.573	1.573	-1.573
2	367.8	33.36	34.93	-34.932
3	1136			

Figure 2a: Geoelectric section for VES A_2.



N	ρ	h	d	Alt
1	23.83	1.973	1.973	-1.9728
2	233.8	24.21	26.18	-26.184
3	1000			

Figure 2b: Geoelectric section for VES A_9.

Table 3a: Summary of interpreted result of the study area

VES	Layer resistivity (Ohm-m)			Layer thickness (m)			Layer depth (m)			Longitudinal Conductance (S)	Aquifer Protective	Curve
Station	ρ_1	ρ_2	ρ_3	h_1	h_2	h_3	d_1	d_2	d_3	(mhos)	Capacity	type
A1	138	347	1072	1.29	40.03	∞	1.29	41.32	∞	0.12	Weak	A
A2	109.9	367.8	1136	1.573	33.36	∞	1.573	34.93	∞	0.11	Weak	A
A3	51.66	404.2	1231	1.486	13.55	∞	1.486	15.04	∞	0.06	Poor	A
A4	82.8	322.2	8068	1.302	3.139	∞	1.302	4.442	∞	0.01	Poor	A
A5	49.74	208.8	40343	5.72	5.83	∞	5.72	11.55	∞	0.14	Weak	A
A6	81.25	647.9	5654	3.11	31.2	∞	3.11	34.31	∞	0.09	Poor	A
A7	57.85	557.1	1099	1.829	24.85	∞	1.829	26.68	∞	0.07	Poor	A
A8	163	32.7	2383	1.64	2.719	∞	1.64	4.359	∞	0.09	Poor	H
A9	23.83	233.8	1000	1.973	24.21	∞	1.973	26.18	∞	0.18	Weak	A
A10	367.8	121.9	1012	1.254	1.128	∞	1.254	2.383	∞	0.01	Poor	H
B1	304.5	29.32	623.9	4.974	18.41	∞	4.974	23.38	∞	0.65	Moderate	H
B2	589.5	411.9	2010	1.129	23.15	∞	1.129	24.28	∞	0.06	Poor	H
B3	662.5	103.8	1000	1.829	23.39	∞	1.829	25.22	∞	0.22	Moderate	H
B4	523.4	106	965.7	1.231	2.378	∞	1.231	3.609	∞	0.02	Poor	H
B5	698.7	127.8	1163	2.474	27.98	∞	2.474	30.45	∞	0.22	Moderate	H
B6	358.7	256.5	1000	1.468	2.811	∞	1.468	4.279	∞	0.01	Poor	H
B7	389.1	20.35	828	1.973	11.55	∞	1.973	13.53	∞	0.58	Moderate	H
B8	45.26	176.2	1019	2.383	13.65	∞	2.383	16.03	∞	0.13	Weak	A
B9	262.2	100	20469	1.332	27.15	∞	1.332	28.48	∞	0.29	Moderate	H
B10	216.8	176.8	1136	1.9	32.85	∞	1.9	34.75	∞	0.19	Weak	H
C1	573	112.3	1000	1.486	11.54	∞	1.486	13.02	∞	0.11	Poor	H
C2	470.5	107.8	1177	1.573	34.89	∞	1.573	36.46	∞	0.33	Moderate	H
C3	200.3	104.4	1078	1.327	1.718	∞	1.327	3.045	∞	0.17	Weak	H
C4	272.9	116.3	812.5	1.696	2.051	∞	1.696	3.747	∞	0.02	Poor	H
C5	418	250.6	341.1	1.556	1.498	∞	1.556	3.054	∞	0.01	Poor	H
C6	293.2	414.3	6717	2.483	30.52	∞	2.483	33	∞	0.08	Poor	A
C7	272.9	116.3	1000	1.696	25.49	∞	1.696	27.19	∞	0.23	Moderate	H
C8	179.5	118.5	29838	2.168	37.49	∞	2.168	39.66	∞	0.32	Moderate	H
C9	256.1	111	782.4	1.431	2.316	∞	1.431	3.747	∞	0.03	Poor	H
C10	269.1	105.8	981.3	1.431	12.61	∞	1.431	14.05	∞	0.12	Weak	H
D1	444.2	567.7	876.3	1.254	28.63	∞	1.254	29.88	∞	0.05	Poor	H
D2	1009	228.4	17600	2363	16.4	∞	2.363	18.76	∞	0.07	Poor	H
D3	204.3	658.9	8675	1.367	37.77	∞	1.367	39.13	∞	0.06	Poor	A
D4	382.6	261	932.6	3.541	18.51	∞	3.541	22.05	∞	0.08	Poor	H
D5	709.3	329.7	4706	3.535	11.05	∞	3.535	14.59	∞	0.04	Poor	H
D6	804.5	19.79	1431	1.459	3.242	∞	1.459	4.701	∞	0.17	Weak	H
D7	513.8	109.9	893	2.389	31.08	∞	2.389	33.47	∞	0.29	Moderate	A
D8	1407	197.8	5995	6.486	37.37	∞	6.486	43.86	∞	0.19	Weak	H
D9	11.41	282.4	1405	4.721	26.31	∞	4.721	31.03	∞	0.5	Moderate	H
D10	753.5	100	963	4.721	15.77	∞	4.721	20.49	∞	0.16	Weak	H

Table 3b Summary of interpreted result of the study area

VES	Layer resistivity (Ohm-m)			Layer thickness (m)			Layer depth (m)			Longitudinal Conductance (S)	Aquifer Protective	Curve
Station	ρ_1	ρ_2	ρ_3	h_1	h_2	h_3	d_1	d_2	d_3	(mhos)	Capacity	type
E1	427.7	113.6	6987	1.696	1.023	∞	1.696	2.719	∞	0.01	Poor	H
E2	299.4	19.08	725.6	1.548	2.729	∞	1.548	4.277	∞	0.15	Weak	H
E3	378.3	109.9	1060	4.042	26.85	∞	4.042	30.89	∞	0.26	Moderate	H
E4	230.3	963	4974	2.757	25.48	∞	2.757	28.24	∞	0.04	Poor	A
E5	225.7	130.2	1110	1.292	27.63	∞	1.292	28.92	∞	0.22	Moderate	H
E6	739.4	121.9	1000	1.936	39.39	∞	1.936	41.33	∞	0.33	Moderate	H
E7	526.4	225.1	900.6	1.795	2.103	∞	1.795	3.898	∞	0.01	Poor	H
E8	393.2	114.1	1012	2.78	20.16	∞	2.78	22.94	∞	0.18	Weak	H
E9	369.4	13.21	7315	1.668	20.3	∞	1.668	21.97	∞	1.54	Good	H
E10	56.77	11.93	93.26	1.544	1.272	∞	1.544	2.816	∞	0.13	Weak	H
F1	503.5	116.3	1038	1.795	25.71	∞	1.785	27.51	∞	0.23	Moderate	H
F2	283.1	14.31	1000	1.573	2.105	∞	1.573	3.678	∞	0.15	Weak	H
F3	283.1	151.5	927.3	1.573	30.05	∞	1.573	31.62	∞	0.2	Weak	H
F4	713.7	151.5	1024	4.588	16.35	∞	4.588	20.94	∞	0.11	Weak	H
F5	50.55	20.94	12.33	1.532	37.91	∞	1.532	39.44	∞	1.84	Good	Q
F6	347.5	44.89	1019	1.532	44.89	∞	1.532	46.45	∞	0.43	Moderate	H
F7	230.7	112.3	965.7	1.327	1.496	∞	1.327	2.823	∞	0.02	Poor	H
F8	230.7	380.4	965.7	1.22	35.56	∞	1.22	36.78	∞	0.09	Poor	A
F9	303.6	140.1	820.6	4.012	11.37	∞	4.012	15.3	∞	0.09	Poor	H
F10	369.8	112	6122	1.576	1.819	∞	1.576	3.395	∞	0.02	Poor	H

Iso-Resistivity Contour Maps at Various Layers

The Iso- resistivity maps were generated for the layers in order to investigate the resistivity variation beneath the sounding locations. The layer were contoured by surfer 11.0 All the values for each layer were picked corresponding to the inter grid/profile distance before moving to the next layer. The process was repeated until the entire area was contoured. The contoured maps for first layer, second layer and third layer show the conductivity pattern through slicing of the whole study area horizontally.

Iso-Resistivity Contour Maps at first layer

At first layer the map show relatively high resistivity values at the north eastern part, which indicate /outcrop of fresh basement with resistivity values of about 1000 Ωm and 1400 Ωm (figure 3a). The highest resistivity values at first layer were recorded around VES D$_7$.

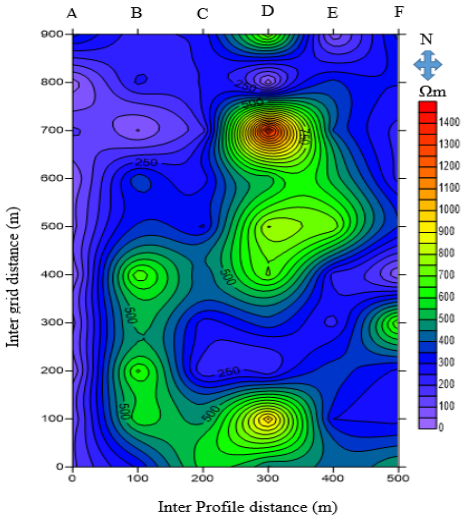


Figure 3a: Iso Resistivity contour map of the area at first layer

Iso-Resistivity Contour Maps at second layer

At second layers the resistivities are lower than at first layer which show decrease in resistivity downwards. This could have resulted from the presence of water saturated geologic formations (figure 3b). However, relatively high resistivity values were recorded at the south eastern part of the study area around VES E_3.

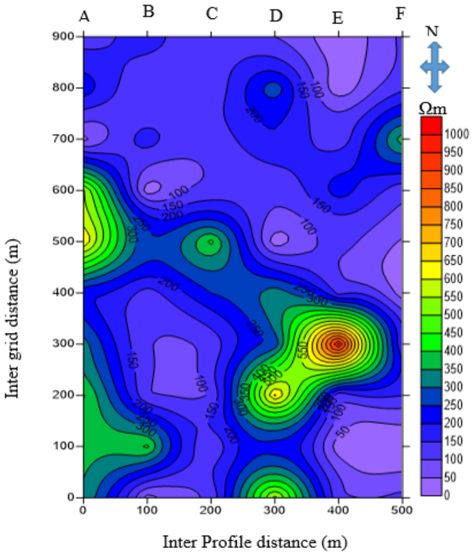


Figure 3b: Iso Resistivity contour map of the area at second layer

Iso-Resistivity Contour Maps at third layer

At third layer the resistivity values are very high throughout the study area which is an indication of fresh basement (figure 3c). The resistivity values of about 1000 Ωm and 42000 Ωm were recorded in the study area.

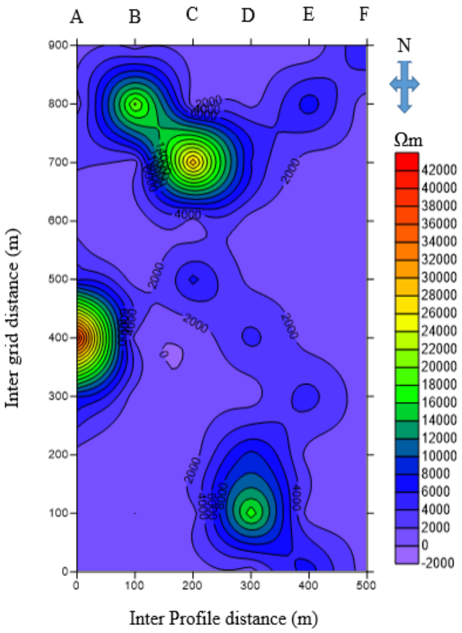


Figure 3c: Iso Resistivity contour map of the area at third layer

Groundwater Potential Evaluation

Zones where thickness of the aquifer is greater than 25 m and with low clay content (average resistivity values between100 and 300ohm-m) are considered zones of high groundwater potentials (Abiola *et al*., 2009).

The north central and south western parts of the study area constitute the high potential zones.

The extreme northern, east central and southern patches, which have aquifer thickness ranging from10–25m with moderate clay contents (average resistivity values lies between 80 -100ohm-m), are classified under medium groundwater potential (Abiola *et al*., 2009).The south and the east central portions of the study area fall within the low groundwater potential rating, where the thickness of aquifer is below 10m and with average resistivity value less than 80ohm-m (Abiola *et al*., 2009). It was observed that about 35% of the area falls within the low groundwater potential rating while about 65% constitutes the high/medium potential rating. This suggests a generally high groundwater prospect of the study area.

Table 4: VES delineated for aquifer potential

VES	Layer resistivity (Ohm-m)			Layer thickness (m)			Layer depth (m)			Longitudinal Conductance (S)	Aquifer Protective
Station	ρ_1	ρ_2	ρ_3	h_1	h_2	h_3	d_1	d_2	d_3	(mhos)	Capacity
A1	138	347	1072	1.29	40.03	∞	1.29	41.32	∞	0.12	Weak
A2	109.9	367.8	1136	1.573	33.36	∞	1.573	34.93	∞	0.11	Weak
A6	81.25	647.9	5654	3.11	31.2	∞	3.11	34.31	∞	0.09	Poor
A7	57.85	557.1	1099	1.829	24.85	∞	1.829	26.68	∞	0.07	Poor
B2	589.5	411.9	2010	1.129	23.15	∞	1.129	24.28	∞	0.06	Poor
B5	698.7	127.8	1163	2.474	27.98	∞	2.474	30.45	∞	0.22	Moderate
B9	262.2	100	20469	1.332	27.15	∞	1.332	28.48	∞	0.29	Moderate
B10	216.8	176.8	1136	1.9	32.85	∞	1.9	34.75	∞	0.19	Weak
C2	470.5	107.8	1177	1.573	34.89	∞	1.573	36.46	∞	0.33	Moderate
C6	293.2	414.3	6717	2.483	30.52	∞	2.483	33	∞	0.08	Poor
C7	272.9	116.3	1000	1.696	25.49	∞	1.696	27.19	∞	0.23	Moderate
C8	179.5	118.5	29838	2.168	37.49	∞	2.168	39.66	∞	0.32	Moderate
D3	204.3	658.9	8675	1.367	37.77	∞	1.367	39.13	∞	0.06	Poor
D4	382.6	261	932.6	3.541	18.51	∞	3.541	22.05	∞	0.08	Poor
D7	513.8	109.9	893	2.389	31.08	∞	2.389	33.47	∞	0.29	Moderate
D8	1407	197.8	5995	6.486	37.37	∞	6.486	43.86	∞	0.19	Weak
D9	11.41	282.4	1405	4.721	26.31	∞	4.721	31.03	∞	0.5	Moderate
E3	378.3	109.9	1060	4.042	26.85	∞	4.042	30.89	∞	0.26	Moderate
E5	225.7	130.2	1110	1.292	27.63	∞	1.292	28.92	∞	0.22	Moderate
E6	739.4	121.9	1000	1.936	39.39	∞	1.936	41.33	∞	0.33	Moderate
E8	393.2	114.1	1012	2.78	20.16	∞	2.78	22.94	∞	0.18	Weak
F1	503.5	116.3	1038	1.795	25.71	∞	1.785	27.51	∞	0.23	Moderate
F3	283.1	151.5	927.3	1.573	30.05	∞	1.573	31.62	∞	0.2	Weak
F6	347.5	44.89	1019	1.532	44.89	∞	1.532	46.45	∞	0.43	Moderate
F8	230.7	380.4	965.7	1.22	35.56	∞	1.22	36.78	∞	0.09	Poor

Evaluation of Aquifer Protective Capacity

The earth medium acts as a natural filter to percolating fluid. Its ability to retard and filter percolating ground surface polluting fluid is a measure of its protective capacity (Olorunfemi *et al.*, 1999 and Abiola *et al.*, 2009). The highly impervious clayey overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underlying aquifer. The longitudinal unit conductance (S) values obtained from the study area from 0.01 to 1.54mhos (figure 3). About 30% of the area falls within the good/moderate rating and 70% revealed weak/poor rating.

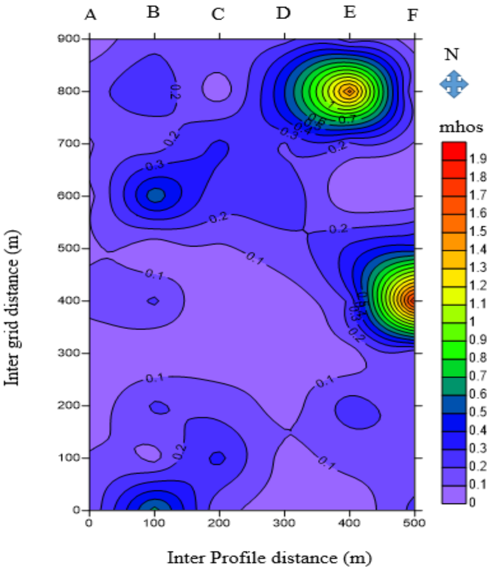


Figure 4. Contour map of longitudinal conductance distribution of the study area

Conclusion

The groundwater potential and protective capacity evaluation of the rock units around Gidan kwano, was undertaken using 60 vertical electrical soundings (VES). The curve types are simple three-layer A, H and Q-types. The computer assisted sounding interpretation revealed subsurface sequence composing top-soil with limited hydrologic significance, weathered/fractured basement and the fresh basement. The weathered/fractured layer constituted the aquifer in the area; the yield being dependent on degree of the clay content. The lower the clay content, the higher the groundwater yield. About 35% of the study area falls within the low rated groundwater potential zone while the remaining 65% constituted the high/medium groundwater potential zone. Hence, the groundwater potential rating of the area is considered generally high. Twenty five (25) VES stations were delineated as aquifer potential of the area (table 4)

The study also revealed parts of the area are underlain by materials of moderate to good protective capacity. The central and south western portions of the area are underlain by materials of moderate to good protective capacity. The groundwater in the area of weak/poor protective capacity is therefore vulnerable to pollution. Vulnerable zones include the east central, southern and northern segments.

Recommendations

The area delineated as groundwater potential should be considered for drilling borehole.

Areas with weak/poor protective capacity should be avoided for borehole development.

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