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Integrated Geophysical Techniques for Groundwater Exploration in Karlahi, Northeastern, Nigeria

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Abstract
Karlahi is underlain by (3) lithological units and are clearly demarcated by topographic forms, and in most cases reflect the geology of the underlying rocks which are basically coarse grained granite, medium grained granite and banded gneiss. The study was aimed at delineating groundwater potential zones in Karlahi, Northeast Nigeria by integrating electromagnetic method (EM), vertical electrical sounding and borehole logging techniques. Ten (10) EM profiles of 200 m lengths were conducted at 20 m coil separation using EM 34 - 3 meter/device, perpendicular to tectonic structures of the area. The result revealed sandy clay and weathered basement with relatively low to high conductivity values. The locations with the highest conductivity values of vertical dipole with 30m penetration were used to conduct 30 Vertical Electrical Soundings (VES) using Schlumberger electrode configuration. The VES results revealed 4 layers, the first layer is sandy clay with thickness ranging from 0.812 to 5.92 m and resistivity values between 21.18 to 303.5 Ωm, the second layer a weathered basement with thicknesses from 12.51 to 27.86 m and resistivity values ranging from 10.15 to 1669.9 Ωm, the third layer a slightly weathered basement with thicknesses of 24.49 to 37.98 m and resistivity values ranging from 14.18 to 7063.4 Ωm. The fourth layer a fresh basement environment has resistivity values ranging from 342 to 9811 Ωm. Potential aquifer units in the area have been delineated into upper highly weathered and lower slightly weathered layers. The thickness of the highly weathered layers range from 9 to 18.41 m with an average of 13.7 m. While that of the slightly weathered range from 13 to 50 m with an average of 31.5 m. The highly weathered and slightly weathered basement aquifer units are unconfined and should be exploited for groundwater development. It is recommended that 35 to 50% of the total thickness of the highly weathered and slightly weathered formations should be screened in borehole projects for optimal borehole water yields and the borehole should be cased to the bottom.

Keywords: *Electromagnetic, Vertical Electrical Sounding, Groundwater potential, Basement Complex and Borehole.*

Introduction

Karlahi is topographically regarded as low lying with about 80% of the entire area being at less than 300m above sea level, while the remaining 20% are more elevated hills and mountains (Fufore Local Government Area, 2013). The communities depend on surface and few ground water sources. The sources include streams, ponds and lakes which are not safe for drinking and domestic use. Villagers will have to travel long distance in search of clean sources. Groundwater is obtained from hand-dug wells and isolated boreholes in the area (Ishaku, et al., 2010). Lack of integrated geophysical investigation for groundwater exploration result in drilling of boreholes with low yield or abortive (Oladunjoye, 2019). Geophysical investigation methods/techniques have proved useful in groundwater exploration (Hubbard and Rubin, 2006): According to Maheswari, et al., (2013) integrated geophysical techniques are more reliable for delineating water bearing zones most especially in basement complex terrain. The aim of this study is to delineate groundwater bearing zones in Karlahi area using integrated geophysical techniques and borehole logs. An integrated study will improve the knowledge of the aquifer geometry and at least reduce abortive boreholes in the area and save the communities from wasting their resources in drilling low yield or abortive boreholes.

Electromagnetic (EM) surveys are suitable for locating conductive materials such as weathered basement and are useful for delineating potential area for carrying out vertical electric sounding (VES) survey. EM geophysical survey is based on propagation of electromagnetic field which on encounter with conductive material generate eddy field secondary current as a result of passing alternating electromagnetic energy through coils of wires (Telford, et al., 1990). The use of EM technique is now popular in groundwater prospecting especially in the Basement Complex terrain (Olurunfemi, et al., 2005). Karlahi is located between latitudes 8°48′N to 8°58′ N and longitudes 12°30′ E to 12°38′ E (Fig.1).

The primary objective of geophysical survey methods in groundwater exploration is to locate sub surface material that are electrically conductive (Omeje, et al., 2015). The electrical resistivity methods have been recognized to be more appropriate for hydrogeological studies. In the recent past, electromagnetic depth sounding, which is based on the measurement of the variation of conductivity with depth at a variety of

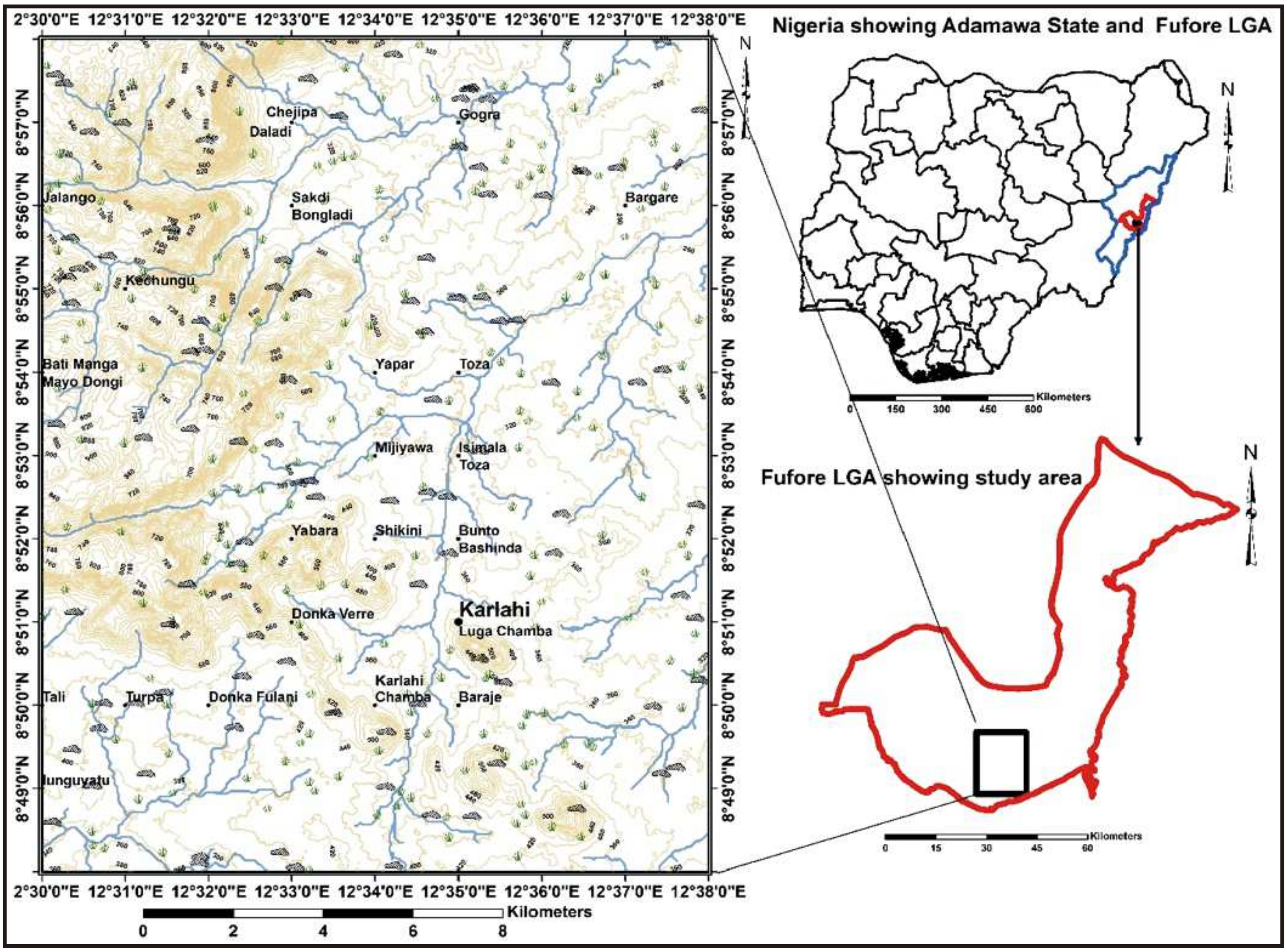

Fig. 1: Karlahi and Environs (NGSA, 2006)

frequencies, has become an important tool for groundwater exploration in sub Saharan African countries (Nimmagadda and Ochad, 2016). Also Vertical Electrical Soundings is one of the geophysical methods widely used for groundwater exploration in sub-saharan Africa (Anomohanran, 2013). The fundamental reason for its wide use is because of its ease in field procedure and relatively simple data interpretation (Anomohanran, 2015).

Geology of Karlahi Area

Geological mapping of the area was carried out on a scale of 1:50,000 and this contributed in understanding the geology and interpretation of the geophysical data in the study area. Karlahi is underlain by (3) lithological units, most of these lithological units are clearly demarcated by topographic forms, and in most cases reflect the geology of the underlying rocks. The Older Granite suite which constitutes about 60% of outcrops in the area is the most obvious manifestation of the Pan-African Orogeny in this part of Nigeria and West Africa (Rahaman, 1988). They form prominent features such as boulders, steep-sided craggy tors and sub-elliptical plutons to masses of batholithic dimensions as outcropped around Korkai, Lugga Chamba, Karlahi Chamba, Mamlaipa, Donrupa, Bongladi and Begni communities respectively (Fig. 2). The Older granites range from coarse to medium grained, the coarse grained granite underlies the central part of the study area and north western parts while the medium grained granites underlie the area in the northern part and extending to the western and southern parts of the study area. The banded gneiss underlies the north eastern and extending to the southern parts of the study area. Banded gneisses, quartz dyke and amphibolite form low-lying and in some places flat outcrops are found around Baraje, Belwa Gite, Donkan Vera, Sabon Gari Koma and Kila Sarka communities.

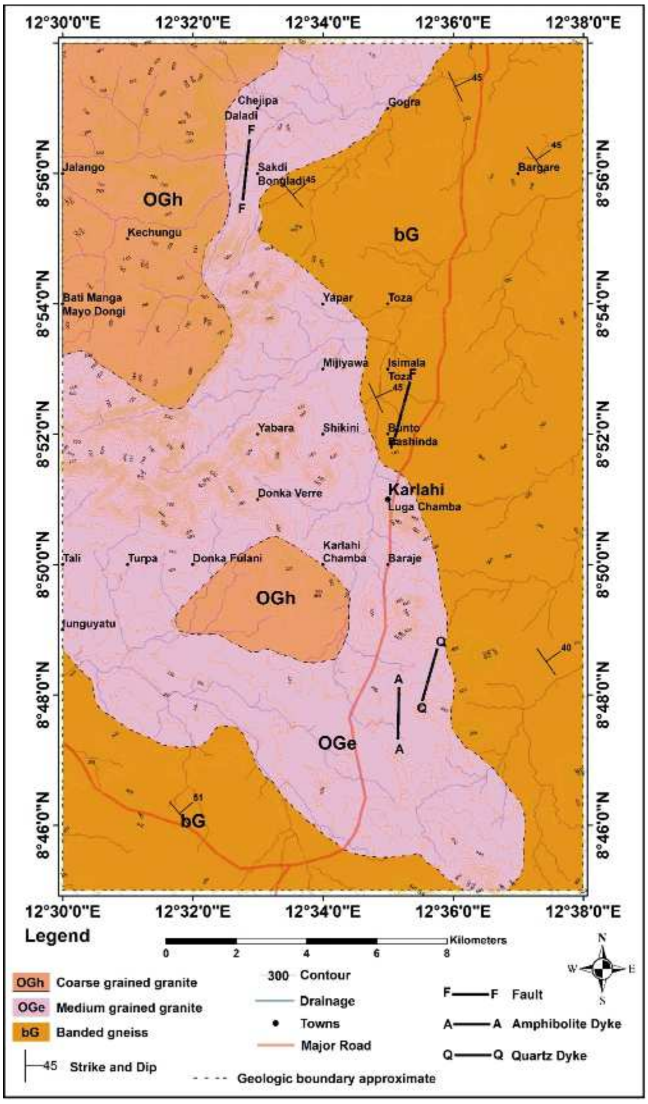

Fig. 2: Geological map of Karlahi (N. G. S. A. 2006)

Materials and Methods

Geonics EM 34-3 equipment was used to acquire the electromagnetic data at 20m coil separation on ten (10) different profiles of 200m length each, for both vertical and horizontal dipoles as shown in Fig. 3, the profiles were taken at perpendicular direction to the regional structures of the area. The stations were taken at 0, 20, 40, 60, 80, and 100…m respectively. The first reading was taken when the transmitter coil Tx is at station 0 while the receiver coil Rx was situated at 20m to obtain the value at σ_a 20, then the receiver coil Rx remained stationary while the transmitter coil Tx is placed at station 40m to obtain σ_a 40, this procedure was done until the whole profile data were recorded. It is therefore, strongly recommended that the value at σ_{an} plotted at every 20m is at the midpoint of Tx/Rx array (McNeil, 1985). The midpoint of the two coils represents the point where measurement was taken for each profile, the unit of measurement was taken in mS/m McNeill, 1980. During the field procedure, the two coils must be aligned in the same direction/position facing each other.

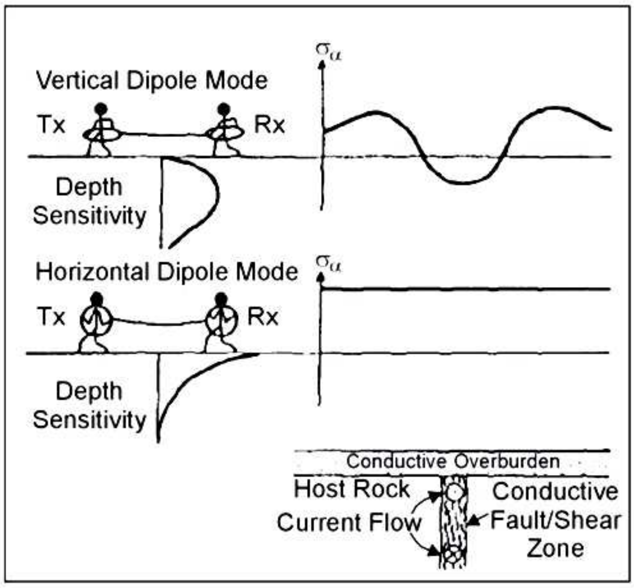

Fig. 3: Field arrangement for vertical and horizontal dipole position in electromagnetic (EM) survey (Geonics Limited 50th Anniversary, 1962-2012)

The dipole positioning gave a significantly different response in respect of depth investigation which is dependent on inter-coil separation of 20m interval. Advantage of frequency sounding in groundwater investigations is based on layer conductivity with depth (Patra and Shastri, 1991).

Electromagnetic surveys use electrical fields within the earth to detect if the geologic materials beneath the surface are good or poor conductors of electricity (McNeil, 1985). The maximum effective depth of investigation with the coils in horizontal conditions (Vertical Dipole Mode) is approximately twice that with the coils in vertical conditions (Horizontal Dipole Mode), being 1.5 times the coil spacing compared with 0.7 times the coil spacing, respectively (Barker, 1999). However, surveys made with the coils horizontal, are much more sensitive to errors in the coils alignment (McNeil, 1985). High conductivities correspond to low resistivities and that apparent conductivity is being measured. Electromagnetic method determines the apparent conductivity (σ_a) which is dependent on coil separation (s), amplitudes of secondary and primary electromagnetic fields (Hs/Hp) and frequency (f) Osinowo, et al., (2018).

$$\sigma_a = \frac{4}{\omega\mu_0} s^{2} \frac{H_s}{H_p} \quad \text{...(1)}$$

Where $\omega = 2\pi f$

In carrying out resistivity sounding surveys, electrodes are distributed along a line, centered about a midpoint that is considered the location of investigation. The instrument used was SYSCAL JUNIOR Resistivity meter. It is a digital system which calculates the voltage by the current and multiplies it by the constant of the electrode separation. Thirty (30) Vertical Electrical Sounding points were conducted for the purpose of this study. Metal electrodes are aligned in a straight line in the order of AMNB with AB $\geq$ 5MN which is commonly known as Schlumberger array and the apparent resistivities were calculated based on the principle derived by Maillet, 1947, Keller and Frischknecht, 1966.

The thickness and resistivity of all the layers were determined within the given spread of AB = 200m which was determined by INTERPEX software (2006). A resistivity model was based on borehole logs, using apparent resistivity and thickness of each layer inputted into the software and iterated to give the resistivity and thickness of the various layers.
A value of apparent resistivity (ρa) is calculated in each distance AB using equation:

$$\rho a = (\Delta V/I)G \qquad (2)$$

Where G = Π (AB/2)2/MN is geometrical factor determined by field array

Borehole logs from drilled wells in the area were collected and correlated with VES results to determine the aquifer units corresponding with the lithological sections. These were achieved by preparing a correlation panel consisting of series of geo - electric sections with corresponding lithological sections from the existing boreholes arranged horizontally in accordance with the spatial distribution on the location map of Karlahi by drawing three profiles trending in different directions and analyzing the correlation outcome in order to achieve the objective of the study.

Results

Electromagnetic Results

Ten (10) Electromagnetic profiles were carried out to determine locations suitable for vertical electrical soundings (VES) in order to delineate potential area for groundwater exploitation. These profiles are presented in Fig. 4 to 13. The VES points were sited directly on areas corresponding to conductive zones identified on the EM profiles. Inferred pseudo sections were created based on the data generated from each electromagnetic profile. The apparent conductivity values recorded across the study area for the 10 profiles with 20 m coil separation and 30 m penetration depth of investigation showed a relatively low to high conductivity values ranging from 4 to 55 mS/m for the vertical dipole and -8 to 29 mS/m for the horizontal dipole. The profiles with lowest value of -3 to -8mS/m for the HD were recorded in Belwa Gite (Fig. 6), Lugga Chamba community (Fig. 7) and Kila Sakra communities (Fig. 13). The highest value of 29 mS/m for the HD and 55 mS/m for the VD were recorded in Toza Gada community (Fig. 9). The communities with the lowest values are situated towards the southern part and the highest situated from the central towards the northern part of the study area. The inferred pseudo-section of each of the EM profile describes the layered lithology based on the interpretation of the vertical dipole data (VD), this is because the VD has greater penetration depth when compared to the HD. The pseudo-sections revealed topsoil/sandy clay and weathered basement. The topsoil ranges in thickness from 0 to 5 m while the weathered basement ranges in thickness from 5 to 29 m.

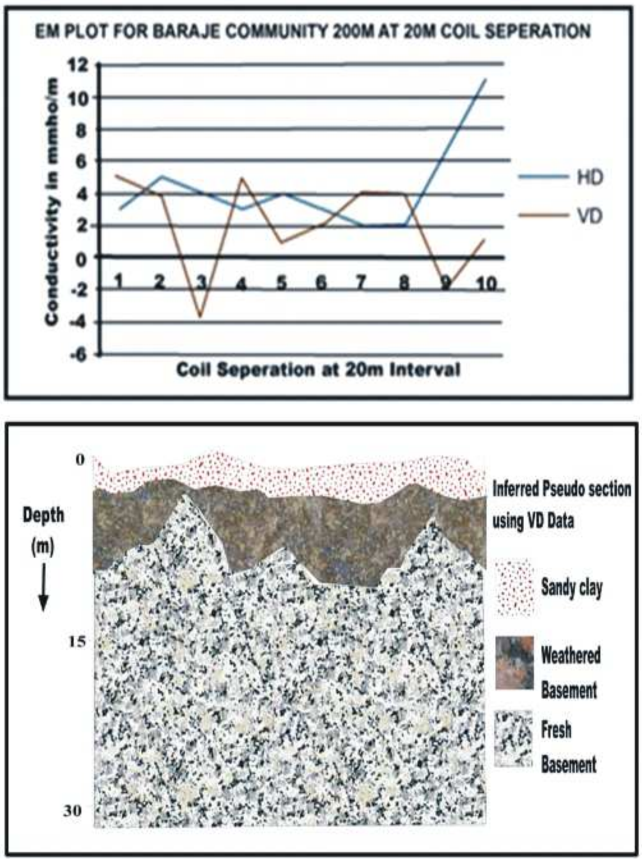

Fig. 4: EM/Geologic section of Baraje

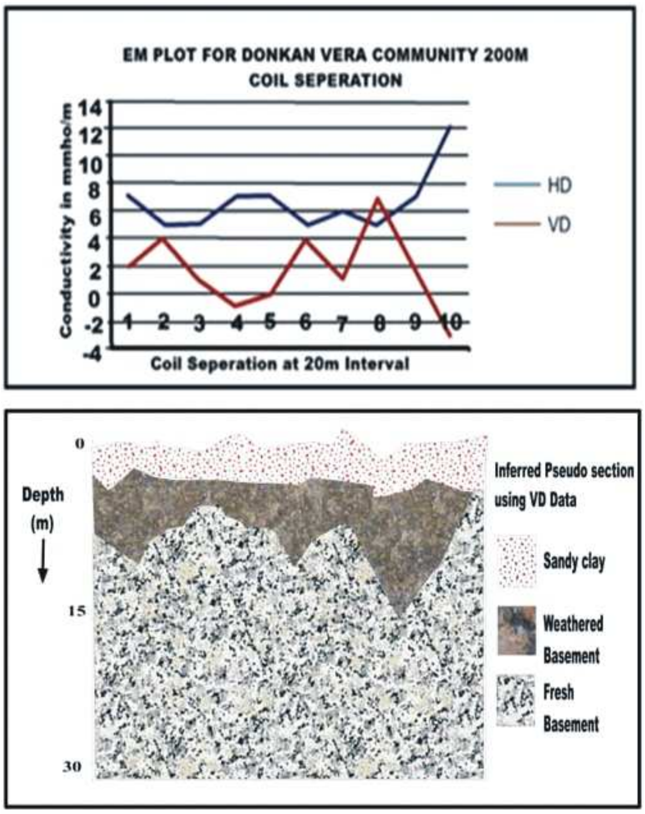

Fig. 5: EM/Geologic section of Donkan

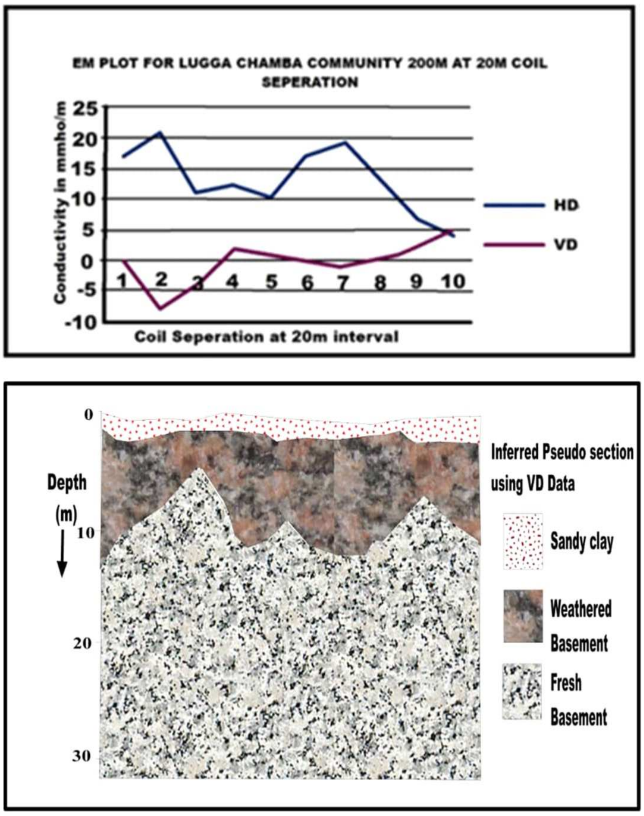

Fig. 7: EM/Geologic section of Lugga Chamba

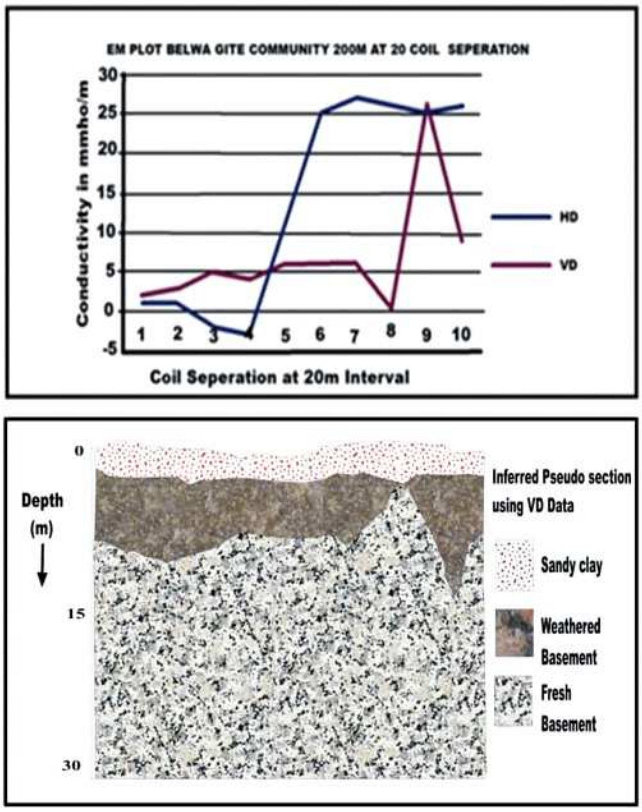

Fig. 6: EM/Geologic section of Belwa

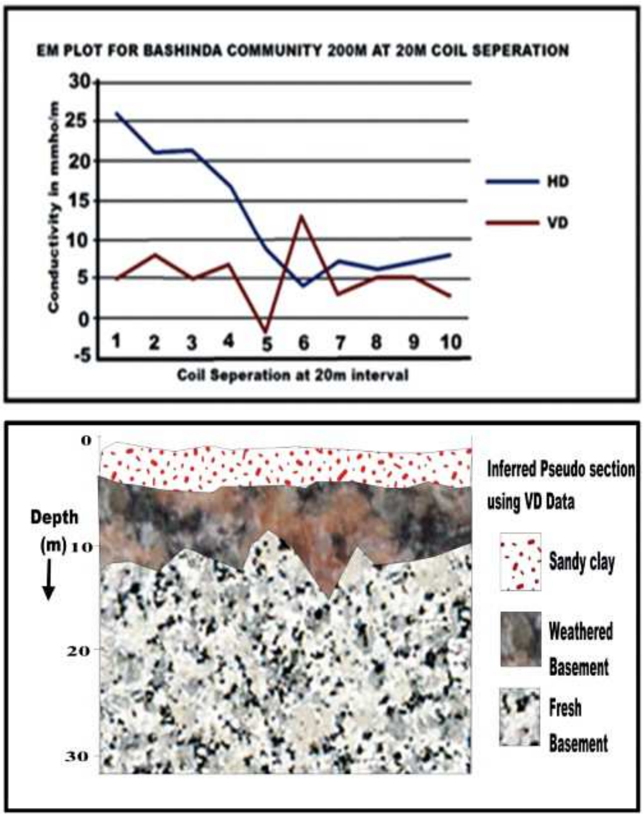

Fig. 8: EM/Geologic section of Bashinda

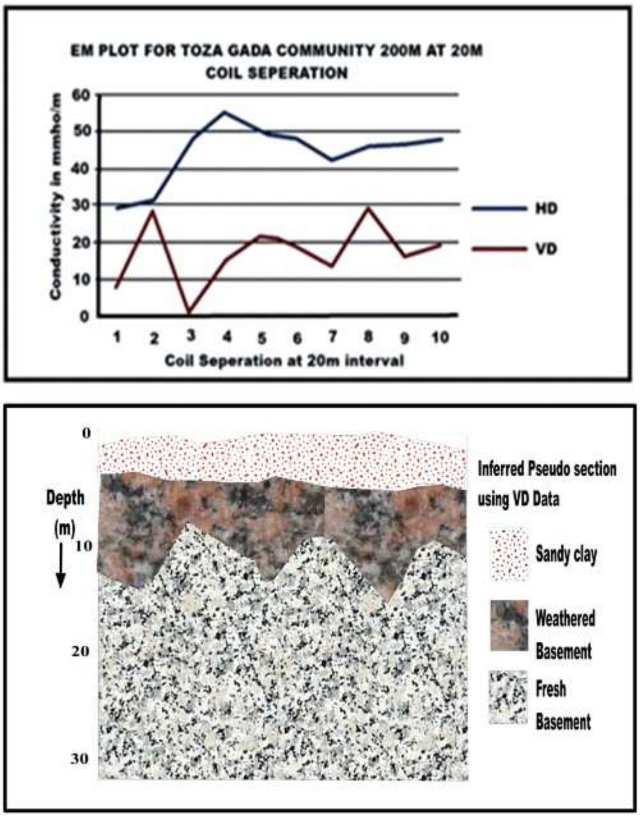

Fig. 9: EM/Geologic section of Toza Gada

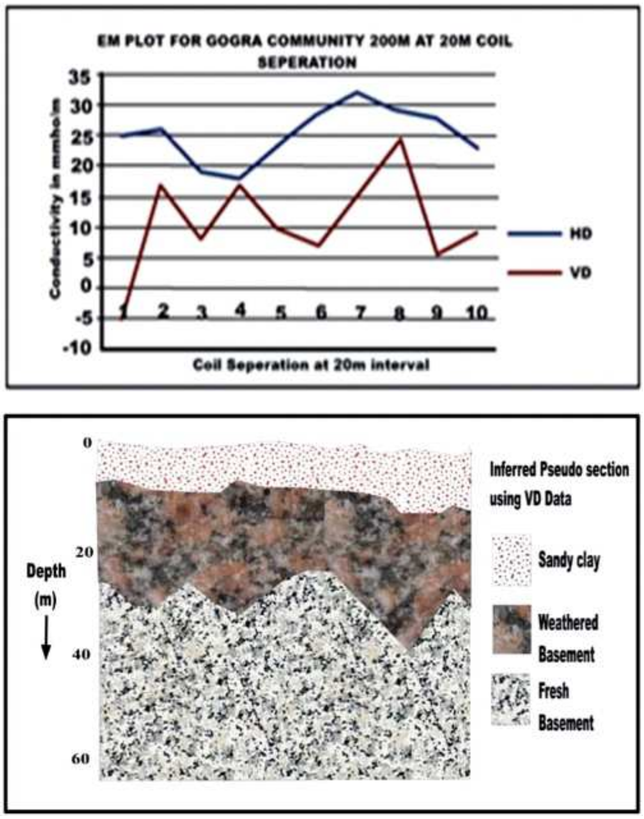

Fig. 11: EM/Geologic section of Gogra

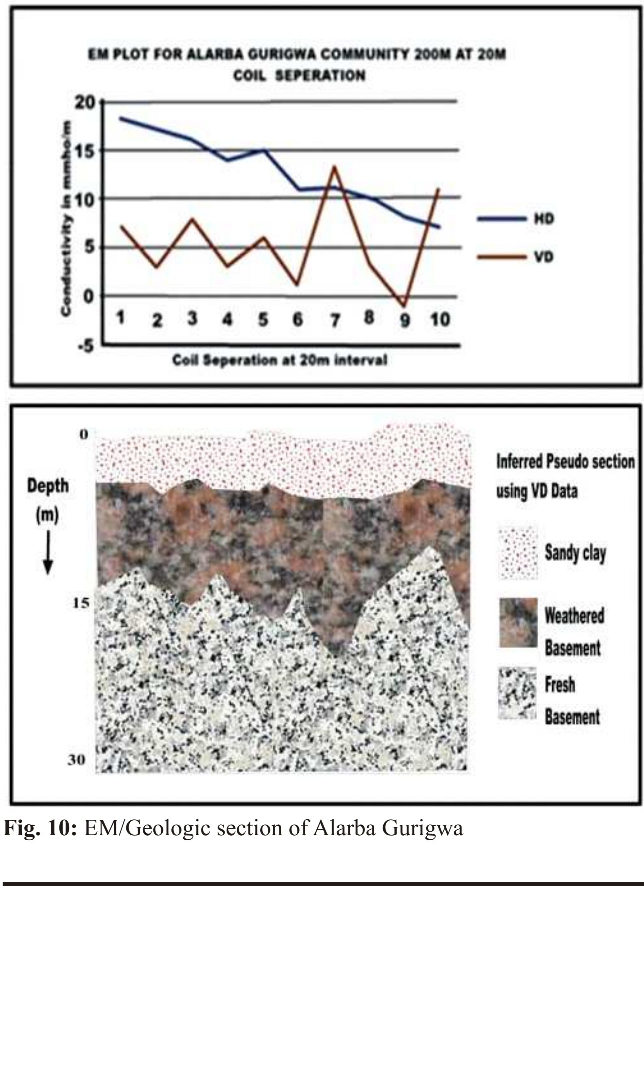

Fig. 10: EM/Geologic section of Alarba Gurigwa

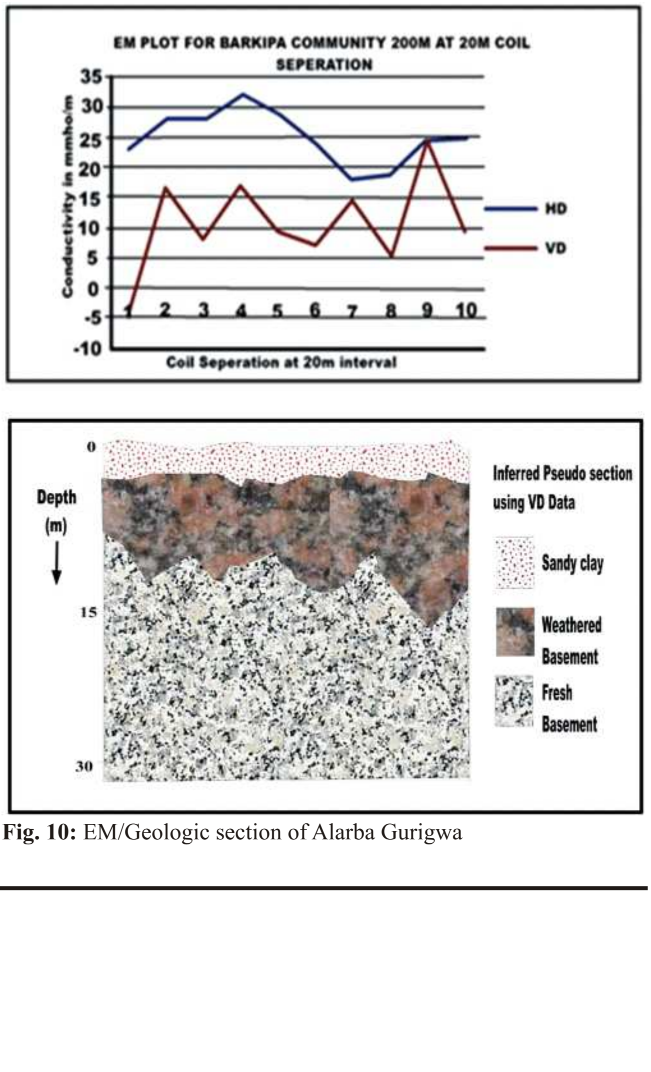

Fig. 10: EM/Geologic section of Alarba Gurigwa

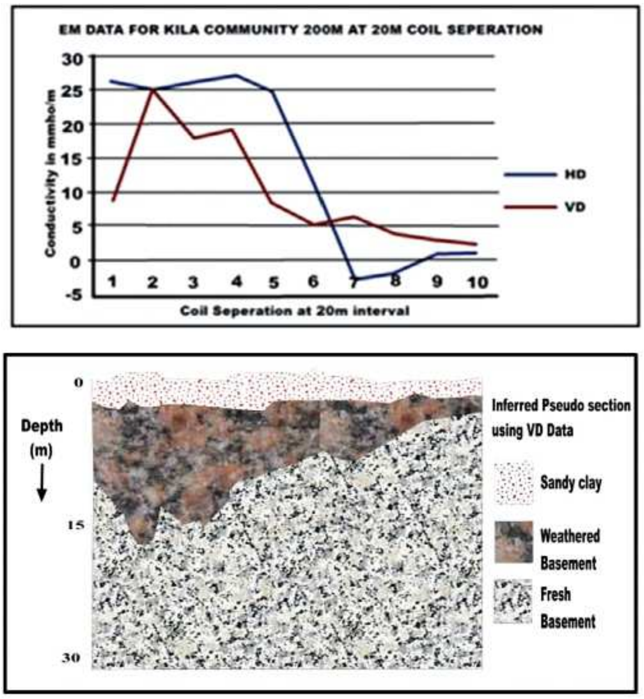

Fig. 13: EM/Geologic section of Kila Sakra

Vertical Electrical Sounding Results

The result of thirty (30) Vertical electrical sounding measurements are presented in table 1, the field data showed 66.7% of the VES points were identified as H-Type curve and 16.7% as HA-Type curve while 10% were identified as A-Type curve and 6.6% as KH-Type curve. The VES data in the area revealed four layers with varying resistivities and thicknesses. Sandy clay topsoil made up the first layer and has a relatively uniform thickness of overburden ranging from 0.812 to 5.92 m with resistivity values ranging between 21.18 to 303.5 Ωm, the weathered basement made up the second layer and has varying thicknesses ranging from 2.666 to 27.86 m with resistivity values ranging from 10.15 to 1669.9 Ωm and the slightly weathered basement made up the third layer with thicknesses ranging from 24.49 to 37.98m with resistivity values ranging from 14.18 to 7063.4 Ωm. The fourth layer has resistivity values ranging from 342 to 9811 Ωm which is typical of fresh basement environment.

The potential aquifer system in the study area as deduced from the inferred lithologies (Table 1) comprises mostly of weathered basement and the slightly weathered basement. The weathered lithological unit in Karlahi area is overlain by the sandy clay formation. This sometimes act as reservoir and water bearing zones very close to the river channel for hand dug wells and very shallow tube wells used for water supply by the communities.

Table 1: VES locations, coordinates, geo - electric parameters, inferred lithology, curve types and aquifer unit.

S/NO.	LOCATION	EASTINGS	NORTINGS	RESISTIVITY (Ωm)				THICKNESS (m)		
				Layer1	Layer 2	Layer 3	Layer 4	Layer1	Layer 2	Layer 3
1	Belwa Gite 1	12.55082	8.81486	125.5	10.47	102.6	318.3	2.32	5.617	40.5
2.	Belwa Gite 2	12.55432	8.8124	55.78	19.59	462.1	8520.5	4.75	6.843	37.832
3.	Belwa Gite 3	12.55623	8.80975	95.84	17.39	130.3	367	4.32	4.693	41
4.	Donkan Vera 1	12.54724	8.83605	529.2	77.74	336.4	836.4	4.17	12.622	46.47
5.	Donkan Vera 2	12.54755	8.83325	186.2	28.25	216.2	6676	3.66	14.997	38.302
6.	Donkan Vera 3	12.54846	8.83082	196.4	19.73	258	342	4.9	6.919	39.211
7.	Kila Sakra 1	12.52622	8.82504	21.18	1669.9	2564.1	2724.7	2.89	5.513	42.262
8.	Kila Sakra 2	12.52638	8.82515	86.09	58.59	595	1234	3.73	4.351	50
9.	Kila Sakra 3	12.52653	8.82522	28.54	76.97	1607.8	1987	3.59	3.962	37
10.	Baraje 1	12.58628	8.83736	32.11	12.17	312.1	9811	4.8	9.042	30.907
11.	Baraje 2	12.58578	8.83353	180.4	29.65	318	2150.6	3.47	6.63	44.387
12.	Baraje 3	12.58943	8.82941	19.47	1587	2063.4	2936.8	5.92	3.933	37.866
13.	Lugga Chamba 1	12.58122	8.85804	21.61	677.7	1468.1	2012	3.12	2.666	46
14.	Lugga Chamba 2	12.5818	8.85876	137.2	18.15	333.4	1860.7	4.78	7.569	39.325
15.	Lugga Chamba 3	12.582	8.85948	108.2	12.57	280.5	633.4	2.11	12.689	42.204
16.	Bashinda 1	12.57155	8.87869	128.3	27.3	76.82	5613.5	5.2	23.24	24.89
17.	Bashinda 2	12.57479	8.87824	69.92	17.62	104.8	2726.3	4.38	17.65	27.33
18.	Bashinda 3	12.57153	8.87836	94.06	25.02	211.4	9887.6	3.84	21.81	24.76
19.	Toza Gada 1	12.59386	8.89958	67.49	10.15	161	1331.5	3.68	27.86	36.14
20.	Toza Gada 2	12.5918	8.89965	303.5	47.05	1211.4	1200.8	0.812	20.45	37.98
21.	Toza Gada 3	12.59109	8.89972	135.7	25.52	3664.1	22610	4.8	15.78	28.92
22.	Alarba Gurigwa 1	12.59576	8.91573	74.75	14.86	24.12	173.9	4.65	18.41	29.41
23.	Alarba Gurigwa 2	12.60024	8.9168	77.3	45.65	19.43	1287.2	5.5	16.35	28.93
24.	Alarba Gurigwa 3	12.60126	8.91696	78.38	34.91	18.53	1992.4	3.12	17.83	28.56
25.	Barkipa 1	12.54082	8.93457	110	35.77	27.58	571.7	3.99	13.24	34.18
26.	Barkipa 2	12.54024	8.93454	91.89	22.12	14.18	2261.2	4.16	15.1	29.78
27.	Barkipa 3	12.54007	8.93454	77.19	27.54	154.3	3347.9	4.71	19.41	26.44
28.	Gogra 1	12.58021	8.94458	148.7	13.95	173.7	5796.7	3.98	15.95	33.66
29.	Gogra 2	12.57668	8.94578	186.2	28.15	216.2	6676	4.66	19.99	30.3
30.	Gogra 3	12.57345	8.94577	228.9	21.81	387.5	542	3.56	27.59	28

Correlation of Geo – Electric and Borehole Lithological Sections

The correlation of borehole logs in the study area were done and presented in Fig. 14. Profile lines were drawn along A-A^I, B-B^I and C-C^I with lithological sections drawn across boreholes 1, 2 and 3 with some VES points 8, 16, 17, 21, 22, 24 and 25 located along the profiles.

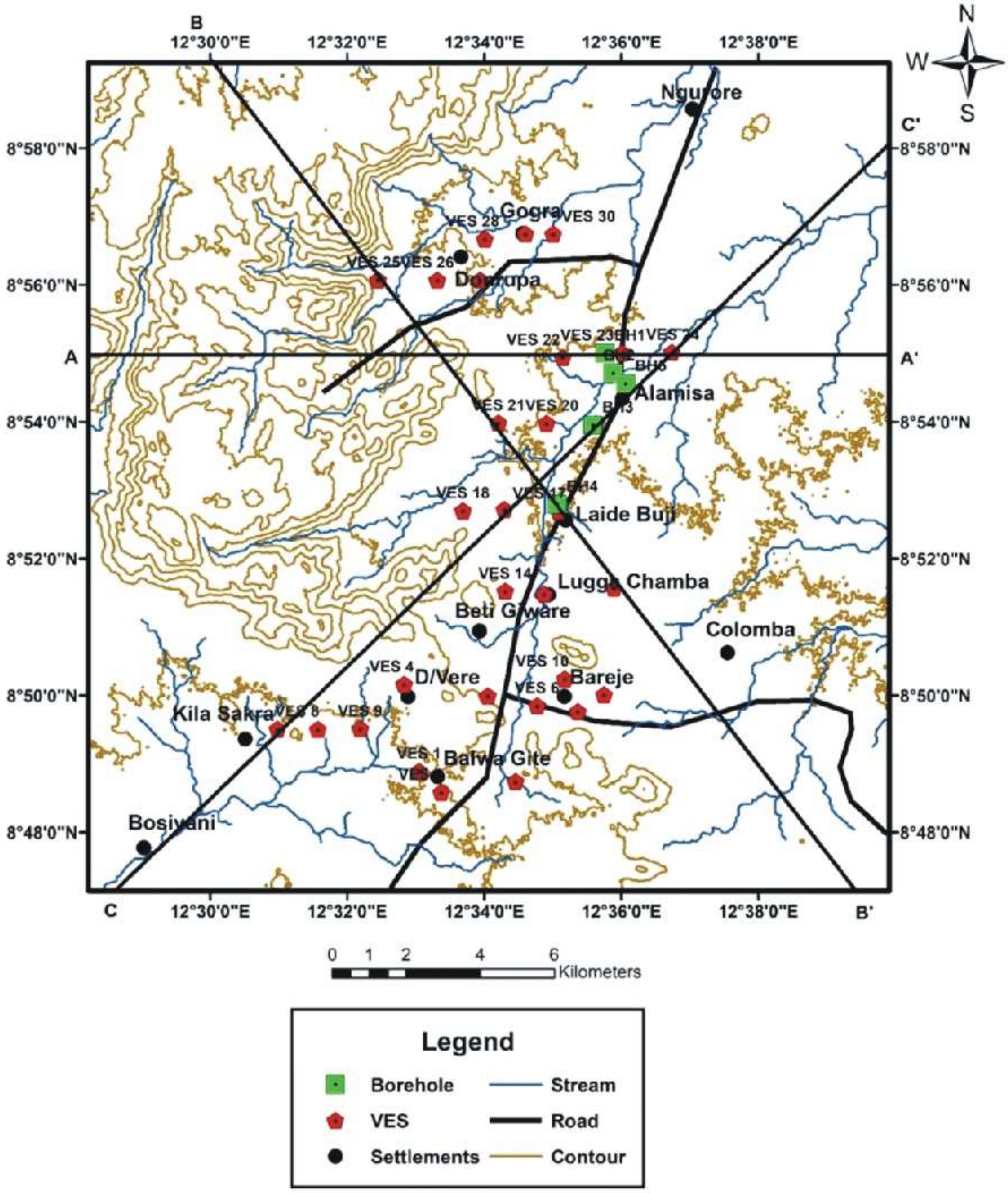

Fig. 14: Location of correlated lines along A-AI, B-BI and C-CI with VES points and existing boreholes (1, 2, 3, 4 and 5)

Profile A-A^I

Line A-A^I in Fig. 15 trends along E-W and cut across BH 2, VES 22, VES 23 and VES 24. The correlation between lithological log of BH 2 with the inferred lithologies of VES 22, VES 23 and VES 24 revealed the first layer to be sandy clay with fine grained texture and brownish also appeared in BH 2 with a thickness of 3m.

This same layer appeared in VES 22, VES 23 and VES 24 with thicknesses of 4.65, 5.5 and 3.12m respectively. A second layer which is water bearing layer presented in BH 2 which is 10m thick. The inferred aquiferous layers in VES 22, VES 23 and VES 24 are 18.41, 16.35 and 17.83 m thick respectively. The second layer therefore has a thickness which ranged from 10 to 18.41 m. A third layer which was slightly weathered appeared in BH 3 with a thickness of 30 m and in VES 22, VES 23 and VES 24 is 29.41, 28.93 and 28.56 m respectively. This layer therefore has a thickness ranging from 28.56 to 30.00 m with an average of 29.00 m. The fourth layer is the fresh basement which appeared in BH 3 at the depth of 34 m.

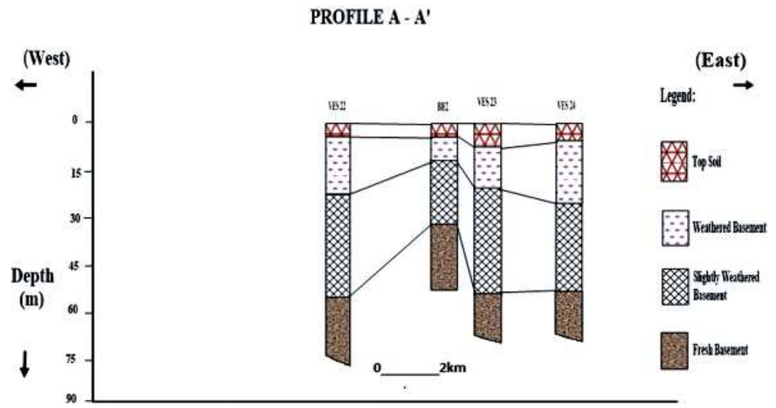

Fig. 15: Correlation of Borehole lithologic section (BH 2) and Geo - electrical sections (VES 22, VES 23 and VES 24)

Profile B-B[l]

The correlation between lithologic section of BH 2 with the inferred lithologies of VES 16, VES 21 and VES 25 revealed first layer to be sandy (Fig. 16), fine in texture and brownish which also appeared in BH 2 with a thickness of 2 m. This same layer appeared in VES 16, VES 21 and VES 25 with thicknesses of 5.2, 4.8 and 3.99 m respectively. This layer therefore ranges from 2 to 5.2 m in thickness, with an average thickness of 3.6 m. The second layer which is clayey sand and appears in BH 2 with 5 m thickness and is not present in VES 16, VES 21 and VES 25 rather as a contact zone between first and third layers in VES 16, VES 21 and VES 25 and therefore was not detected by the VES. A third layer which is the aquiferous layer of BH 2, has a thickness of 15.5 m, this layer appeared as second layer in the inferred aquiferous layer of VES 16, VES 21 and VES 25 with thicknesses of 23.24, 15.78 and 13.24 m respectively.This layer range from 15 to 24 m with an average of 19.5 m. A fourth layer which appeared as fresh basement in BH 2 is encountered at 24 m. This slightly weathered formation appeared as layer 3 in VES 16, VES 21 and VES 25 with thicknesses of 24.89, 28.92 and 34.18 m respectively. The fourth layer is the fresh basement that appeared in BH 3 at the depth of 34 m in VES 16, VES 21 and VES 25.

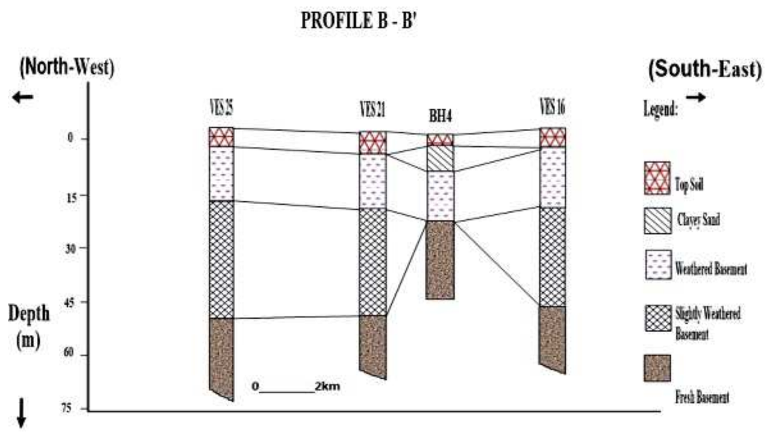

Fig. 16: Correlation of Borehole lithologic section (BH 4) and Geo - electrical sections (VES 16, VES 21 and VES 25)

Profile C-C[l]

The correlation between lithologic section (BH 3) with the inferred lithologies of VES 8, VES 17 and VES 24 revealed the first layer of the section which is a sandy clay which also appeared in BH 3 with a thickness of 3 m (Fig. 17). This same layer is present in VES 8, VES 17 and VES 24 with thicknesses of 3.73, 4.38 and 3.12 m respectively. This layer therefore ranges from 3 to 4.5 m in thickness, with an average of 3.6 m. The second layer which is the aquiferous layer of BH 3 has a thickness of 9 m and the thicknesses of inferred aquiferous layers in VES 8, VES 17 and VES 24 are 4.351, 17.65 and 17.83 m respectively. This layer ranges from 4 to 18 m with an average of 12.2 m. The third layer which is a slightly weathered layer appeared in BH 3 with 16m thickness and in VES 8, VES 17 and VES 24 with thicknesses of 50, 27.33 and 28.56 m respectively. The layer therefore ranges from 16 to 50 m with an average of 30.5 m. The fourth layer is the fresh basement which appeared in BH 3 at the depth of 27 m.

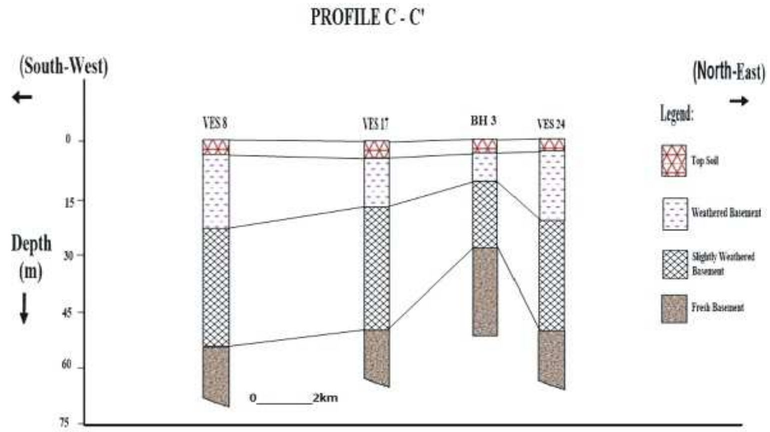

Fig. 17: Correlation of Borehole lithologic section (BH 3) and Geo - electrical sections (VES 8, VES 17 and VES 24) from profile C-C[l].

Discussion

The present study was aimed at delineating groundwater potential zones using integrated geophysical techniques and borehole data. EM survey conducted in the study area delineated conductive zones across the profiles which decided the suitable location for carrying out vertical electrical soundings in the area. The inferred pseudo - section of each of the EM profile describes the layered formation based on the interpretation of the vertical dipole data (VD). The result revealed sandy clay and weathered basement and it shows a relatively low to high conductivity values. In EM surveys, highs values along traverses represent conductive zones in the subsurface, showing good location for VES data collection. Larry, et al., (2009) employed EM methods to accurately locate groundwater bearing zones in Voltain region of Ghana on the basis of high values of EM. These locations were drilled and correlated with borehole logs with drill penetration rate which indicated a weathered zone. Darby (2003) used EM to detect the difference in conductivity between saturated and unsaturated soils in Alpine Lake area based on the high values for saturated areas. Fernando, et al., (2002) outlined shallow conductive structures in Vilarelho Da Raia. The data revealed the influence of structures lying in the uppermost part of the subsurface 50-60 m. In this study, EM revealed the conductivity high values around Toza Gada, Alarba Gurigwa, Gogra, Barkipa and Donrupa in the central to northern parts of the study area. Baraje, Donkan Vera, Belwa Gite, Lugga Chamba and Bashinda recorded conductivity low values situated in the southern part of the study area. These imply that the central and northern part of the study area are more promising for large scale groundwater development.

The interpreted VES results revealed 4 layered formations; Sandy clay making up the first layer, the second layer is a weathered basement formation while slightly weathered basement makes the third layer and the fourth layer as fresh basement. The aquifer units in the study area is made up of weathered basement and slightly weathered basement as seen in the geo - electric sections and lithologic sections of the few existing boreholes. The weathered and slightly weathered lithological units act as reservoir and water bearing zones for boreholes used for water supply by the communities. The analysis of the results indicate that groundwater exist in the second and third layers corresponding to the borehole lithologic sections. The aquifer units in Karlahi has been delineated in the upper highly weathered and lower slightly weathered. The highly weathered range from 9 to 18.41 m with an average of 13.7 m. While the slightly weathered range from 13 to 50 m with an average of 31.5 m. The average thickness of the two aquifer units ranges from 20 to 32 m.

Conclusion

The following outcomes were derived from the work carried out in Karlahi area; The EM survey showed relatively low to medium conductive zones and delineated sandy clay and weathered basement. Analysis of the results of VES results revealed sandy clay, weathered basement, slightly weathered and fresh basement. Correlation of borehole lithologic sections and geo - electric section revealed highly weathered and slightly weathered basement as the aquiferous zones. The highly weathered and slightly weathered basement aquifer units are unconfined and should be exploited for groundwater development. It is recommended that 35 to 50% of the total thickness of the highly weathered and slightly weathered aquiferous formations should be screened in borehole projects for optimal borehole water yields and the borehole should be cased to the bottom. These boreholes should be properly developed for large scale groundwater development. Boreholes are recommended to be sited in the central to the northern part of the study area where there are more weathered horizons than in the southern part.

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