GEOTECHNICAL INVESTIGATION OF THE EARTH SUBSURFACE FORMATION FOR ITS SUITABILITY FOR HIGH-RISE BUILDINGS IN SOUTHERN PART OFPAIKO, NIGER STATE, NORTH CENTRAL NIGERIA

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Abstract
Vertical electrical sounding (VES) was carried out insouthern Paiko, north central Nigeria, using AbemTerrameter model SAS 4000. The study was carried out with a view of determining the subsurface layer parameters (resistivity, depth and thickness) which were employed in delineating the sites for building construction. A total of six transverses with ten VES stations along each traverse, having separation of 50 m apart were investigated. It has a maximum current electrode separation (AB/2) of 100 m. Three to four distinct geoelectric layers were observed namely; Top layer, weathered/fractured layer, and fresh basement. The observed frequencies in curve types include 21.6% of H, 0.6% of HA, 2.4% of K, 0.6% of A, 3.6% of KH, 6% of QA and 1.2% of HK. Eight VES stations were delineated for building site construction, having depths to bedrock varying between 0.63 m and 3.99 m.

Key words: Vertical electrical sounding, site, construction, resistivity, depth, geoelectric layer, bedrock, Abem Terrameter

Introduction
Paiko (the study area).is the headquarter of Paikoro local government area in Niger state, North Central, Nigeria. The population of Paiko is increasing rapidly as a result of people migrates from rural areas to urban towns to earn a living. As such, there is need for more estate development to accommodate the growing population of the area. However, in Nigeria Presently there are several cases of building collapse and cracking of walls as a result of poor foundation and lack of site investigation. There is need to search for the areas where the consolidated basement is shallow which can provide strong base for building construction. Therefore, the aim of this work is to applied geophysical method to determine sites where the fresh basement is intruded close to the surface that can support foundations to buildings. Presently, there is only one known geophysical survey conducted in the area (Dangana, 2007).
Among several geophysical methods employed in determine depth to bedrock (electrical resistivity, gravity, seismic, magnetic, remote sensing, and electromagnetic), the electrical resistivity method is the most effective (Keareyet al., 2002). It is an effective and a reliable tool in slicing the earth into geoelectric layers. It has the advantage of non-destructive effect on the environment, cost effective, rapid and quick survey time and less ambiguity in interpretations of results when compared to other geophysical survey methods (Todd, 1980). The vertical electrical sounding (VES) technique provides information on the vertical variations in the resistivity of the ground with depth (Ariyo, 2005). It is used to solve a wide variety of problems, such as; determination of depth, thickness and boundary of aquifer (Asfahani, 2006; Bello & Makinde, 2007).

Geology of the Study Area
The study area is located within the north central Nigerian basement complex. It has an elevation of 304 m above sea level with population of about 736,133 people as at 2006 census.

It is bounded by latitudes 9°25'N and 9°27'N and longitudes 6° 37'E and 6° 39'E.Generally, the area mapped forms part of the Minna - granitic formation that consists of Metasediment' and metavolcanics. The Metasediment include quartzites, gneisses and the metavolcanics are mainly granites. Among the main rock groups are granites which occur at the central and northern parts of the area, while on the south and east, cobbles of quartzite are found especially along the channels and valley. However, the other bodies like pegmatites and quartz veins also occur within the major rock types (Figure 1).The rocks are mainly biotite –granites with medium to coarse grained, light colored rocks with some variation in biotite content. The mineral constituents are leucocratic to mesocratic. However, the biotite minerals are thread like and are arranged rough parallel streak, although some are disoriented in the groundmass. The feldspar minerals occur as fine to medium grained, though grains are cloudy as a result of alteration mostly along the twin planes, while the quartz minerals are constituents of the granitic rocks which show strong fracturing in the granitic rocks of the area (Ajibade, 1980).

The raining period runs from April to October with the highest amount of rainfall recorded in August while the average annual rainfall is between 1200mm- 1300mm (Niger State Water and Sanitation Board, 2001). The mean annual temperature is between 22°C to 25°C. The period between November and February are marked with the NE trade wind called the harmattan, which often causes very poor visibility during this period.

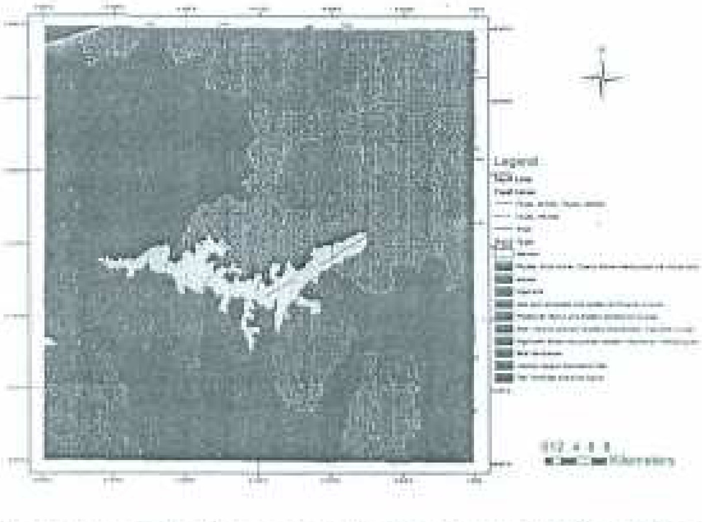


Figure 1: Geological Map of Paiko area (Modified after NGSA 2010)

Methodology

This research has utilized the electrical resistivity method in delineating the shallow consolidated basement of the study area. Sixty vertical electrical soundings were carried out using SAS 4000 model Terrameter and its accessories. The conventional Schlumberger array pattern with half electrode spacing (AB/2) varying from 1 m to a maximum of 100 m was adopted. The apparent resistivity was computed using equation 1

$$\rho_a = KR \quad (1)$$

Where

ρ_a is an apparent resistivity

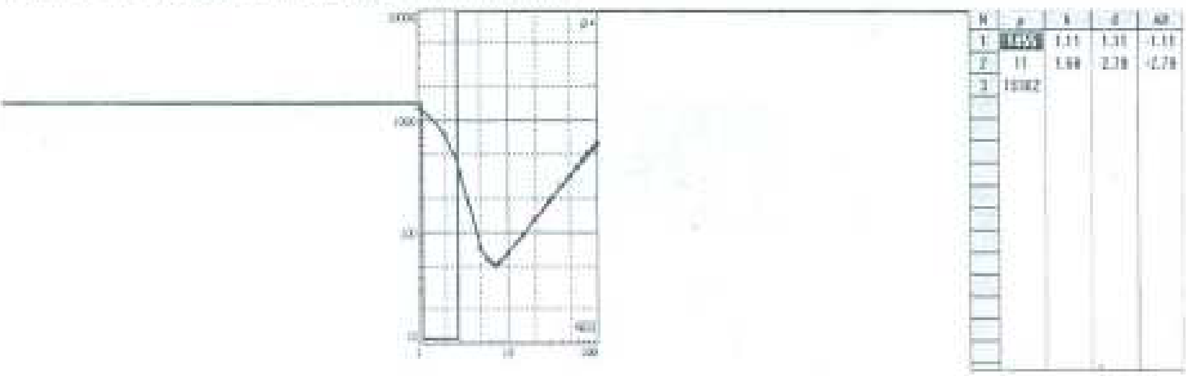
$R = \frac{\Delta V}{I}$, is the earth resistance (2)

$K = \pi\left(\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right)$ is the geometric factor (3)

The apparent resistivity values obtained from equation (1) were plotted against the half current electrode separation spacing using IPI2WIN software. From these plots, vertical electrical sounding curves were obtained (Figure 2) and qualitative deductions such as resistivity of the layers, the depth of each layer, the thickness of each layer, number of layers and curve types were made.

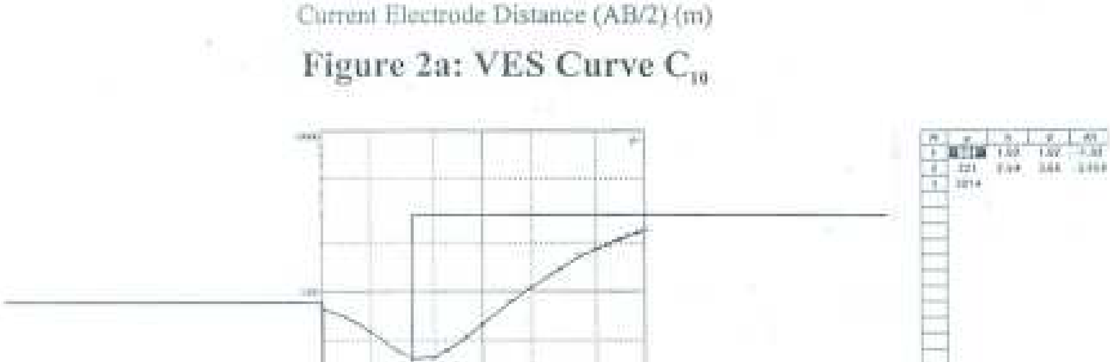
Analysis, Results and Discussion

The summary of the interpreted electrical resistivity survey is presented in Tables 1, 2, 3 and 4. Table 1 consists of VES stations A_1toC$_{10}$ while table 2 comprised of VES stations D_1 to F_{10}. Tables 3 and 4 show the depth to consolidated basement. The geoelectric section (Figure 3 a-f) reveals that the area is characterized by 3 to 4 geoelectric subsurface layers. Six profiles with sixty VES stations were covered and their subsurface geoelectric sections were presented in Figure 3. From the figure, 3- layer type occurring more and are characterized by H curve type. Some are characterized by A and K curve types. The 3- layer geoelectric sections are generally made up of topsoil, weathered/fractured layer and fresh basement rock from top to the bottom with variable depths, thicknesses and resistivities. The 4- layer geoelectric sections are characterized by HA; QA, KH and HK curve types. The observed frequencies in curve types include 21.6% of H, 0.6% of HA, 2.4% of K, 0.6% of A, 3.6% of KH, 6% of QA and 1.2% of HK. The 4- layer geoelectric section is made up of topsoil, weathered layer, fractured layer and fresh basement rock. Generally, the topsoil of the area is made up of loose sand, gravels, sandy clay, laterite and clay. In a basement complex terrain, areas with fresh basement layer depth of 4 m and below are good for building construction.



Current Electrode Distance (AB/2) (m)

Figure 2a: VES Curve C_{10}



Current Electrode Distance (AB/2) (m)

Figure 2b: VES Curve D_1

Table 1: Layers resistivity, depth, thickness and curve types.

VES station	Latitud (degree)	Longitud (degree)	No of Layer	—	—			Layer depth (m)				Layer Thickness (m)				Curve type
				ρ_1	ρ_2	ρ_3	ρ_4	d_1	d_2	d_3	d_4	h_1	h_2	h_3	h_4	
A_1	09.41662	006.61831	3	836	59	3818		2.63	7.88			2.62	5.63	=		H
A_2	09.41675	006.61790	3	1164	203	3654		1.15	12.50	=		1.15	11.40	=		H
A_3	09.41687	006.61747	4	2387	801	81.30	2464	1.23	3.32	9.32	=	1.23	2.09	6.01	=	QA
A_4	09.41715	006.61671	4	1060	472	73.30	4277	1.23	3.66	9.40	=	1.23	2.43	5.74	=	QA
A_5	09.41725	006.61631	3	918	112	1443		1.97	8.85	=		1.97	6.88	=		H
A_6	09.41749	006.61580	4	1366	768	142	4620	1.22	3.57	9.54	=	1.22	2.35	5.96	=	QA
A_7	09.41767	006.61548	3	980	297	1998		2.35	12.60	=		2.35	10.20	=		H
A_8	09.41774	006.61507	4	459	1050	286	40444	0.50	3.31	26.70	=	0.50	2.81	23.40	=	KH
A_9	09.41783	006.61461	3	1346	237	124764		6.90	23.40	=		6.90	16.50	=		H
A_{10}	09.41804	006.61410	3	1621	546	43036		3.88	59.60	=		3.68	55.70	=		H
B_1	09.41619	006.61822	3	1457	174	97309		1.43	22.00	=		1.43	20.60	=		H
B_2	09.41629	006.61772	4	1371	126	309	113313	3.48	10.60	25.00	=	3.48	7.12	14.40	=	HA
B_3	09.41635	006.61732	4	1300	582	113	145699	0.50	4.77	16.00	=	0.50	4.27	11.20	=	QA
B_4	09.41646	006.61690	3	608	157	3101		2.50	14.50	=		2.50	12.00	=		H
B_5	09.41660	006.61646	3	781	236	95144		2.25	21.00	=		2.25	18.80	=		H
B_6	09.41639	006.61587	4	290	1132	217	179122	0.97	1.58	24.80	=	0.97	0.60	23.30	=	QA
B_7	09.41653	006.61548	3	799	225	142855		2.79	23.90	=		2.79	21.10	=		H
B_8	09.41700	006.61519	4	592	2238	54.90	111801	1.10	2.5	7.16	=	1.10	1.41	4.55	=	KH
B_9	09.41700	006.61474	4	968	391	42	91457	1.25	6.72	13.20	=	1.25	5.47	6.51	=	QA
B_{10}	09.41688	006.61424	4	729	1317	143	54961	2.50	7.13	20.40	=	2.50	4.63	13.20	=	KH
C_1	09.41498	006.61760	2	387	32711			47.90	=			47.90	=			A
C_2	09.41505	006.61715	3	22130	84752	305		0.50	1.33	=		0.50	0.83	=		K
C_3	09.41500	006.61663	4	1648	512	48.80	45332	1.06	4.75	15.50	=	1.06	3.69	10.80	=	QA
C_4	09.41502	006.61623	3	2175	40.20	19998		3.52	12.50	=		3.52	9.00	=		H
C_5	09.41535	006.61672	3	215	51.80	96394		1.02	3.64	=		1.02	2.62	=		H
C_6	09.41510	006.61634	3	1487	165.0	1850		1.00	4.67	=		0.99	2.61	=		H
C_7	09.41483	006.61597	3	194	50.30	78052		1.01	3.62	=		1.01	2.61	=		H
C_8	09.41458	006.61562	3	2954	144.0	64875		1.17	9.18	=		1.17	8.01	=		H
C_9	09.41424	006.61528	3	468	27.20	38527		1.61	3.99	=		1.61	2.38	=		H
C_{10}	09.41383	006.61491	3	1455	11.00	19302		1.11	2.79	=		1.11	1.68	=		H

VES-vertical electrical sounding; ρ-layer resistivity; d- layer depth; h – layer thickness; m-met

Table 2: Layers resistivity, depth, thickness and curve types

VES station	Latitud (degree)	Longitud (degree)	No of Layer	Layer resistivity (Ωm)				Layer depth (m)				Layer Thickness (m)				Curve type
				ρ_1	ρ_2	ρ_3	ρ_4	d_1	d_2	d_3	d_4	h_1	h_2	h_3	h_4	
D_1	09.41425	006.61774	3	861	221	3014		1.02	3.66	∞		1.02	2.64	∞		H
D_2	09.41437	006.61752	3	3620	51	78106		5.41	12.70	∞		5.41	7.31	∞		H
D_3	09.41456	006.61714	3	1724	12.70	20794		0.99	3.07	∞		0.99	2.08	∞		H
D_4	09.41469	006.61676	3	1288	84.20	1377		3.58	11.70	∞		3.58	8.15	∞		H
D_5	09.41483	006.61633	3	1070	88.90	42100		3.10	21.00	∞		3.10	17.90	∞		H
D_6	09.41504	006.61570	3	547	145	104870		3.56	23.4	∞		3.56	19.80	∞		H
D_7	09.41515	006.61550	4	823	917	193	70063	1.66	3.12	27.10	∞	1.66	1.46	24.00	∞	KH
D_8	09.41552	006.61475	3	852	154	1203		5.83	18.00	∞		5.83	12.20	∞		H
D_9	09.41575	006.61440	3	4582	74814	442		1.23	4.51	∞		1.23	3.28	∞		K
D_{10}	09.41588	006.61396	3	1356	140	939		4.46	7.91	∞		4.46	3.45	∞		H
E_1	09.41379	006.61769	3	1788	106	336		1.38	14.6	∞		1.38	13.30	∞		H
E_2	09.41402	006.61705	3	1592	76.5	45894		2.76	17.70	∞		2.76	14.90	∞		H
E_3	09.41420	006.61666	3	1199	53.3	2261		4.79	12.40	∞		4.79	7.64	∞		H
E_4	09.41440	006.61623	4	580	1015	38	86514	1.33	3.62	9.67	∞	1.33	2.28	6.06	∞	QA
E_5	09.41452	006.61581	3	855	49.5	88577		2.09	8.79	∞		2.09	6.70	∞		H
E_6	09.41475	006.61539	4	315	608	107	899	2.24	5.05	10.40	∞	2.24	2.80	5.36	∞	QA
E_7	09.41489	006.61500	3	26068	58093	259		1.94	10.00	∞		1.94	8.06	∞		K
E_8	09.41994	006.61456	4	1062	130	3686	50.20	3.90	14.20	32.10	∞	3.90	10.30	17.90	∞	HK
E_9	09.41511	006.61409	3	4262	575	65539		1.08	20.20	∞		1.09	19.10	∞		H
E_{10}	09.41528	006.61363	3	2073	49	77337		4.81	11.00	∞		4.81	6.24	∞		H
F_1	09.41335	006.61747	3	1320	40.40	1394		1.60	4.26	∞		1.60	2.67	∞		H
F_2	09.41362	006.61750	3	839	33	17193		4.72	11.00	∞		4.72	6.31	∞		H
F_3	09.41386	006.61090	3	2052	44.80	46860		3.74	10.20	∞		3.74	6.45	∞		H
F_4	09.41402	006.61565	3	1005	140	1039		3.52	18.70	∞		3.52	15.20	∞		H
F_5	09.41423	006.61529	3	38093	12628	380		0.50	0.63	∞		0.50	0.13	∞		K
F_6	09.41454	006.61494	4	489	1139	95	1470	1.40	3.52	10.00	∞	1.40	2.11	6.49	∞	KH
F_7	09.41467	006.61450	3	963	198	82835		7.28	25.70	∞		7.28	18.40	∞		H
F_8	09.41468	006.61401	4	1494	536	98	2093	1.13	5.76	12.70	∞	1.13	4.63	6.94	∞	QA
F_9	09.41490	006.61370	4	762	3772	151	118102	1.11	3.55	9.62	∞	1.11	2.44	6.07	∞	KH
F_{10}	09.41498	006.61315	4	1910	280	4126	316	8.41	18.70	32.60	∞	8.41	10.30	14.00	∞	HK

VES-vertical electrical sounding; ρ-layer resistivity; d- layer depth; h – layer thickness; m-meter.

Table 3: Depths to Fresh Basement of the Area

VES STATION	Latitude (degrees)	Longitude (degrees)	Elevation (m)	Depth to Bedrock (m)
A_1	09.41662	006.61831	296	7.88
A_2	09.41675	006.61790	300	12.50
A_3	09.41687	006.61747	297	9.32
A_4	09.41715	006.61671	294	9.40
A_5	09.41725	006.61631	294	8.85
A_6	09.41749	006.61580	297	9.54
A_7	09.41767	006.61548	295	12.60
A_8	09.41774	006.61507	296	26.70
A_9	09.41783	006.61461	297	23.40
A_{10}	09.41804	006.61410	296	59.60
B_1	09.41619	006.61822	299	22.00
B_2	09.41629	006.61772	301	25.00
B_3	09.41635	006.61732	303	16.00
B_4	09.41646	006.61690	294	14.50
B_5	09.41660	006.61646	296	21.00
B_6	09.41639	006.61587	297	24.80
B_7	09.41653	006.61548	295	23.90
B_8	09.41700	006.61519	299	7.16
B_9	09.41700	006.61474	299	13.20
B_{10}	09.41688	006.61424	301	20.40
C_1	09.41498	006.61760	296	47.90
C_2	09.41505	006.61715	284	1.33
C_3	09.41500	006.61663	287	15.50
C_4	09.41502	006.61623	246	12.50
C_5	09.41535	006.61672	301	3.64
C_6	09.41510	006.61634	302	4.67
C_7	09.41483	006.61597	302	3.62
C_8	09.41458	006.61562	301	9.18
C_9	09.41424	006.61528	298	3.99
C_{10}	09.41383	006.61491	296	2.79

Table 4: Depths to Fresh Basement of the Area

VES STATION	Latitude (degrees)	Longitude (degrees)	Elevation (m)	Depth to Bedrock (m)
D_1	09.41425	006.61774	290	3.66
D_2	09.41437	006.61752	292	12.70
D_3	09.41456	006.61714	289	3.07
D_4	09.41469	006.61676	291	11.70
D_5	09.41483	006.61633	293	21.00
D_6	09.41504	006.61570	288	23.4
D_7	09.41515	006.61550	292	27.10
D_8	09.41552	006.61475	301	18.00
D_9	09.41575	006.61440	286	4.51
D_{10}	09.41588	006.61396	296	7.91
E_1	09.41379	006.61769	289	14.6
E_2	09.41402	006.61705	289	17.70
E_3	09.41420	006.61666	287	12.40
E_4	09.41440	006.61623	291	9.67
E_5	09.41452	006.61581	287	8.79
E_6	09.41475	006.61539	280	10.40
E_7	09.41489	006.61500	254	10.00
E_8	09.41994	006.61456	298	32.10
E_9	09.41511	006.61409	293	20.20
E_{10}	09.41528	006.61363	302	11.00
F_1	09.41335	006.61747	285	4.26
F_2	09.41362	006.61750	275	11.00
F_3	09.41386	006.61090	282	10.20
F_4	09.41402	006.61565	292	18.70
F_5	09.41423	006.61529	294	0.63
F_6	09.41454	006.61494	294	10.00
F_7	09.41467	006.61450	304	25.70
F_8	09.41468	006.61401	313	12.70
F_9	09.41490	006.61370	236	9.62
F_{10}	09.41498	006.61315	284	32.60

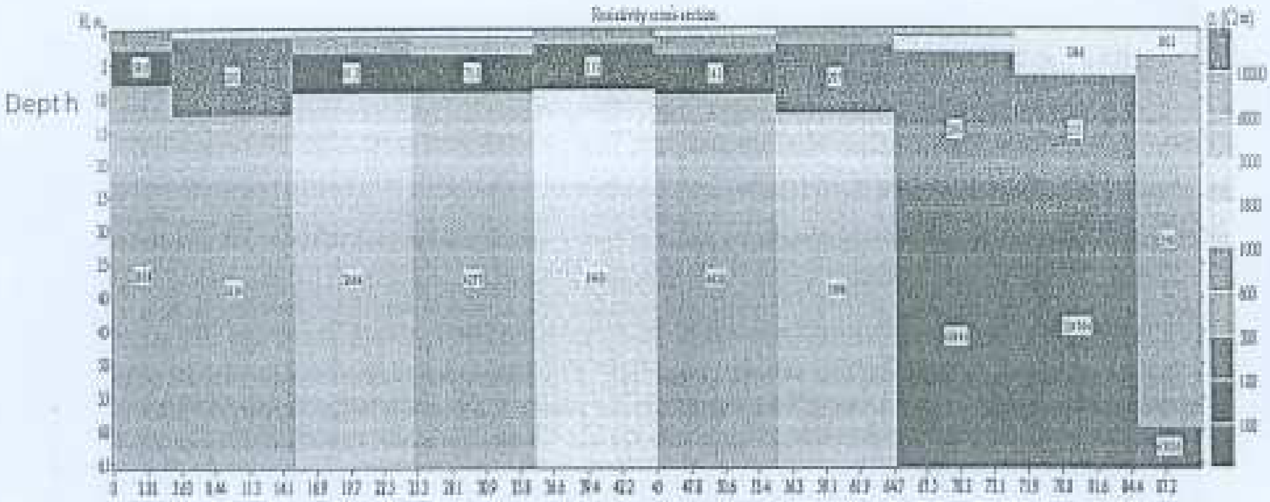


Figure 3a: Geoelectric Section for Tranverse A

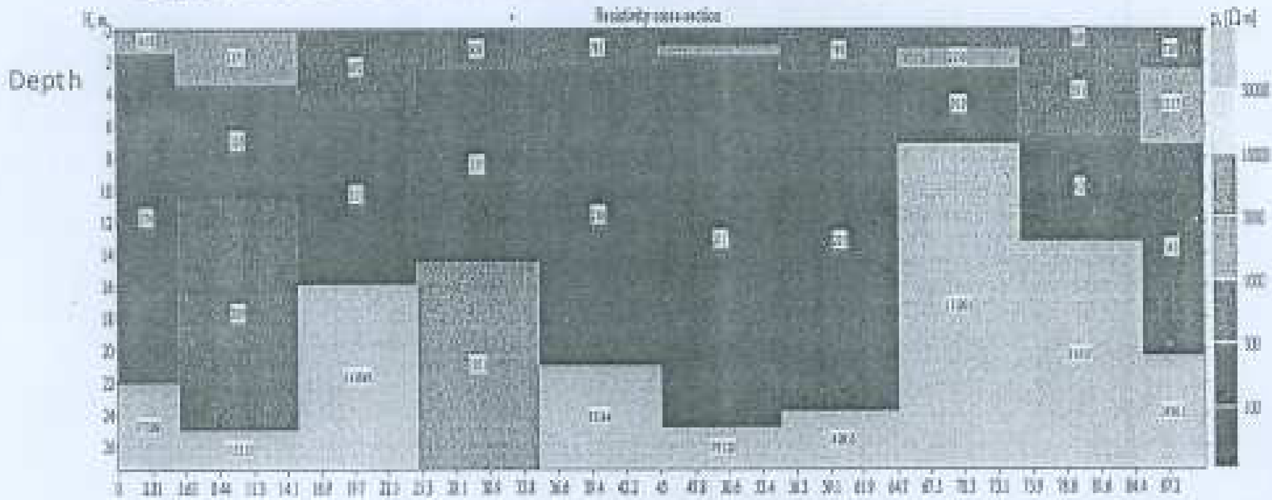


Figure 3b: Geoelectric Section for Tranverse B

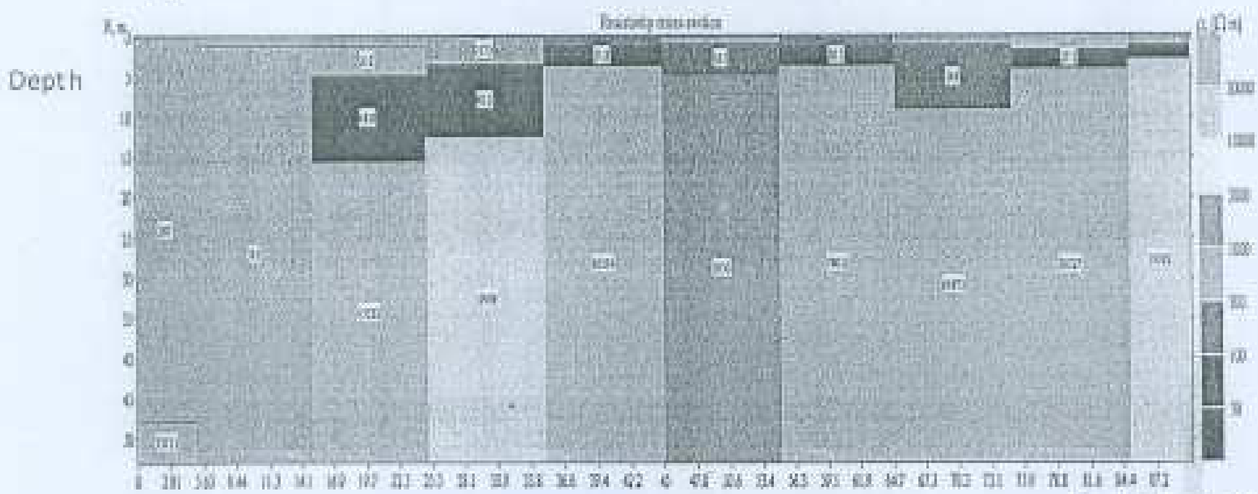


Figure 3c: Geoelectric Section for Tranverse C

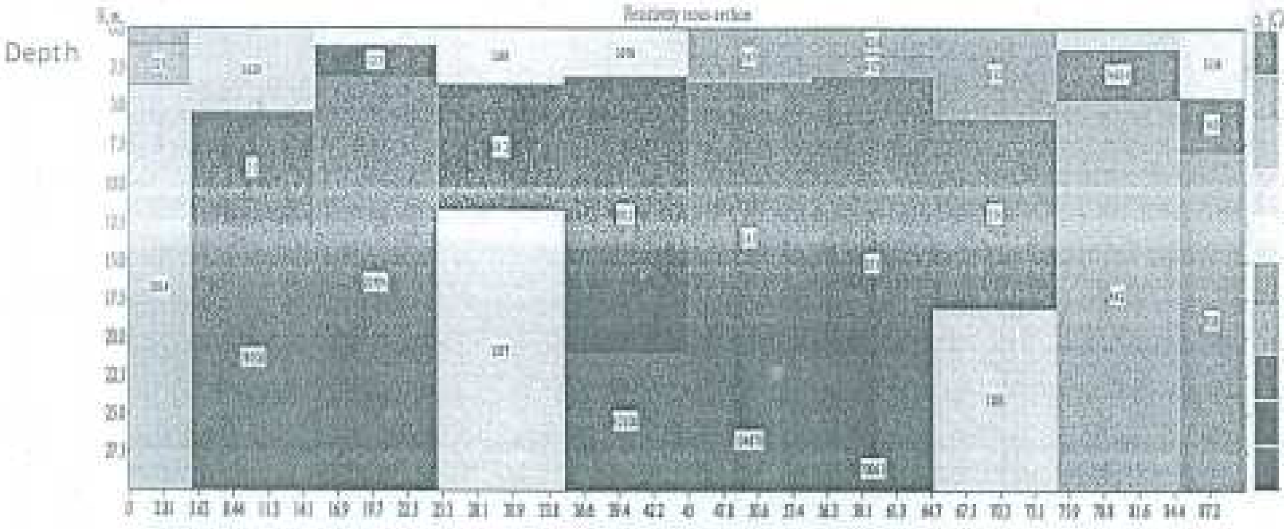


Figure 3d: Geoelectric Section for Tranverse D Profile Length

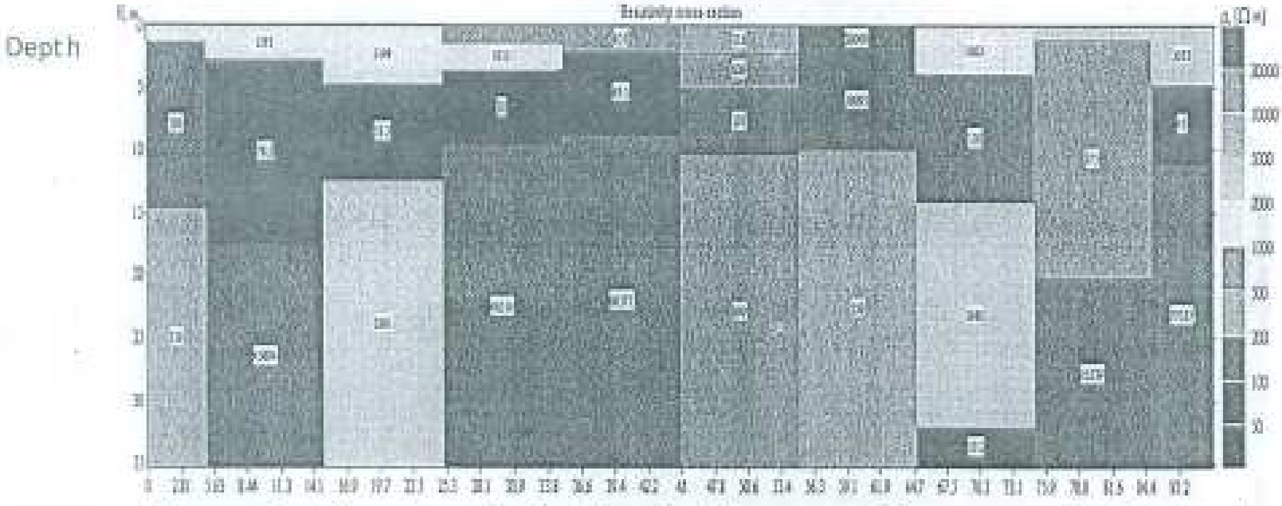


Figure 3e: Geoelectric Section for Tranverse E Profile Length

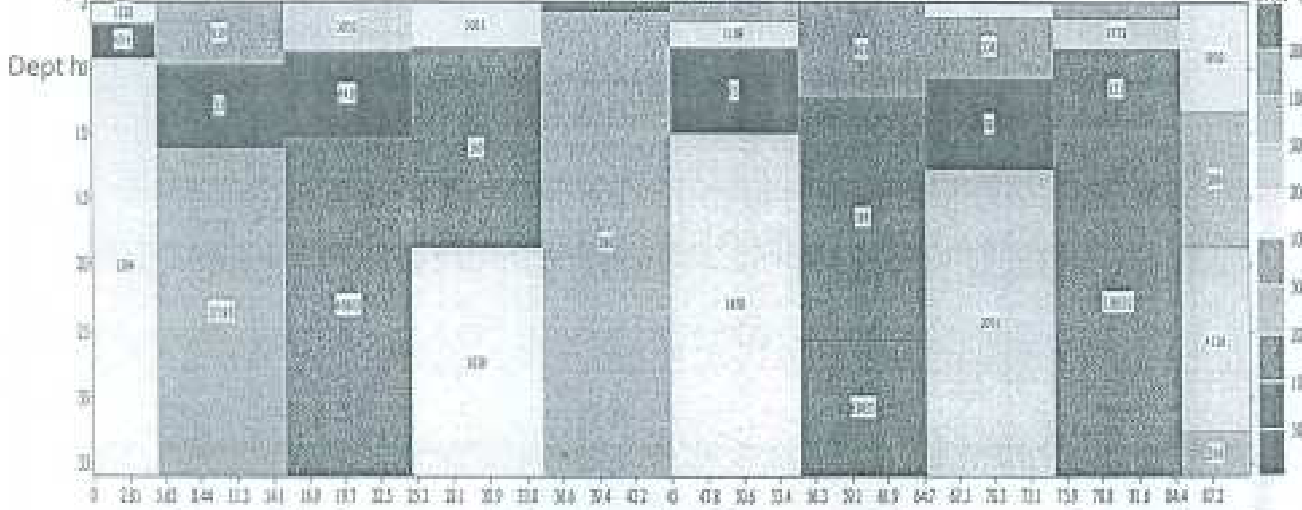


Figure 3f: Geoelectric Section for Tranverse F Profile Length

Table 5: Areas Delineated for Building Construction

VES STATION	Latitude (degrees)	Longitude (degrees)	Elevation (m)	Depth to Bedrock (m)
C_2	09.41505	006.61715	284	1.33
C_5	09.46535	006.63672	305	3.64
C_7	09.46483	006.63597	306	3.62
C_9	09.46424	006.63528	308	3.99
C_{10}	09.46383	006.63491	296	2.79
D_1	09.41425	006.61774	290	3.66
D_3	09.41456	006.61714	289	3.07
F_5	09.41423	006.61529	294	0.63

Eight VES stations were delineated for building construction having depths to fresh basement varying between 0.63 m and 3.99 m, where consolidated basement is shallow (Table 5).In investigating the continuous variation of resistivity with depth, iso-resistivity map using Golden software (Surfer 11.0) version were obtained for the layers (Figure 4). It shows the color range corresponding to resistivity range of the earth materials. The iso-resistivity map of the first layer reveal that blue represent gravels, sky blue represent sand, green correspond to laterite and yellow represent alluvial deposits (Figure 4a).

The iso-resistivity map of the second layer shows that blue color corresponds to clay and sky blue represent laterite (Figure 4b). Third layer iso-resistivity maps reveal that blue represent granite, sky blue represent gneiss, green correspond to igneous rock, yellow represent gabbros rock and red correspond to ultramafic rock (Figure 4c).

The depth to consolidated basement map shows the depth distribution within the area (figure 5). From the map, the area with black and blue coloration corresponds to depth range of 0 m to 8 m and therefore be the suitable areas suggested for building construction.

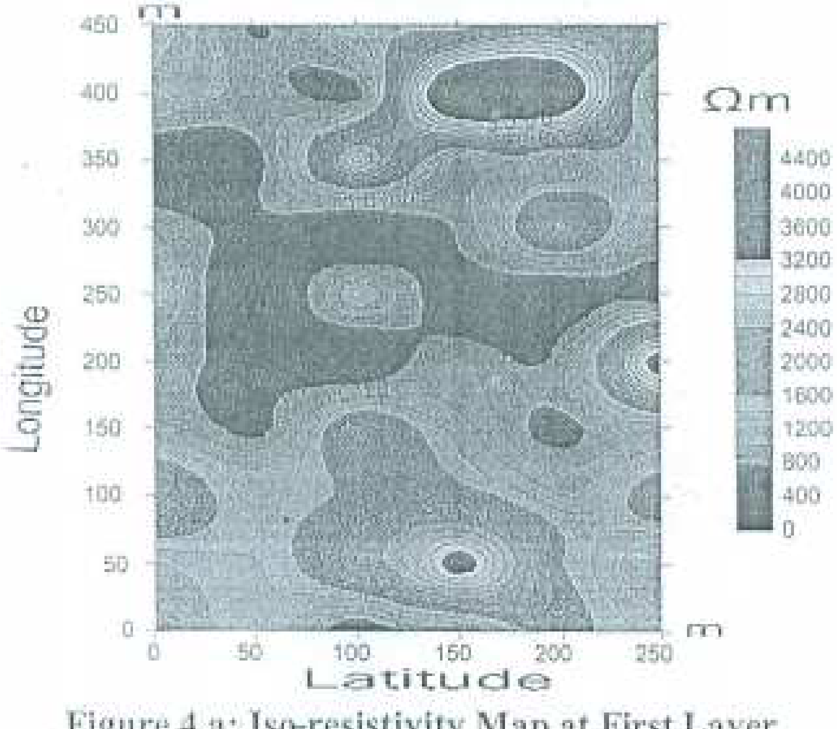


Figure 4 a: Iso-resistivity Map at First Layer

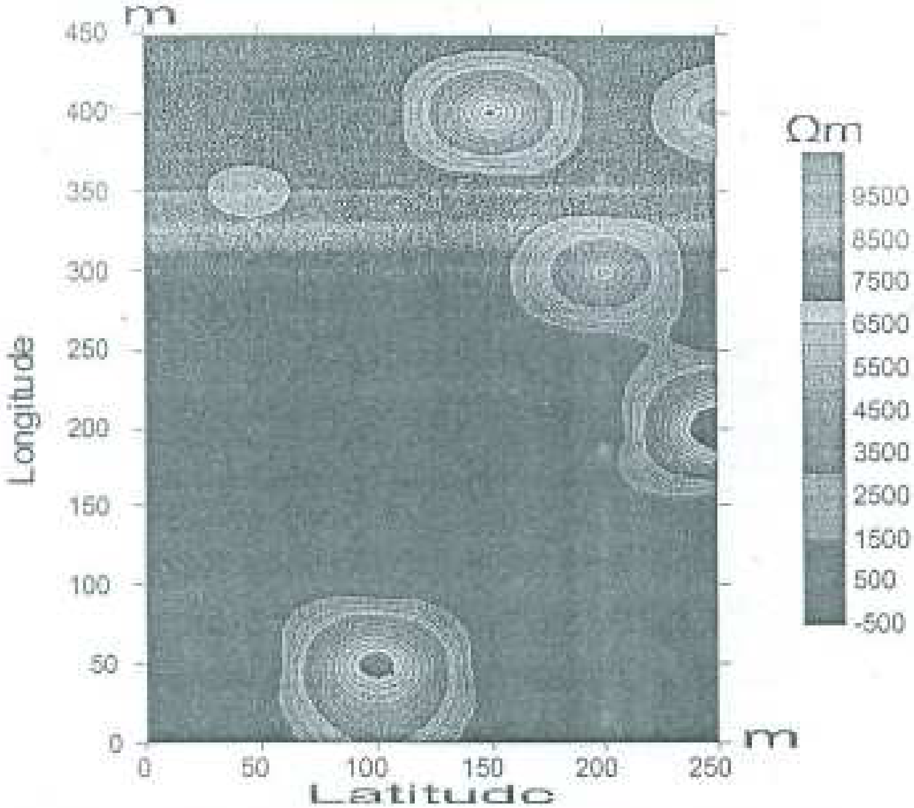


Figure 4 b: Iso-resistivity Map at Second Layer

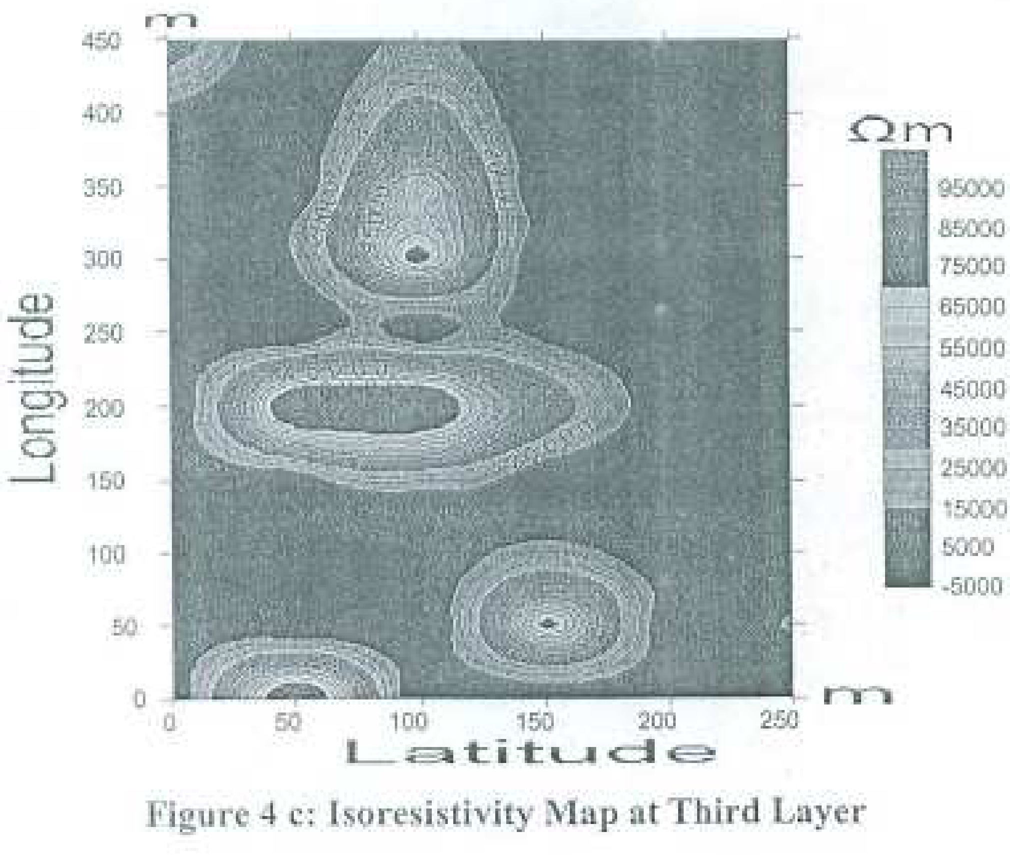


Figure 4 c: Isoresistivity Map at Third Layer

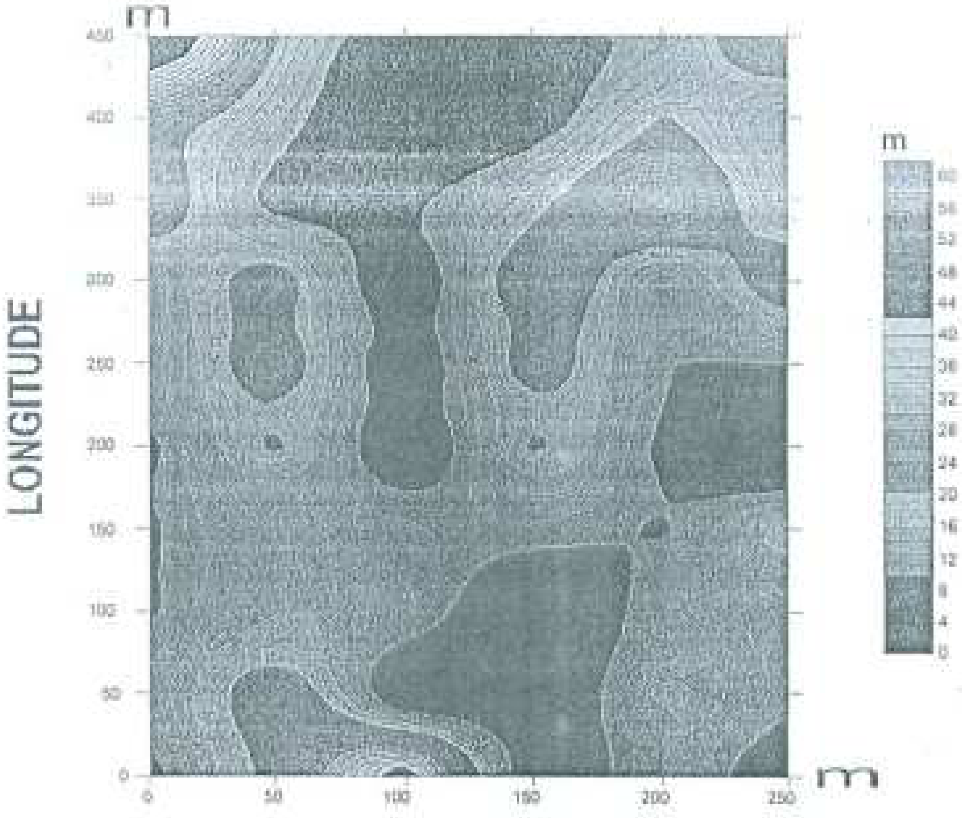


Figure 5: Depth to Basement Map of the Area

Conclusion

The use of various electrical resistivity parameters (resistivity of the layer, depth of the layer and thickness of the layer) were employed to determine the suitable site for building construction. Three to four distinct geoelectric layers were observed namely; Top layer, weathered layer, fractured layer, and fresh basement layer. The observed frequencies in curve types include 21.6% of H, 0.6% of HA, 2.4% of K, 0.6% of A, 3.6% of KH, 6% of QA and 1.2% of HK. Eight VES stations were delineated for building construction, having depths to fresh basement varying between 0.63 m and 3.99 m.Government and estate developers inPaiko are encouraged to make use of the results of this study for building construction site selection to reduce the problem of building collapse and cracking of walls. More research work in this area would contribute to solving the problemof collapse of building completely.

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