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ASSESSMENT OF SUBSURFACE PROPERTIES FOR PRE-FOUNDATON INVESTIGATION AT NIGERIA UNION OF TEACHERS HOUSING ESTATE SITE, PAGGO, MINNA, NIGERIA

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ABSTRACT

The vertical electrical sounding (VES) was carried out to evaluate the subsurface properties of Nigeria Union of Teachers housing estate, Paggo, Minna for pre-foundation investigation. The Abem terrameter model SAS 4000 was used to determine the subsurface layer parameters (resistivity, depths and thickness) that were employed in evaluating the properties of subsurface. A total of sixty VES points were sounded with interval of 100 m apart. It has a maximum current electrode separation (AB/2) of 100 m. Three and four geoelectric layers were observed namely; topsoil, weathered layer, fractured layer and fresh basement layer. The strata sequence of the subsurface shows: topsoil (67.5 – 941.2 Ωm), weathered layer (65.84 – 1199 Ωm), fractured layer (118.9 – 886.8 Ωm) and the fresh basement layer (1094 – 8692 Ωm). Ten VES stations were recommended for building construction where basement is intruded close to the surface, with depths to fresh basement varying between 1.575 and 3.825 m (shallow depths) and have high resistivity values of the fresh basement.

Keywords: *Vertical electrical sounding, high rise, resistivity, depth, geologic layers, corrosivity and foundation.*

INTRODUCTION

Subsurface geologic sequence and concealed geological structures can be mapped by geophysical methods (Olorunfemi and Mesida, 1987; Ojo and Olorunfemi, 1995) hence; geophysics is quite relevant in mapping subsurface lithologic units. This geophysical survey of the subsurface involves the measurement/establishment of geoelectric parameters such as layer resistivity (p_a), thickness and depth of each lithologic unit. These geoelectric parameters can than used to describe the hydrological condition of the subsurface. Geophysical investigation applies the principle of physics to the study of the earth (usually the earth's surface). In other to achieve this, measurements are made at or near the earth surface to obtain data, the interpretation of this data obtained are capable of dictating and delineating local and regional features that could be of economic interest which are uncommon in nature such as anomalies, so the geophysical investigation provides rapidly collected information on the geological structure and prevailing lithology of a region without the large cost extensive drilling program or for building construction, the results of the geophysical investigation determines the location of any structures.

In the recent time, building collapse has become a familiar occurrence on the street in Nigeria with higher reported cases between 1980 and 2014 (Alamu & Gana, 2014). Most problems of structural failure are often associated with improper founding of foundations and poor quality of building materials (Akintorinwa & Abiola, 2011; Ofomola, Adiat, Olayanju, & Ako, 2009). The choice of location, foundation/soil investigation, design of structural type, building construction expertise among others, is highly essential in building constructions. Buildings are affected not only by design errors but also by foundation inadequacies such as sitting them on incompetent earth layers. A good foundation should safely sustain the super structure to be erected on it in such a way as not to cause any settlement or other movement which would impair stability or cause damage to the whole or any part of the buildings. In recent time resistivity method is widely used in preliminary site investigation to show the materials existing in the subsurface (Omowumi, 2014).

Over the years, geophysical methods have come to play a significant role in foundation investigations. Geophysical resistivity techniques are based on the response of the earth to the flow of electrical current.

Theory of Electrical Resistivity Method

Electrical resistivity method is used to determine the subsurface resistivity distribution by making measurements on the ground surface. From the measurements made, the true resistivity of the subsurface can be determined. The electrical resistivity method uses a series of electrodes nailed into the ground about six inches deep along a selected straight profile. The distance between the electrodes depends on the desired depth of investigation and the target being imaged. The farther apart the electrodes, the "deeper" the current goes into the earth, at the expense of resolution. The most commonly used configurations is the schlumberger array which uses four electrodes at a time, two for passing current into the ground and two for measuring the potential difference. In recent times, it has been used for environmental surveys. The resistivity measurements are usually made by injecting current into the ground through two current electrodes (C_1 andC_2), and measuring the resulting voltage difference at two potential electrodes (P_1 andP_2). From the current (I) and voltage (V) values, an apparent resistivity (ρ_a) value is calculated. The ground resistivity is associated with several geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock.

Geology of the Study Area

This area forms part of Minna granitic formation which consist of meta-sediments and meta-volcanics. These meta-sediments includequartzite, gneisses and the meta-volcanics are granites. Around the northern and central part of this area the rock types are mainly granites while in the eastern and southern part of the area cobbles of quartzite are found there. Although pegmatite and quartz veinexist. The rock type in this area is made of monolithic rocks of granite origin and it can be grouped into two,which are the porphyritic to coarse grained granites and medium to fine grained granites due to their relative grain size. The rocks are mostly weathered and believed to be part of the older granite suite and are mostly exposed along the river channel.

The land structure is related to the rock type underlying it. The impermeable igneous and metamorphic rocks underlying the North Central basement complex terrain are considered as poor sources of groundwater. However, tectonic features such as fracturing, jointing and fissuring often modify the water bearing characteristics of the rocks and make them amenable to containing water in discontinuous and isolated places through the development of secondary permeability. The capacity of these crystalline rocks to store and allow movement and yield water chiefly depend on the extent, pattern, size, openness and continuity of the fracture, and to the degree to which these fractures are hydraulically connected (Todd, 1980). Groundwater occurrence in the Precambrian basement terrain is hosted within the zones of weathering and fracturing which often are not continuous in vertical and lateral extent (Alhassan *et al.,* 2017). The aquifers of the basement complex rocks are the regolith and the fractures in the fresh basement bedrock which are known to be interconnected at depth (Alhassan *et al.,* 2017).

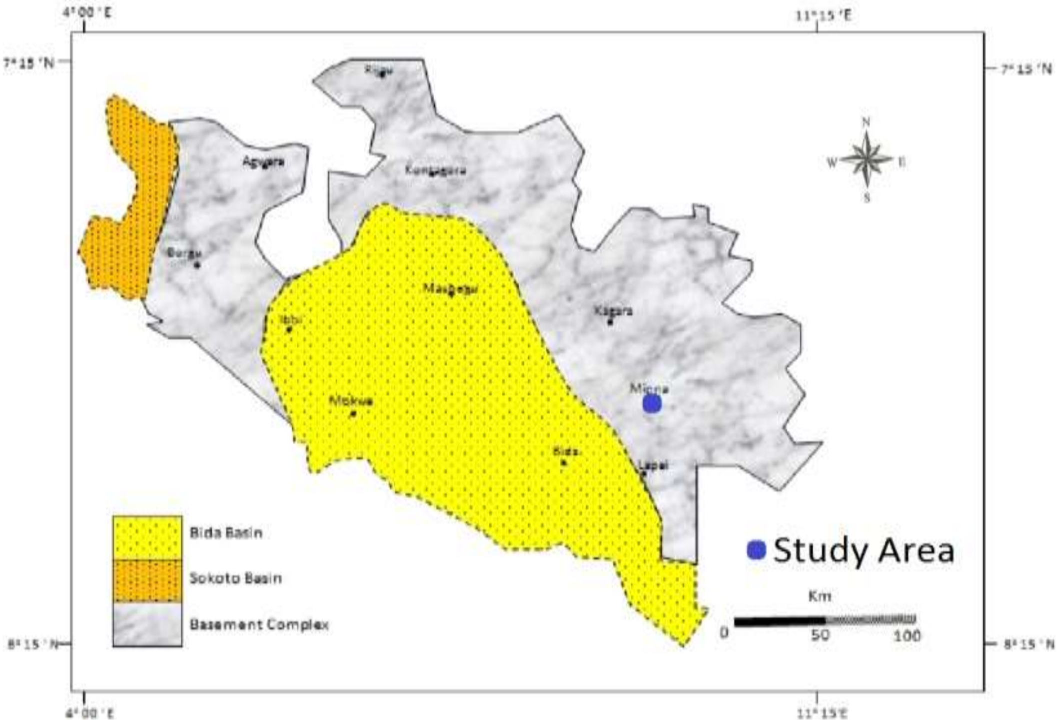


Fig. 1: Geological map of Niger state basement complex and sedimentary basin.

MATERIALS AND METHOD

The data was acquired with the ABEM SAS 4000 Terrameter: It has digital meters capable of displaying the value of resistivity for each measurement. Global Positioning System (GPS) for taking accurate coordinate of the VES point and elevations, Metal Electrodes, Measuring Tape, Labelled Tag (used in locating station position), Hammer (used in driving the electrodes into the ground), Connecting Cables. In this methods, an electrical current is passed through the ground and two potential electrodes allow us to record the resultant potential difference between them, giving us a way to measure the electrical impedance of the subsurface material. The apparent resistivity is then a function of the measured impedance (ratio of potential to current) and the geometry of the electrode array. Depending upon the survey geometry, the apparent resistivity data are plotted as 1-D soundings, 1-D profiles, or in D cross-sections in order to look for anomalous regions.

The Schlumberger array was adopted. The electrode spread of AB/2 was varied from 1 to a maximum of 100m. Sounding data were presented as sounding curves, by plotting apparent resistivity against AB/2. The earth resistance obtained were multiplied by the corresponding geometric factor (k) to obtain the apparent resistivity. The resistance was calculated using the Ohm's law.

$$V = IR \qquad \text{(Ohm's law)} \tag{1}$$

where V is the potential difference (in volt), I, the current (in ampere) and R, the resistance measured in ohm's meter.

$$\rho = kR \quad (2)$$

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

The Resistance is then multiplied by the Geometric Factor K, to obtain the Apparent Resistivity. The Apparent Resistivity data was presented as depth sounding curves by plotting the Apparent Resistivity along the ordinate axis and the half current electrode spacing along the abscissa on a log-log graph paper. The depth sounding curves was classified based on layer resistivity, thickness of each layer, depths of layer and number of layers in the subsurface. This was done using the IP12WIN software. This software automatically interprets the Schlumberger sounding curves and gives the equivalent n-layered model from each sounding point. The suffer software was then used to produce the contour maps.

RESULTS AND DISCUSSION

The interpretation of the resistivity value for the n-layers was done for 60 VES points. The surfer11 computer programme was then used to produce iso-resistivity contour maps. This result gives more information about the subsurface structure. The VES plot along the various profiles generates the geoelectric sections from where the resistivity variation with depth and thickness were obtained (Figure 2). The results were summarised in a tabular form (Tables 1& 2).

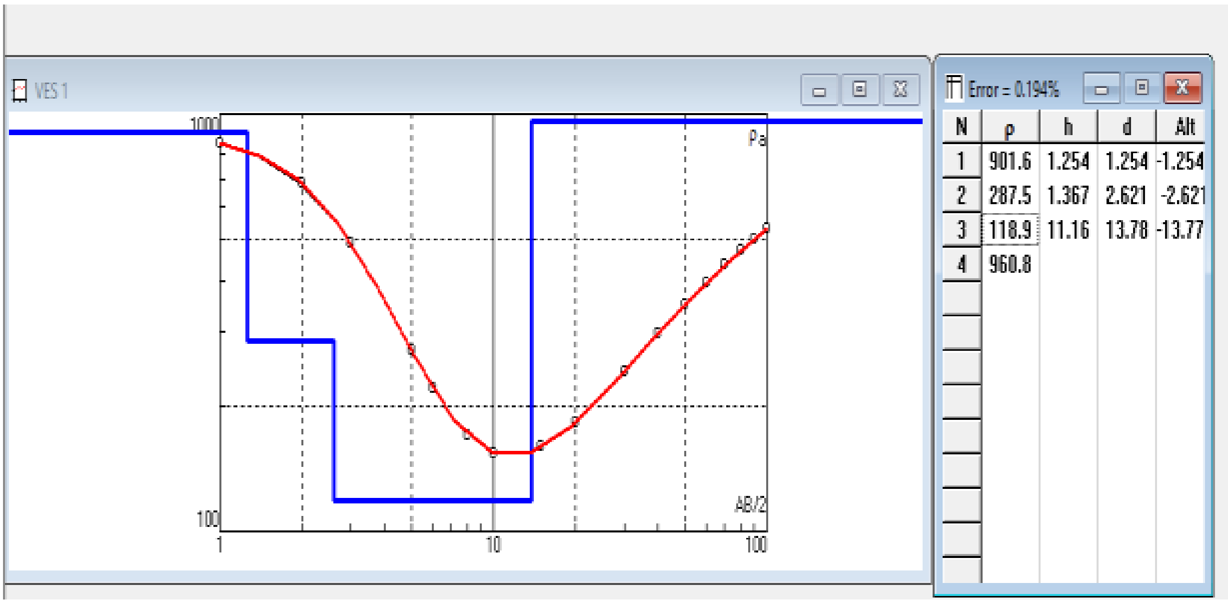


Fig. 2: VES Curve A1

Table 1: Layer Resistivity, Depth and Thickness

VES STATION	LATITUDE (degree)	LONGITUDE (degree)	NO OF LAYERS	LAYER RESISTIVITY				LAYER DEPTH			LAYER THICKNESS		
				ρ1	ρ2	ρ3	ρ4	d1	d2	d3	h1	h2	h3
A1	09.46521	06.63871	4	901.6	287.5	118.9	9608	1.254	2.621	13.78	1.254	1.367	11.16
A2	09.46500	06.63832	4	399	586	652	7864	2.64	5.49	23.31	2.64	2.86	17.82
A3	09.46463	06.63797	3	684.8	112.8	8692		1.222	3.403	∞	1.222	2.181	∞
A4	09.46435	06.63756	3	165	743.4	9231		1.222	17.52	∞	1.222	16.30	∞
A5	09.46410	06.63720	4	816.9	173.7	367.5	8692	1.104	1.68	24.37	1.104	0.576	22.69
A6	09.46379	06.63683	3	213.3	123.6	5060		2.133	3.68	∞	2.133	1.547	∞
A7	09.46360	06.63642	3	784.5	127.4	4960		2.082	3.416	∞	2.082	1.334	∞
A8	09.46330	06.63602	3	715.7	293.5	3124		2.183	21.4	∞	2.183	19.22	∞
A9	09.46294	06.63575	4	539.7	143.4	725.9	1249	1.585	2.056	18.98	1.585	0.471	16.92
A10	09.46264	06.63533	3	282.2	108	8941		1.25	22.4	∞	1.25	21.20	∞
B1	09.46567	06.63856	4	802.3	130.7	755.4	8520	1.216	2.97	24.88	1.216	1.754	21.91
B2	09.46538	06.63799	3	431	135	1094		1.272	1.575	∞	1.272	0.303	∞
B3	09.46502	06.63739	3	353.9	137.6	9231		1.222	3.825	∞	1.222	2.603	∞
B4	09.46469	06.63698	3	923	126.6	8692		1.324	6.791	∞	1.324	5.467	∞
B5	09.46443	06.63658	3	741.4	173	8133		1.197	5.791	∞	1.197	4.594	∞
B6	09.46413	06.63629	3	67.4	675	9132		1.35	18.30	∞	1.35	17.00	∞
B7	09.46382	06.63595	3	251.1	939.7	9048		1.222	24.33	∞	1.222	23.01	∞
B8	09.46353	06.63560	3	941.2	454.9	9231		1.354	10.61	∞	1.354	9.255	∞
B9	09.46279	06.63505	3	913.1	108.3	4138		1.199	3.569	∞	1.199	2.370	∞
B10	09.46278	06.63501	4	287	111	242	9231	1.20	2.04	17.10	1.20	0.837	15.10
C1	09.46609	06.63838	3	304.2	363.8	8520		1.35	13.50	∞	1.35	12.15	∞
C2	09.46596	06.63795	3	685	149.2	7864		2.228	6.438	∞	2.28	4.21	∞
C3	09.46572	06.63758	3	534.4	136.6	8200		1.297	14.34	∞	1.297	13.04	∞
C4	09.46557	06.63718	3	106	148.4	9412		1.690	5.260	∞	1.690	3.560	∞
C5	09.46535	06.63672	3	181	289	9232		1.40	4.69	∞	1.40	3.290	∞
C6	09.46510	06.63634	3	786.4	177.2	1970		1.324	5.02	∞	1.324	3.696	∞
C7	09.46483	06.63597	3	429.7	503.8	6437		1.38	12.40	∞	1.38	11.00	∞
C8	09.46458	06.63562	3	835.1	186.4	8820		1.297	4.412	∞	1.297	3.115	∞
C9	09.46424	06.63528	3	308.5	179.8	8859		1.354	4.778	∞	1.354	3.424	∞
C10	09.46383	06.63491	3	332	113	9025		1.11	2.50	∞	1.11	1.39	∞

P = resistivity, h = thickness, d = depth and VES = vertical electrical sounding

Table 2: Layer Resistivity, Depth and Thickness

VES STATION	LATITUDE (degree)	LONGITUDE (degree)	NO OF LAYERS	LAYER RESISTIVITY				LAYER DEPTH			LAYER THICKNESS		
				ρ1	ρ2	ρ3	ρ4	d1	d2	d3	h1	h2	h3
D1	09.46655	06.63817	4	375.6	689	1041	7259	1.246	4.58	24.29	1.246	3.334	19.71
D2	09.46630	06.63778	3	442.4	124.6	8351		1.311	3.52	∞	1.311	2.209	∞
D3	09.46610	06.63736	4	307.1	548.4	662.6	8023	1.585	8.389	14.78	1.585	6.804	6.389
D4	09.46587	06.63693	3	146.6	594.2	4062		4.864	23.14	∞	4.864	18.28	∞
D5	09.46569	06.63650	3	117	206.6	6060		1.251	3.611	∞	1.251	2.36	∞
D6	09.46538	06.63613	3	111.9	833.8	5624		6.504	16.26	∞	6.504	9.757	∞
D7	09.46520	06.63573	3	887	210	9015		1.396	5.975	∞	1.396	4.579	∞
D8	09.46494	06.63538	3	385.9	559.5	7864		1.505	24.27	∞	1.405	22.77	∞
D9	09.46465	06.63501	3	516.5	65.84	8520		1.787	12.47	∞	1.787	10.68	∞
D10	09.46429	06.63460	4	580.2	137.8	332	8186	1.26	2.743	17.11	1.26	1.483	14.37
E1	09.46704	06.63790	3	555.5	420	8520		3.564	15.22	∞	3.654	11.66	∞
E2	09.46672	06.63721	3	617.2	886.8	6373		2.96	23.8	∞	2.96	20.9	∞
E3	09.46640	06.63688	3	517.5	161.7	5307		1.236	3.461	∞	1.236	2.225	∞
E4	09.46617	06.63649	3	171	112.8	8859		1.354	4.196	∞	1.354	2.842	∞
E5	09.46588	06.63613	3	145.1	1199	8595		2.373	10.62	∞	2.373	8.251	∞
E6	09.46560	06.63574	3	168.2	326.4	9231		1.405	14.63	∞	1.405	13.22	∞
E7	09.46533	06.63533	3	472	644	3587		1.297	12.98	∞	1.297	11.68	∞
E8	09.46504	06.63494	3	697.4	116.4	9132		1.354	6.843	∞	1.354	5.489	∞
E9	09.46473	06.63451	3	786.7	127.2	9704		1.274	13.68	∞	1.274	12.41	∞
E10	09.46443	06.63412	3	423	105.1	9213		1.199	2.976	∞	1.199	1.777	∞
F1	09.46746	06.63768	3	299	111	9634		3.57	5.90	∞	3.57	2.33	∞
F2	09.46734	06.63724	3	622.6	137.8	1901		1.18	2.544	∞	1.18	1.364	∞
F3	09.46703	06.63681	3	653.7	146.3	2039		1.174	2.304	∞	1.174	1.133	∞
F4	09.46677	06.63638	3	755.6	231.9	8692		1.211	16.57	∞	1.211	15.29	∞
F5	09.46650	06.63600	3	650.9	281.7	4082		1.557	17.17	∞	1.557	15.61	∞
F6	09.46621	06.63557	3	131.3	390.9	8595		2.198	24.08	∞	2.198	21.88	∞
F7	09.46585	06.63514	3	562.6	354	1267		1.553	8.521	∞	1.553	6.968	∞
F8	09.46552	06.63486	3	852	155.3	8186		2.582	6.624	∞	2.582	4.042	∞
F9	09.46529	06.63436	3	546.4	157.5	7387		1.313	2.86	∞	1.313	1.547	∞
F10	09.46497	06.63390	3	397.9	180	9704		1.129	16.64	∞	1.129	15.51	∞

P = resistivity, h = thickness, d = depth and VES = vertical electrical sounding

The geologic sections (Figure 3) suggest a three to four layer structure. The first layer which is the topsoil has an average layer resistivity of 550.32 Ωm, so it's made up of gravels, alluvium and sand as its lithology. Its layer resistivity and thickness ranges from 165 Ωm to 901.60 Ωm and 1.10 m to 2.64 m respectively. The topsoil is underlain by a second layer that is the weathered basement. The resistivity values ranges from 112.3 Ωm to 743 Ωm and it spreads through the entire area at different depths. The layer thickness ranges from 1.68 m to 22.40 m. The weathered layer is underlain by the fractured layer which is the third layer. It has resistivity value ranging from 118.80 Ωm to 886.8 Ωm. The layer thickness ranges from 11.16 m to 22.69 m. The depth ranges from 13.78 m to 24.37 m. The fourth layer has resistivity value ranging from 1249 Ωm to 9608 Ωm. This last layer forms the fresh basement and it is highly resistive in most places. The fresh basement is uplifted close to the surface at VES A_3, A_6 and A_7 of this profile and suggested to be favourable for building construction due to its shallow nature.

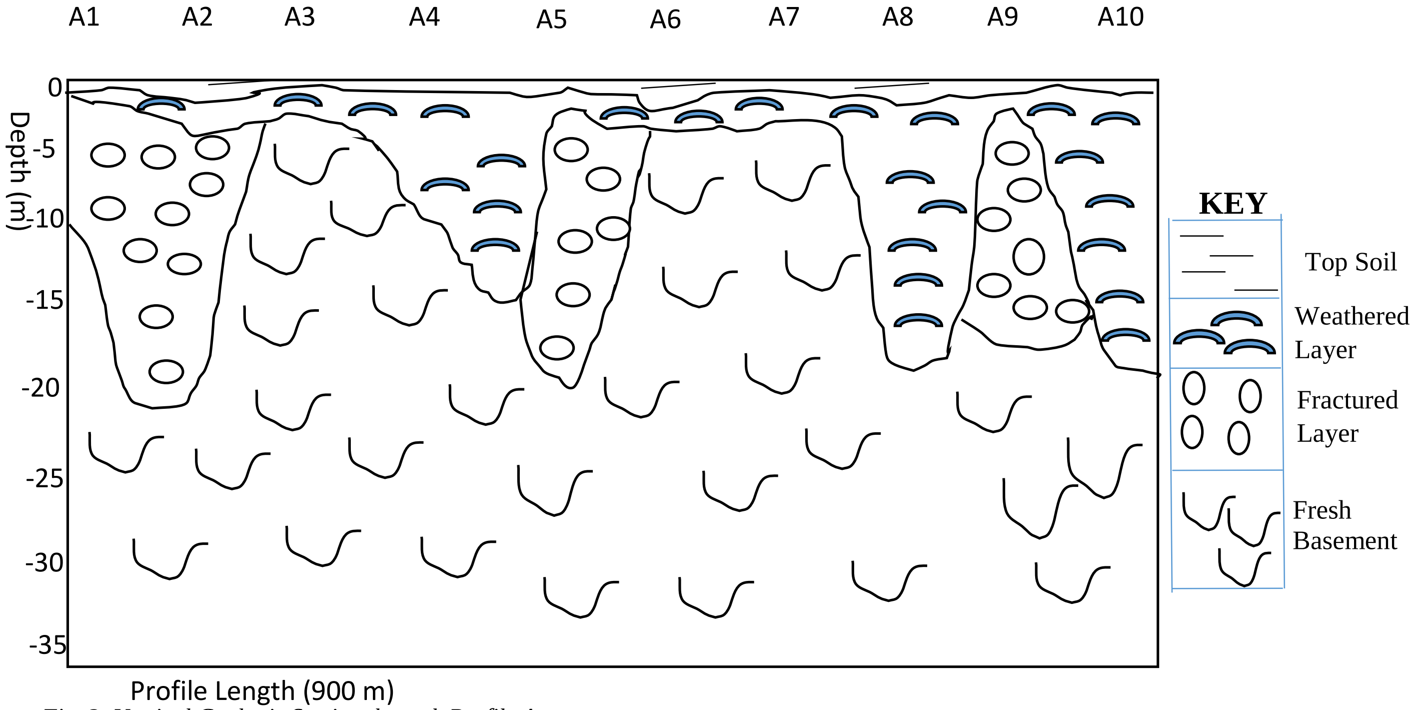


Fig. 3: Vertical Geologic Section through Profile A

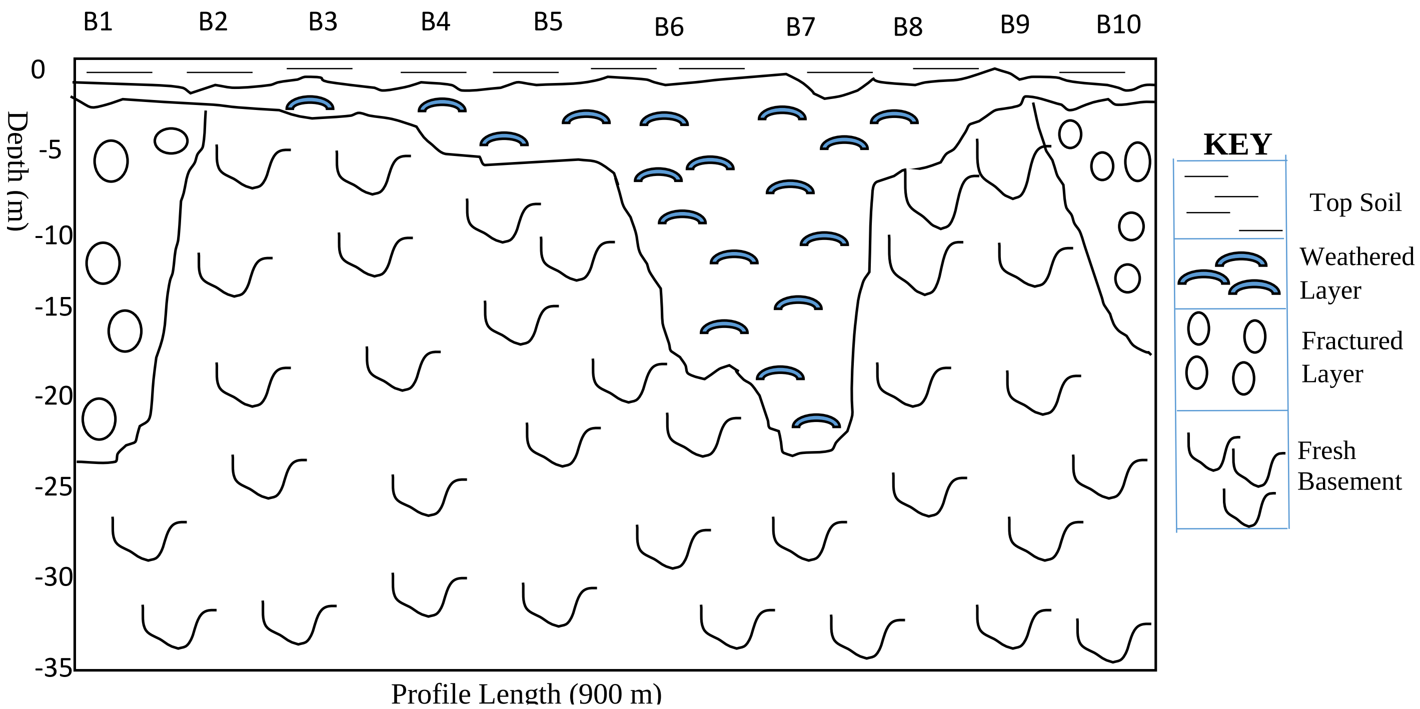


Fig. 4: Vertical Geologic Section through Profile B

The geologic section (Figure 5) suggests a three layer structure. The first layer is the topsoil with an average resistivity value of 480.24 Ωm. It consists of granites, gravels, alluvium, sand, sandy clay and sandy silt as it lithology. It has a resistivity value ranging from 106 Ωm to 835.10 Ωm. The layer spreads through the entire profile at different depths. Its thickness and depth ranges from 1.11 m to 2.23 m. The topsoil is underlain by a second layer of weathered/fractured layer. The layer spreads through the entire profile. The resistivity value ranges from 113 Ωm to 503.80 Ωm. The layer thickness and depth ranges from 1.39 m to 13.04 m and 2.50 m to 14.34 m respectively. The second layer is underlain by a third layer, the fresh basement. This layer is the last of this profile with high resistivity value in most of the VES points. The layer resistivity ranges from 8520 Ωm to 9251 Ωm. The layer has an infinite thickness.

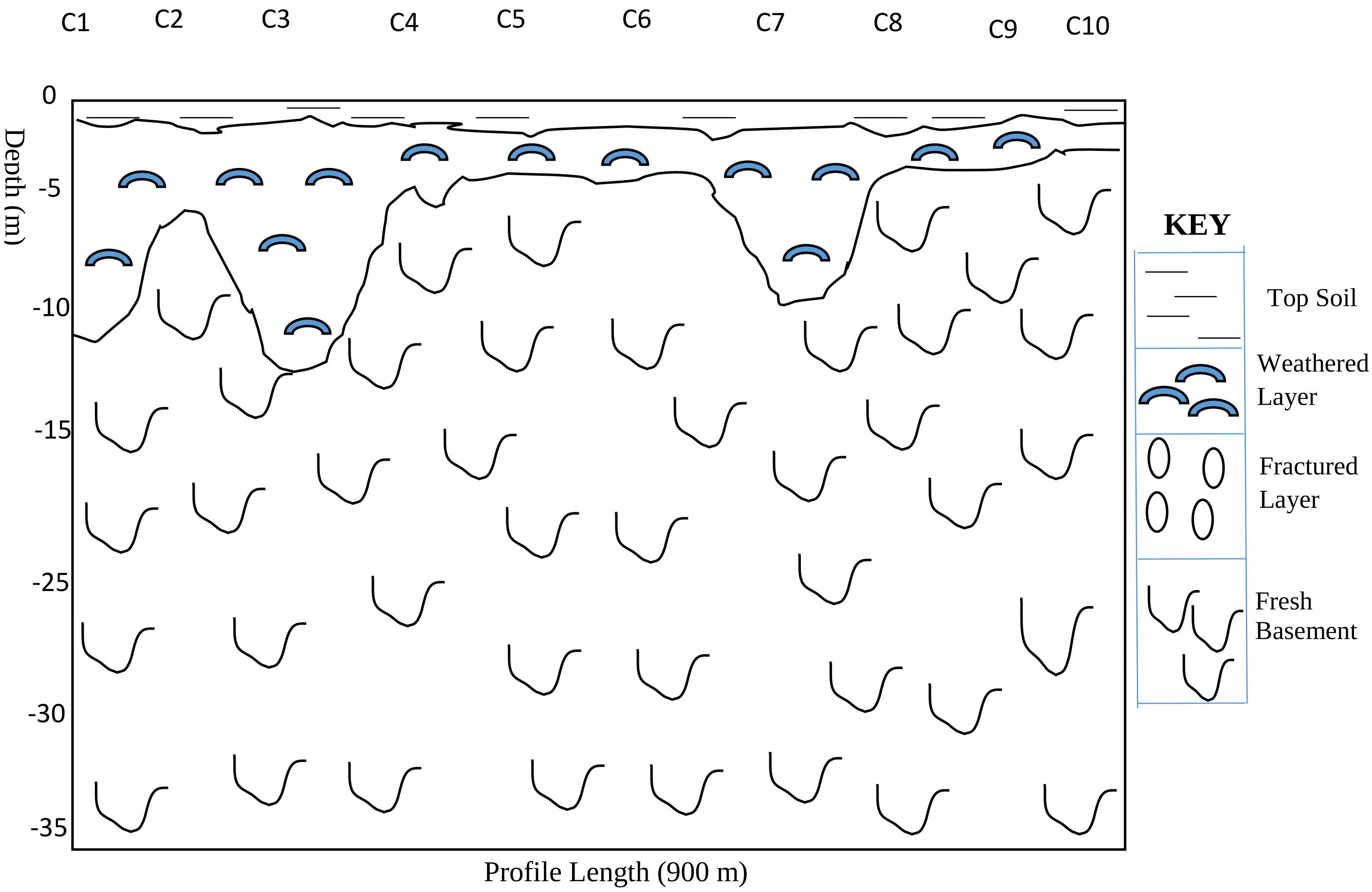


Fig. 5: Vertical Geologic Section through profile C

The geologic section (Figure 6) suggests a three and four layer structures. The first layer is the topsoil with an average resistivity value of 387.02 Ωm. It has a resistivity value ranging from 111.90 Ωm to 887 Ωm. The lithology consists of granites, gravels, alluvium, sand, sandy clay and sandy silt. The layer spreads through the entire profile. It has a depth and thickness range of 1.24 m to 6.50 m respectively. The second layer has a resistivity value ranges from 65.84 Ωm to 833.80 Ωm. The layer underlain the topsoil and it is the weathered layer. It spreads through the entire profile. The layer thickness and depth ranges from 1.48 m to 33.87 m and 2.74 m to 35.27 m respectively. The weathered layer is underlain by a third layer that is the fractured layer. The resistivity value ranges from 606 Ωm to 8351 Ωm. The thickness and depth ranges from 6.39 m to 79.71 m and 14.78 m to 84.28 m. The fourth layer (fresh basement) which is the last layer underlain the fractured layer. It shows a high resistivity at some VES points. Its resistivity value ranges from 8186 Ωm to 9259 Ωm with an infinite thickness. It is uplifted to the surface at VES D_2 and suggested to be favorable for building construction.

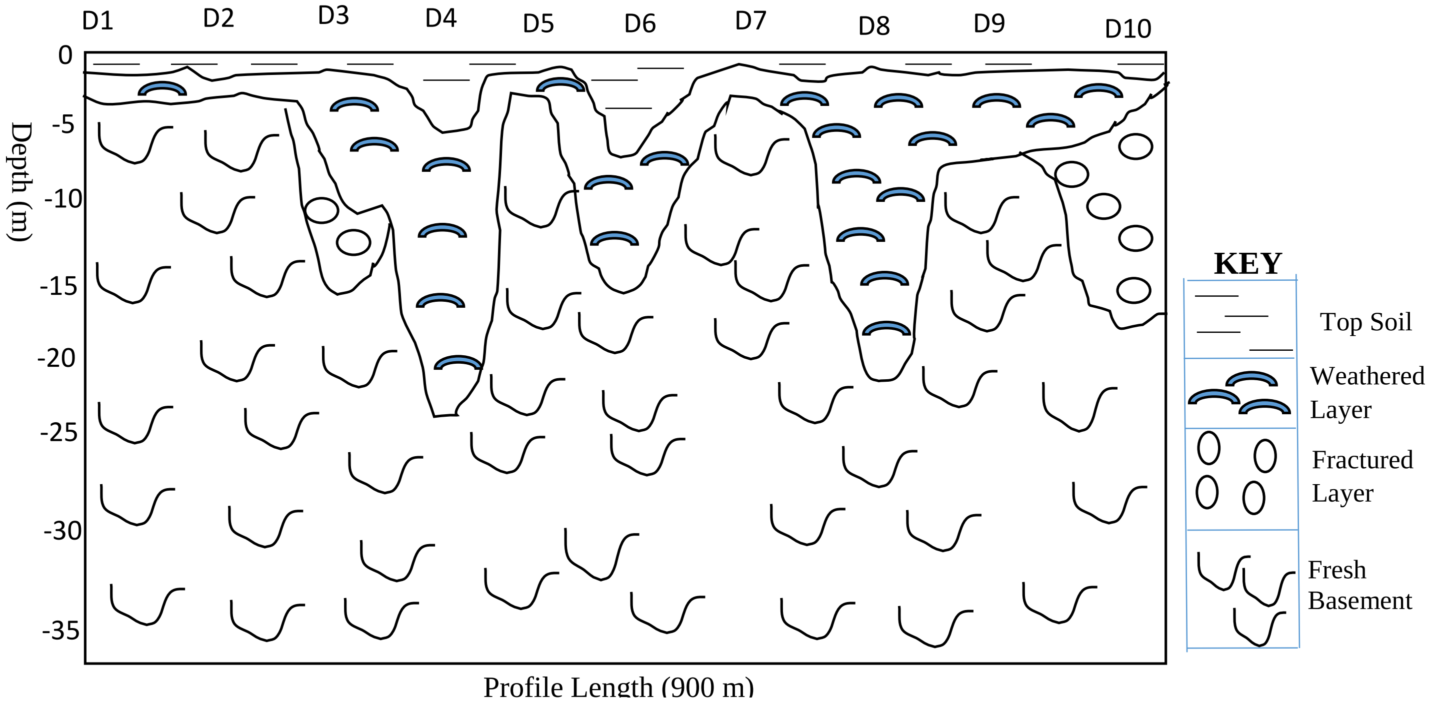


Fig. 6: Vertical Geologic Section through Profile D

The geologic section (Figure 7) suggests three layer structure. The first layer is the topsoil and has an average resistivity value of 455.36 Ωm. The lithology consists of granite, gravels, alluvium, sand, sandy clay and sandy silt. Its resistivity value ranges from 171 Ωm to 786.70 Ωm. The layer spread through the entire profile at different depths. The thickness and depth ranges from 1.20 m to 3.56 m respectively. The second layer underlain the topsoil and is the weathered/fractured layer. It has a resistivity value ranging from 105.10 Ωm to 119.90 Ωm. it has a thickness range of 1.78 m to 20.90 m and a depth range of 2.98 m to 23.80 m. The third layer underlain the second layer with a resistivity value ranging from 923 Ωm to 9231 Ωm. This layer is the fresh basement with an infinite thickness. The fresh basement is uplifted to the surface at VES E_3 and suggests being favorable for building construction.

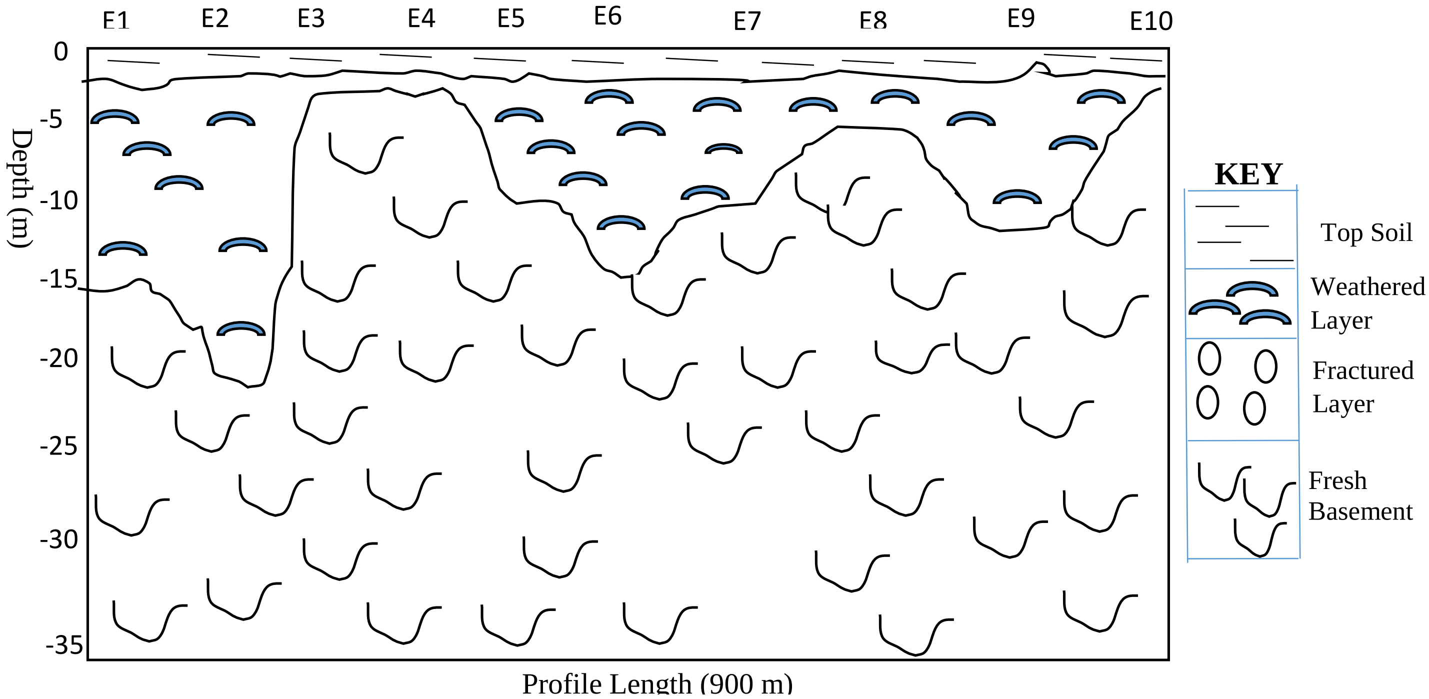
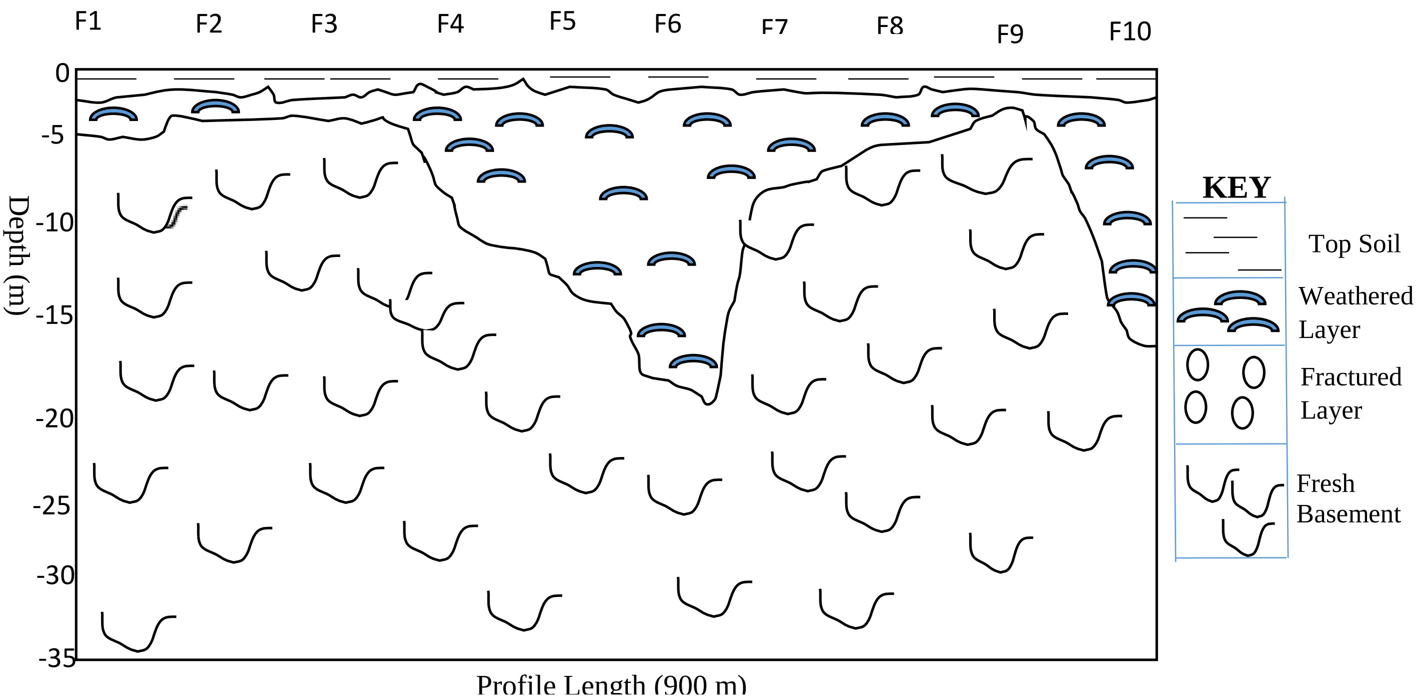


Fig. 7: Vertical Geologic Section through Profile E

The geologic section (Figure 8) suggests three layer structure. The first layer is the topsoil and has an average resistivity value of 547.20 Ωm. The lithology is made up of granites, gravels, alluvium, sand, sandy clay and sandy silt. This layer spread through the entire profile. Its thickness and depth ranges from 1.13 m to 3.57 m. The second layer underlay the topsoil with resistivity value ranging from 111 Ωm to 390.90 Ωm. This layer is the weathered/fractured basement which spreads through the entire profile at different depths. The thickness ranges from 1.13 m to 21.88 m and the depth ranges from 2.30 m to 24.08 m. The second layer is underlain by a third layer which is the fresh basement layer. This layer has an infinite thickness. The fresh basement is uplifted to the surface at F_2 and F_9 and suggests being favorable for building construction.



Fig, 8: Vertical Geologic Section through Profile F

Depth to Fresh Basement (Overburden) Contour Map

In a basement complex terrain, areas with fresh basement layer depth of 4 m and below are good for civil engineering (Alhassan *et al.*, 2015). The depth to basement was contoured at contour interval of 5 m. The depth ranges from 0 to 85 (Figure 9). The depth values used for the contour map correspond to the depth of the last layer for all the sixty VES points. The deepest area is found around the northeastern part and the shallow depth is scattered around the northcentral and southern part of the area. Ten VES stations were recommended for building construction having depths to fresh basement ranging from 1.575 to 3.825m, where consolidated basement is shallow (intruded close to the surface) and having a high resistivity values (Table 3).

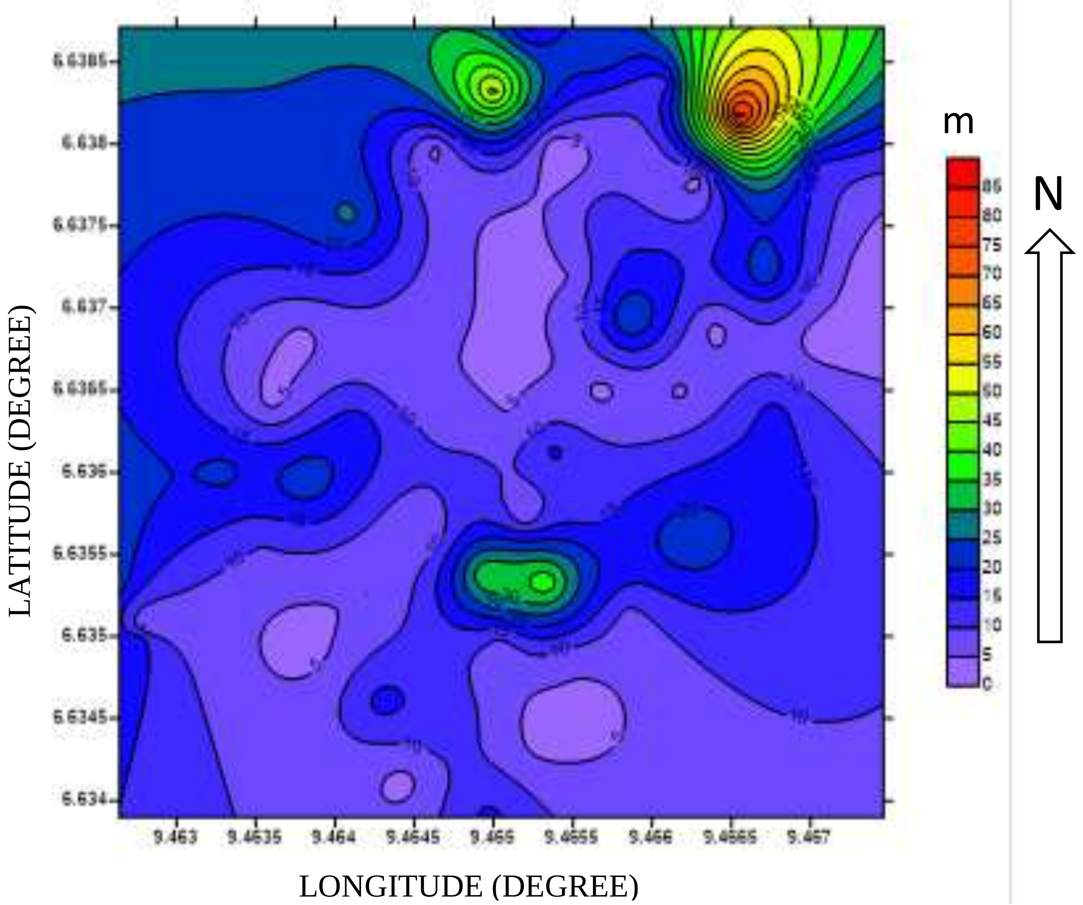


Fig. 9: Contour Map of the Depth to Fresh Basement

Table 3: Areas Recommended for Building Construction

VES Station	Latitude (degrees)	Longitude (degrees)	Elevation (m)	Basement Resistivity (ρ)	Depth to Basement (m)
A3	09.46463	06.63797	307	8692	3.403
A6	09.46379	06.63683	313	5060	3.680
A7	09.46360	06.63642	307	4960	3.416
B2	09.46538	06.63799	305	1094	1.575
B3	09.46502	06.63739	299	9231	3.825
B9	09.46279	06.63505	303	4138	3.569
D2	09.46630	06.63778	311	8351	3.520
E3	09.46640	06.63688	301	5307	3.461
F2	09.46734	06.63724	310	1901	2.544
F9	09.46529	06.63436	304	7387	2.860

CONCLUSION

From the result, it is revealed that the subsurface consist of 3 and 4 lithological units which are top layer, weathered layer, fractured layer and fresh basement. The curve types were identified as H, HA; A.

In a basement complex terrain, areas with fresh basement layer depth of 4 m and below are good for building construction (Alhassan *et al.*, 2015). Ten VES stations were considered for building construction, having varying depth of fresh basement between 1.576 m and 3.825 m. These VES stations are A_3, A_6, A_7, B_2, B_3, B_9, D_2, E_3, F_2 and F_9. The iso-resistivity maps produced shows that the earth material comprises of fadama loam, gravels, granites, clay, sandy silt and sandy clay.

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