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THE ASSESSMENT OF AQUIFER POTENTIALS AND AQUIFER VULNERABILITY OF SOUTHERN PAIKO, NORTH CENTRAL NIGERIA, USING GEOELECTRIC METHOD

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ABSTRACT

Vertical electrical sounding (VES) was carried out in southern Paiko, north central Nigeria, using Abem Terrameter model SAS 4000. The study area which is about 100km square, falls within the basement complex region of Nigeria with an elevation of 304m above sea level. The study was carried out with a view of determining the subsurface layer parameters (resistivities, depths and thicknesses) that were employed in delineating groundwater potential and sites for structural development of the area. A total of six transverses with ten VES stations along each traverse, having separation of 50m apart, were investigated. It has a maximum current electrode separation (AB/2) of 100m. Three to four distinct geoelectric layers were observed namely; Top layer, weathered layer, fractured layer, and fresh basement layer. Top layer has resistivity, depth and thickness range of 194-4582Ωm, 0.5-47.9m and 0.5-47.9m respectively. Second layer has a range of: resistivity, 11-8475.2Ωm; depth, 1.33-59.6m and thickness, 0.13-55.7m. Third layer has a range of: resistivity, 42.0-9730.9Ωm; the depth and thickness are not defined in some part of the area, while the fourth layer has a resistivity range of 50.2-9145.7Ωm, its depth and thickness are not defined. Eighteen VES stations were delineated as groundwater potentials of the area, having third and fourth layer resistivities ranging from 98Ωm to 309Ωm. Depths range found were from 12.50m to 25.70m and thickness varying between 6.94m and 23.98m. The southeastern and northwestern part of the study area having good aquifer at depths ranging from 21.00m to 26.70m, thickness varying between 18.75m and 55.7m are good sites for location of viable boreholes for potable water. Also the southeast and northwestern parts of the area were delineated for structural development having depths to bedrock varying between 0.63m and 3.99m. Most part of the study area have weak protective capacity, hence are prone to contamination.

KEYWORDS: Vertical electrical sounding, groundwater potentials, Southern Paiko, protective capacity, structural development sites, depths to bedrock

INTRODUCTION

Paiko is the headquarters of Paikoro local government area in Niger state, north central Nigeria. The area is considered as one of the most promising areas for future sustainable developments in Niger State because of the location of Ibrahim Badamasi Babagida University (IBBU), Lapai, around the area. The availability of safe and potable water in an environment is a veritable index of a tremendous role to the development and growth of a community (Mohammed et al., 2012). The growing demand for potable water supply has been the major problem of most urban centres in Nigeria. Inhabitants of Paiko depend primarily on hand dug wells and three surface water. At present, groundwater from shallow hand dug wells and few boreholes constitute major source of drinking water supply in the area. The yields are variable and less than expected average considered enough for the growing population. Paiko as a local government headquarter and with the location of the IBB University around the area, is experiencing population explosion and hence, new and big structures are cropping up. Presently in Nigeria, there are several cases of collapsed building 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 bedrock is intruded to the surface which can provide strong base for site construction. Geophysical data provides vital information about the geology of subsurface strata, which is required for any engineering construction, drilling, production or mining activity. Therefore, scrupulous geophysical surveys and assessments of the earth are critical to reduce risk, failure and the cost of design of engineering foundations and structures. Careful geophysical studies that are supported by improved drilling techniques yield very favourable results even in the problematic areas of the basement complex (Offodile, 1983).

In order to ease the problem of water scarcity,

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reduce structural failures and improve the living standard of the community, this study was undertaken to delineate the subsurface geological layers and their hydrogeological characteristics/groundwater potentials in the light of the notably sustainable groundwater yield of typical basement terrains. In a typical Precambrian Basement Complex area, groundwater reservoir is usually contained within the weathered and the tectonically induced geological features; fractured/fissured, sheared or jointed/faulted basement rock unit(s). These geological processes alter the rock units to reduce resistivity at depth of burial and hence increase the porosity and permeability of such units for groundwater accumulation, discharge and exploitation. Groundwater is not found everywhere, though, fairly distributed all over the world. The availability of groundwater in a particular place can only be ascertained using geophysical techniques in which vertical electrical sounding (VES) is widely used.

The increase in population of Paiko has resulted to generation of more wastes which are potential contaminants of groundwater. It is important to delineate areas that have good protection for the underlying aquiferous units and areas where the aquiferous layers are prone to easy contamination. The location of dumpsites and sewage in many parts of Nigeria are done without consideration to the hydrogeological settings of the area, thereby rendering the future of groundwater at risk. Because the people of Paiko are mostly farmers and animal rearers, the widespread use of chemical products, coupled with the disposal of large volumes of waste materials, poses the potential for widely distributed groundwater contamination (Obiora et al., 2015).

The Paiko area is underlain by four geologic sections, namely; laterite, quartz, sandy clay as the first layer, weathered basement as the second layer, fractured basement as the third layer and fresh basement as the fourth layer. It is also observed that a number of rock types which suffered weathering, fracturing and decompositions are granites and quartzites (Dangana, 2007). The low resistivity zone within the bedrock suggests that it is associated with fractured zone (Asry et al., 2012). Groundwater occurrence in a Precambrian basement terrain is hosted within zones of weathering and fracturing which often are not continuous in vertical and lateral extent (Abubakar and Auwal, 2012). The basement complex terrain has many challenges as regards groundwater potential evaluation (Olasehinde and Amadi, 2009). Groundwater usually occurs in discontinuous aquifers in basement complex area. Defining the potentials of the aquifers is normally a tedious exercise because of the intricate properties of the basement rocks (Adeniji et al., 2013). The aquifers of the basement complex rocks are the regolith and the fractures in the fresh bed rock which are known to be interconnected at depth (Abubakar and Auwal, 2012). The electrical resistivity method involving the vertical electrical sounding (VES) technique has extensively gained application in environmental, groundwater and engineering geophysical investigations (Abubakar and Danbatta, 2012). This, therefore, constitutes the basis of the choice of geoelectrical resistivity sounding survey in this study.

2. Geology of the study area

Paiko falls within the north central Nigerian basement complex. It has an elevation of 304m above sea level. It is bounded by latitudes 9^{o}25′N and 9^{o}27′N and longitudes 6 ^{o}37′E and 6 ^{o}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, other bodies like pegmatites and quartz veins also occur within the major rock types. 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).

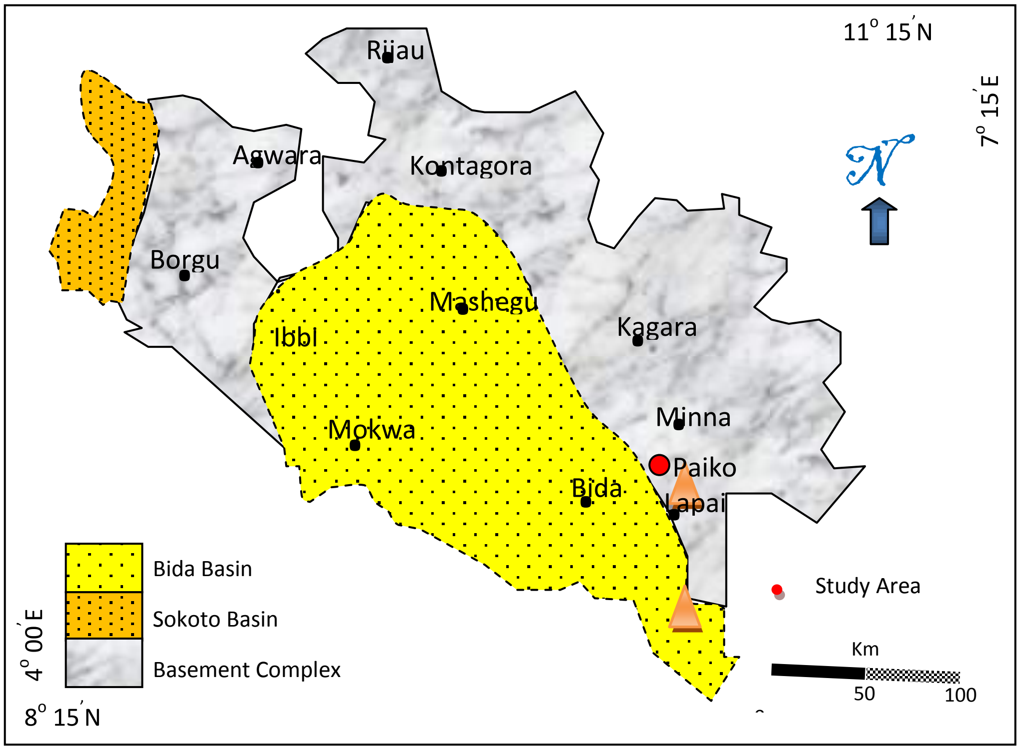


Figure 1.1: Geological Map of Niger State Basement Complex and Sedimentary Basins (Amadi et al., 2012)

The raining period runs from April to October with the highest amount of rainfall recorded in August while the average annual rainfall is between 1200 mm - 1300 mm. The mean annual temperature is between 22^0C to 25^0C. The period between November and February are marked with the NE trade wind called the harmattan, which often causes very poor visibility during its period. There are three surface water available in the area but they are contaminated as a result of man and animal activities in the water. The climatic and the hydrogeologic conditions control the surface and the subsurface water in the area. Chilton and Smith-Carington (1984) and Jones (1985) suggested that the weathered rocks form the important aquifer in the crystalline rocks, while Clark (1985) and Edet et al. (1994) held the view that ground water occurs in fractures of the bedrock. However, Offodile (1983), Wright (1992) and Alagbe (2002) have indicated that ground water occurs in a continuum within both the weathered basement and fractures within the basement rocks. Fig. 1 shows the geological map of Niger State Basement complex and Sedimentary Basins.

3. Methodology

This research has employed the electrical resistivity method in determining the subsurface layer parameters (resistivities, depths and thickness) that were used in delineating the groundwater potentials and sites for structural development of the area. Six transverses with ten VES stations along each traverse, having separation of 50m apart were investigated. A total of sixty vertical electrical soundings (Fig. 2) were carried out using SAS 4000 model Terrameter and its accessories. The conventional Schlumberger array pattern with half electrode spacing (AB/2) varying from 1m to a maximum of 100m was adopted. The apparent resistivity was computed using equation 1

$\rho_a = KR$ -- 1

Where ρ_a is an apparent resistivity,

$R = \frac{\Delta V}{I}$ is the 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 reflection coefficients (Rc) and fracture contrasts (Fc) of the fresh basement rock of the groundwater potential of the study area were calculated using (Bhattacharya and Patra, 1968; Loke, 1999; Adeniji et al., 2013),

$R_C = \frac{\rho_n - \rho_{n-1}}{\rho_n + \rho_{n-1}}$, ------------------------------------ 4

$F_C = \frac{\rho_n}{\rho_{n-1}}$, -------------------------------------- 5

where ρ_n is the layer resistivity of the nth layer and ρ_{n-1} is the layer resistivity overlying the nth layer.

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

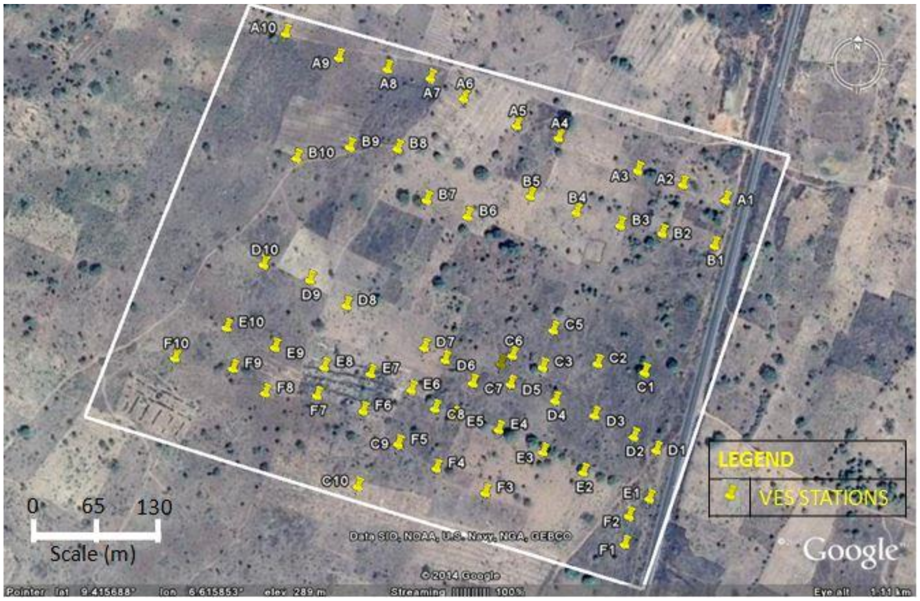


Figure 2: Google earth map of the study area showing VES stations

4. RESULTS AND DISCUSSION

The summary of the interpreted electrical resistivity survey is presented in Tables 1a, 1b, 2a and 2b. Table 1a consists of VES stations A_1 to C_{10} while Table 1b comprised of VES stations D_1 to F_{10}. Tables 2a and 2b show the depth to bedrock. The geoelectric sections (Figs. 3a-f) reveal that the area is characterized by 3 to 4 geoelectric subsurface layers. Six transverses with sixty VES stations (Fig. 2) were covered and their subsurface geoelectric sections are presented in Fig. 3. From the figure, the geoelectric subsurface section ranged from 3 to 4 layers, with 3- layer type occurring more and it is characterized by H curve type, while 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. Fig. 4 (a, b) are examples of VES curve obtained from the field data. 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. Weathered and fractured layers constitute the aquiferous units where they have appreciable depths, thicknesses and low resistivities in the basement complex terrain. The southeast and northwestern part of the study area has been delineated as having good groundwater potentials and having fractured layer resistivities ranging from 98Ωm to 309Ωm. The depths of these weathered/fractured layers are found to be from 12.50m to 25.70m and thickness varying between 6.94m and 23.98m as shown in Table 3. In a basement complex terrain, areas with overburden thickness of 15m and above, and fractured layer resistivity of less than 400Ωm are good for groundwater development. Table 4 shows eighteen VES stations which were delineated as good groundwater potentials. They are located within the southeast and northwestern parts of the study area. The highest groundwater yield is often obtained from a fractured aquifer or a subsurface sequence that has a combination of a significantly thick and sandy weathered layer and fractured aquifer (Olorunfemi, 2009). A correlation of the nearby borehole log with the VES Lithological formation is in agreement (Figure 5). The results of pumping test from two boreholes located in the study area around VES stations A_8 and D_7 respectively are presented in Table 5.

The Groundwater potential indices (Table 3) were used to determine the groundwater potentials of the study area (Table 4). The reflection coefficient at fresh basement rock interface provides some insight into the aquiferous nature of the basement rocks. An area of lower reflection coefficient value exhibits a fracture of the basement rock, and hence, has a higher water potential (Olayinka, 1996). In this study, VES stations with reflection coefficient varying between 0.42 and 0.99 are presented in Table 3. Therefore, VES stations A_8, B_1, B_5, B_6, B_7, D_6 and D_7 are observed to be the best aquifer potentials of the area, having a fine aquifer at depth ranging from 21.00m to 26.70m, with thickness varying between 18.75m and 23.98m (Table 4). A contour map of aquifer resistivity of the study area (Figure 6) shows that aquifer resistivity is high in the eastern part of the area, and this area may be made up of low conducting materials. Also, the greater part of the study area has very low aquifer resistivity. Fig. 7 shows the distribution of aquifer thickness. High thickness is obtainable in the southeast and extreme northwest of the study area. These areas were delineated as probable best water bearing zone, and because of the low resistivity values in these areas, high clay content may also be inferred in these areas. From fig. 8, it is seen that the protective capacity is poor (yellow) in part of the central and eastern region. The green colour indicates areas with weak protective capacity and the red colour indicates areas with moderate protective capacity. The study area has unconfined aquifer.

Table 1a: Layers resistivity, depth, thickness and longitudinal conductance

VES Station	Latitude (degree)	Longitude (degree)	No of Layer	Layer resistivity (Ωm)				Layer depth (m)				Layer Thickness (m)				Long. Cond.
				ρ_1	ρ_2	ρ_3	ρ_4	d_1	d_2	d_3	d_4	h_1	h_2	h_3	h_4	(S) Ω^{-1}
A_1	09.41662	006.61831	3	836	58.60	3818		2.63	7.88	∞		2.62	5.63	∞		0.1
A_2	09.41675	006.61790	3	1164	203	3654		1.15	12.50	∞		1.15	11.40	∞		0.06
A_3	09.41687	006.61747	4	2387	801	81.30	2464	1.23	3.32	9.32	∞	1.23	2.09	6.01	∞	0.07
A_4	09.41715	006.61671	4	1060	472	73.30	4277	1.23	3.66	9.40	∞	1.23	2.43	5.74	∞	0.08
A_5	09.41725	006.61631	3	918	112	1443		1.97	8.85	∞		1.97	6.88	∞		0.06
A_6	09.41749	006.61580	4	1366	768	142	4620	1.22	3.57	9.54	∞	1.22	2.35	5.96	∞	0.04
A_7	09.41767	006.61548	3	980	297	1998		2.35	12.60	∞		2.35	10.20	∞		0.03
A_8	09.41774	006.61507	4	459	1050	286	4044.4	0.50	3.31	26.70	∞	0.50	2.81	23.40	∞	0.08
A_9	09.41783	006.61461	3	1346	237	1247.64		6.90	23.40	∞		6.90	16.50	∞		0.07
A_{10}	09.41804	006.61410	3	1621	546	4303.6		3.88	59.60	∞		3.68	55.70	∞		0.1
B_1	09.41619	006.61822	3	1457	174	9730.9		1.43	22.00	∞		1.43	20.60	∞		0.12
B_2	09.41629	006.61772	4	1371	126	309	1133.13	3.48	10.60	25.00	∞	3.48	7.12	14.40	∞	0.05
B_3	09.41635	006.61732	4	1300	582	113	1456.99	0.50	4.77	16.00	∞	0.50	4.27	11.20	∞	0.1
B_4	09.41646	006.61690	3	608	157	3101		2.50	14.50	∞		2.50	12.00	∞		0.08
B_5	09.41660	006.61646	3	781	236	9514.4		2.25	21.00	∞		2.25	18.80	∞		0.08
B_6	09.41639	006.61587	4	290	1132	217	1791.22	0.97	1.58	24.80	∞	0.97	0.60	23.30	∞	0.21
B_7	09.41653	006.61548	3	799	225	1428.55		2.79	23.90	∞		2.79	21.10	∞		0.09
B_8	09.41700	006.61519	4	592	2238	54.90	1118.01	1.10	2.5	7.16	∞	1.10	1.41	4.55	∞	0.08
B_9	09.41700	006.61474	4	968	391	42	9145.7	1.25	6.72	13.20	∞	1.25	5.47	6.51	∞	0.16
B_{10}	09.41688	006.61424	4	729	1317	143	5496.1	2.50	7.13	20.40	∞	2.50	4.63	13.20	∞	0.09
C_1	09.41498	006.61760	2	387	3271			47.90	∞			47.90	∞			0.12
C_2	09.41505	006.61715	3	2213	8475	305		0.50	1.33	∞		0.50	0.83	∞		0.01
C_3	09.41500	006.61663	4	1648	512	48.80	4533.2	1.06	4.75	15.50	∞	1.06	3.69	10.80	∞	0.22
C_4	09.41502	006.61623	3	2175	40.20	1999.8		3.52	12.50	∞		3.52	9.00	∞		0.22
C_5	09.41535	006.61672	3	215	51.80	9639.4		1.02	3.64	∞		1.02	2.62	∞		0.05
C_6	09.41510	006.61634	3	1487	165	1850		1.00	4.67	∞		0.99	2.61	∞		0.02
C_7	09.41483	006.61597	3	194	50.30	7805.2		1.01	3.62	∞		1.01	2.61	∞		0.05
C_8	09.41458	006.61562	3	2954	144	6487.5		1.17	9.18	∞		1.17	8.01	∞		0.06
C_9	09.41424	006.61528	3	468	27.20	3852.7		1.61	3.99	∞		1.61	2.38	∞		0.15
C_{10}	09.41383	006.61491	3	1455	11.	1930.2		1.11	2.79	∞		1.11	1.68	∞		0.15

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

Table 1b: Layers resistivity, depth, thickness and longitudinal conductance

VES station	Latitude (degree)	Longitud (degree)	No of Layer	Layer resistivity (Ωm)				Layer depth (m)				Layer Thickness (m)				Long. Cond. (S) Ω^{-1}
				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	∞		0.01
D_2	09.41437	006.61752	3	3620	51	7810.6		5.41	12.70	∞		5.41	7.31	∞		0.14
D_3	09.41456	006.61714	3	1724	12.70	2079.4		0.99	3.07	∞		0.99	2.08	∞		0.16
D_4	09.41469	006.61676	3	1288	84.20	1377		3.58	11.70	∞		3.58	8.15	∞		0.1
D_5	09.41483	006.61633	3	1070	88.90	4210.0		3.10	21.00	∞		3.10	17.90	∞		0.2
D_6	09.41504	006.61570	3	547	145	1048.7		3.56	23.4	∞		3.56	19.80	∞		0.14
D_7	09.41515	006.61550	4	823	917	193	7006.3	1.66	3.12	27.10	∞	1.66	1.46	24.00	∞	0.12
D_8	09.41552	006.61475	3	852	154	1203		5.83	18.00	∞		5.83	12.20	∞		0.08
D_9	09.41575	006.61440	3	4582	7481	442		1.23	4.51	∞		1.23	3.28	∞		0.01
D_{10}	09.41588	006.61396	3	1356	140	939		4.46	7.91	∞		4.46	3.45	∞		0.03
E_1	09.41379	006.61769	3	1788	106	336		1.38	14.6	∞		1.38	13.30	∞		0.13
E_2	09.41402	006.61705	3	1592	76.5	4589.4		2.76	17.70	∞		2.76	14.90	∞		0.2
E_3	09.41420	006.61666	3	1199	53.3	2261		4.79	12.40	∞		4.79	7.64	∞		0.14
E_4	09.41440	006.61623	4	580	1015	38	8651.4	1.33	3.62	9.67	∞	1.33	2.28	6.06	∞	0.16
E_5	09.41452	006.61581	3	855	49.5	8857.7		2.09	8.79	∞		2.09	6.70	∞		0.14
E_6	09.41475	006.61539	4	315	608	107	899	2.24	5.05	10.40	∞	2.24	2.80	5.36	∞	0.05
E_7	09.41489	006.61500	3	2606	5809	259		1.94	10.00	∞		1.94	8.06	∞		0.01
E_8	09.41994	006.61456	4	1062	130	3686	50.20	3.90	14.20	32.10	∞	3.90	10.30	17.90	∞	0.05
E_9	09.41511	006.61409	3	4262	575	6553.9		1.08	20.20	∞		1.09	19.10	∞		0.03
E_{10}	09.41528	006.61363	3	2073	49	7733.7		4.81	11.00	∞		4.81	6.24	∞		0.13
F_1	09.41335	006.61747	3	1320	40.40	1394		1.60	4.26	∞		1.60	2.67	∞		0.07
F_2	09.41362	006.61750	3	839	33	1719.3		4.72	11.00	∞		4.72	6.31	∞		0.19
F_3	09.41386	006.61090	3	2052	44.80	4686		3.74	10.20	∞		3.74	6.45	∞		0.14
F_4	09.41402	006.61565	3	1005	140	1039		3.52	18.70	∞		3.52	15.20	∞		0.11
F_5	09.41423	006.61529	3	3809	1262	380		0.50	0.63	∞		0.50	0.13	∞		0.01
F_6	09.41454	006.61494	4	489	1139	95	1470	1.40	3.52	10.00	∞	1.40	2.11	6.49	∞	0.07
F_7	09.41467	006.61450	3	963	198	8283.5		7.28	25.70	∞		7.28	18.40	∞		0.09
F_8	09.41468	006.61401	4	1494	536	98	2093	1.13	5.76	12.70	∞	1.13	4.63	6.94	∞	0.07
F_9	09.41490	006.61370	4	762	3772	151	1181	1.11	3.55	9.62	∞	1.11	2.44	6.07	∞	0.04
F_{10}	09.41498	006.61315	4	1910	280	4126	316	8.41	18.70	32.60	∞	8.41	10.30	14.00	∞	0.03

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

Table 2a: Depths to Bedrock 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 2b: Depths to Bedrock 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

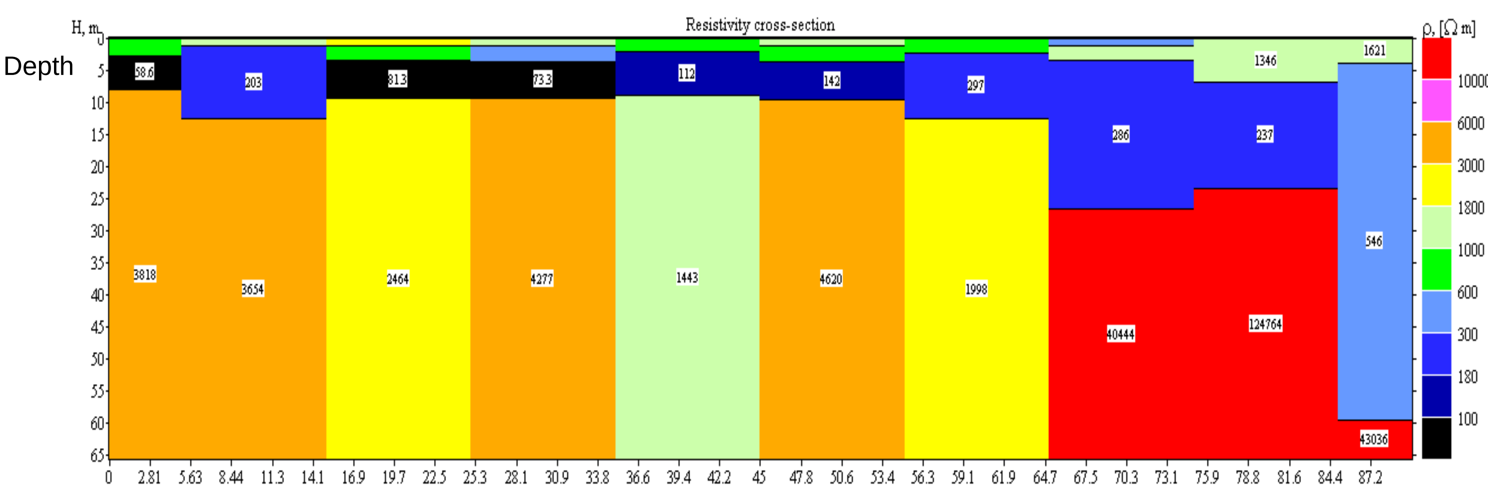


Figure 3a: Geoelectric Section for Tranverse A

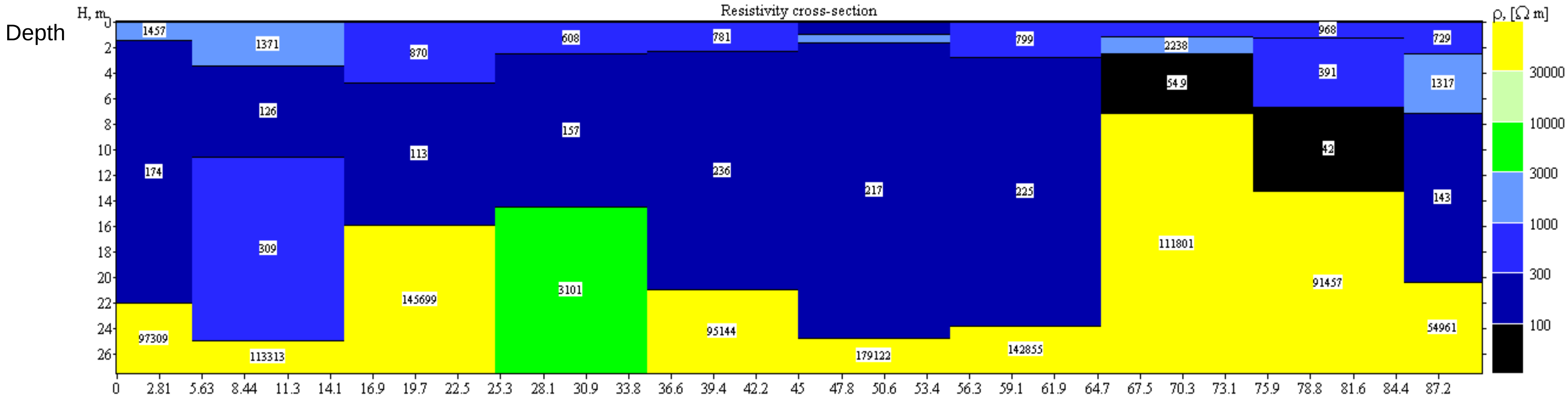


Figure 3b: Geoelectric Section for Tranverse B

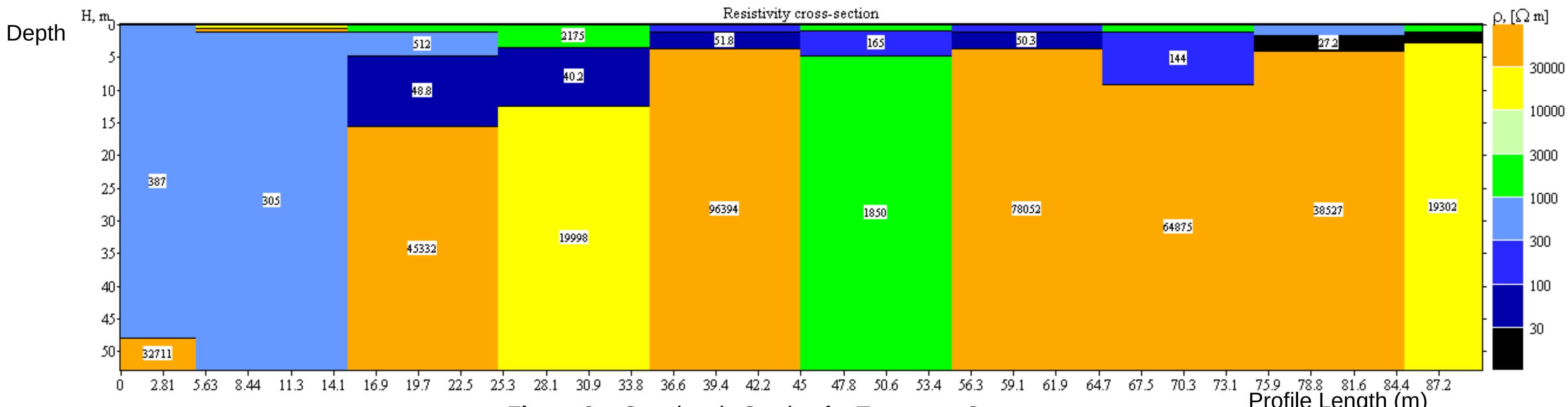


Figure 3c: Geoelectric Section for Tranverse C

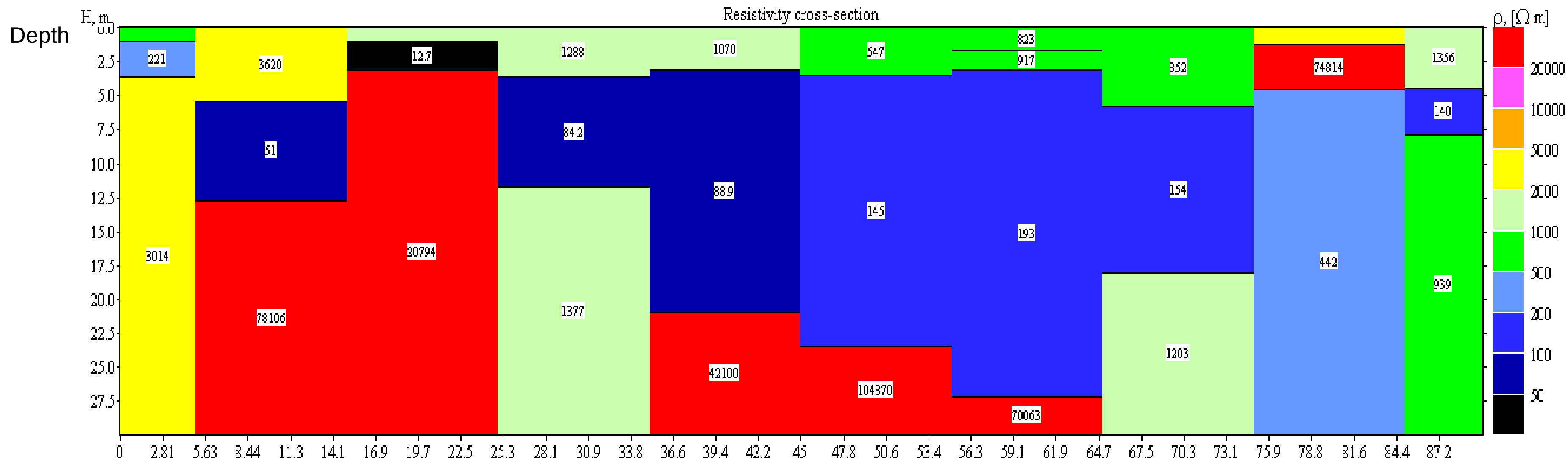


Figure 3d: Geoelectric Section for Tranverse D

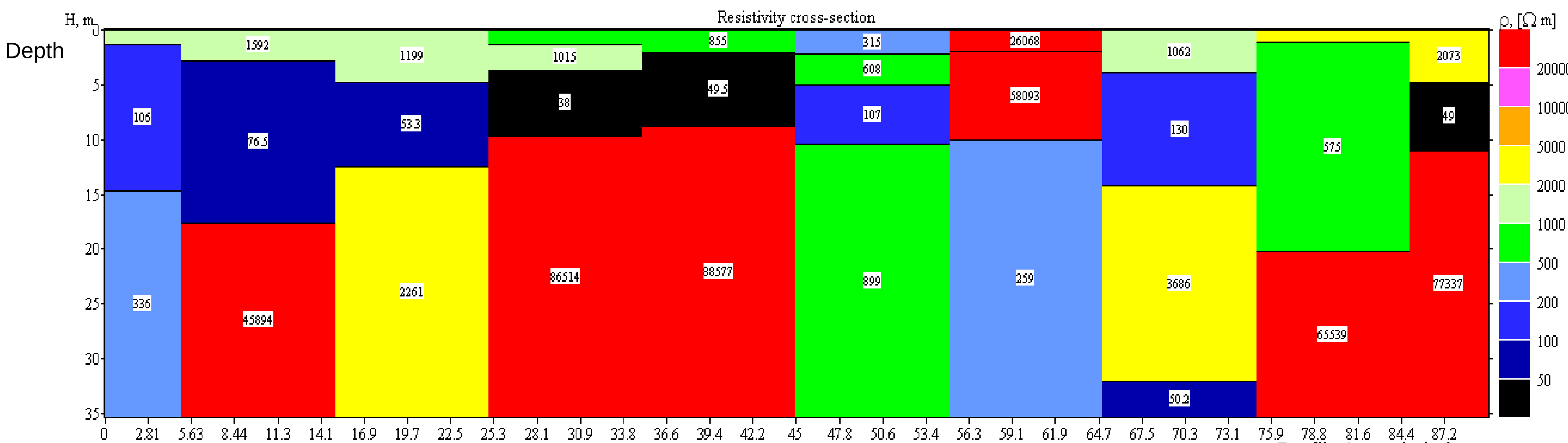


Figure 3e: Geoelectric Section for Tranverse E

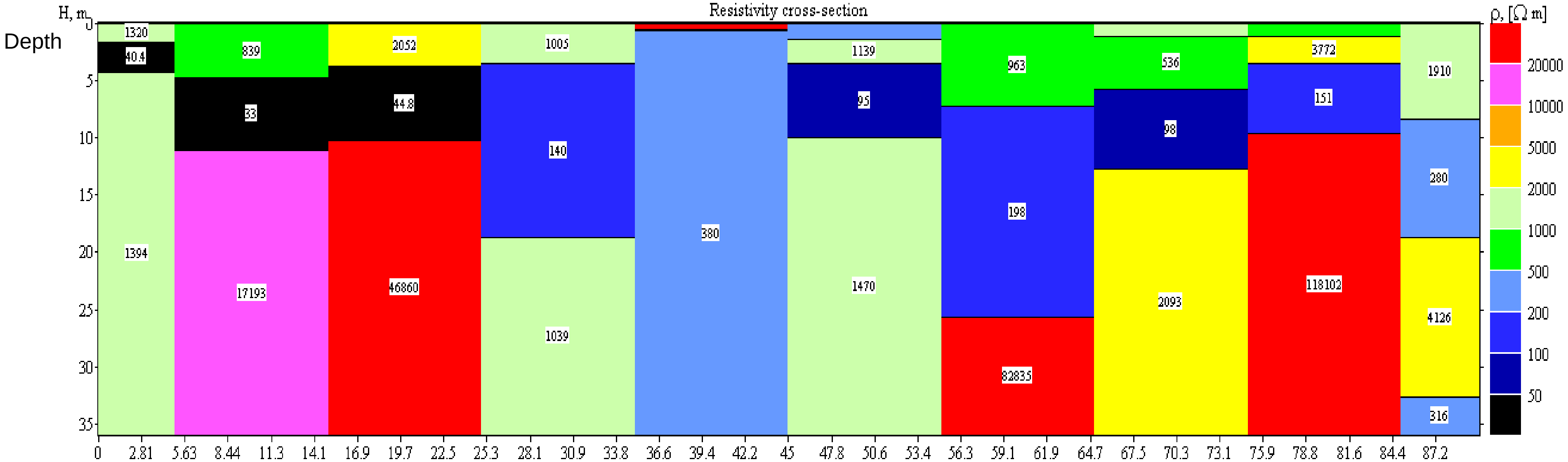
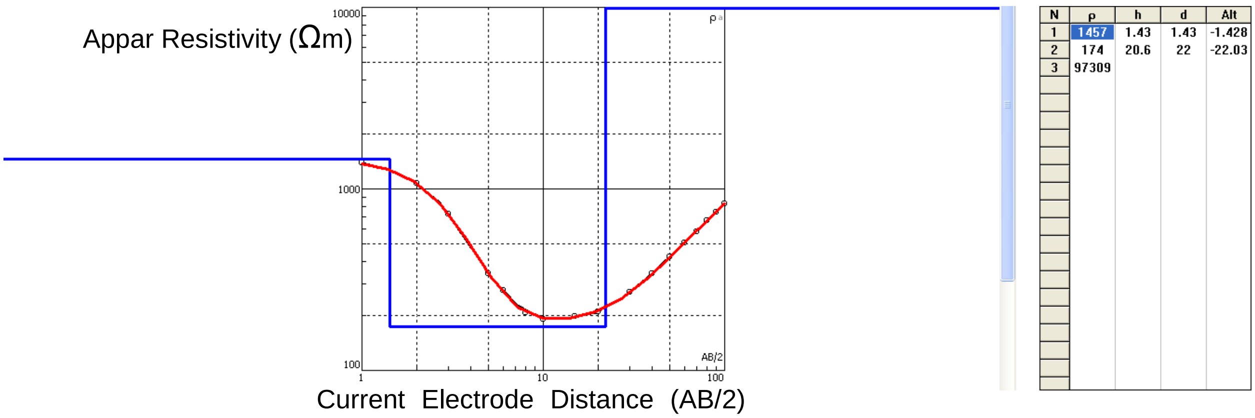
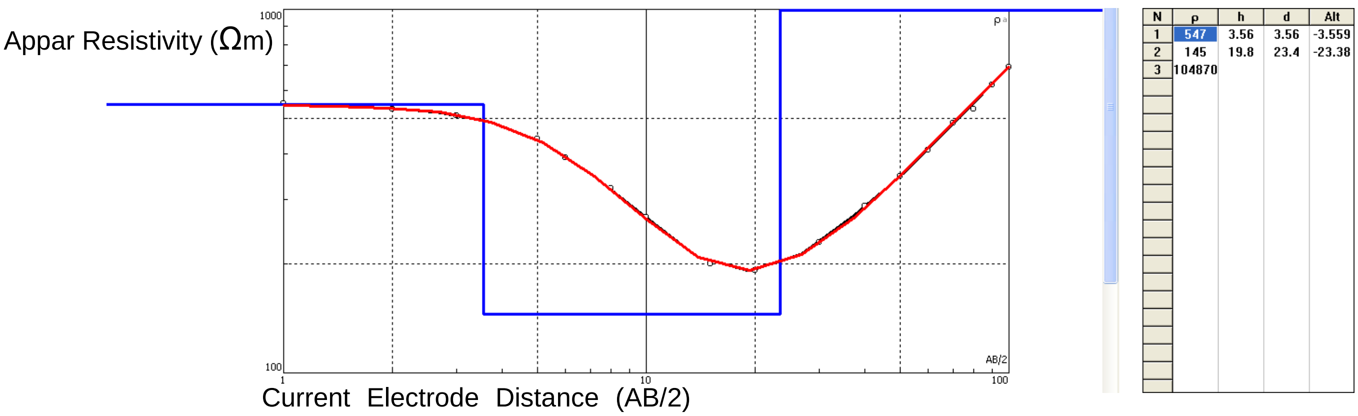


Figure 3f: Geoelectric Section for Tranverse F



N	ρ	h	d	Alt
1	1457	1.43	1.43	-1.428
2	174	20.6	22	-22.03
3	97309			

Figure 4a: VES Curve B_1



N	ρ	h	d	Alt
1	547	3.56	3.56	-3.559
2	145	19.8	23.4	-23.38
3	104870			

Figure 4b: VES Curve D_6

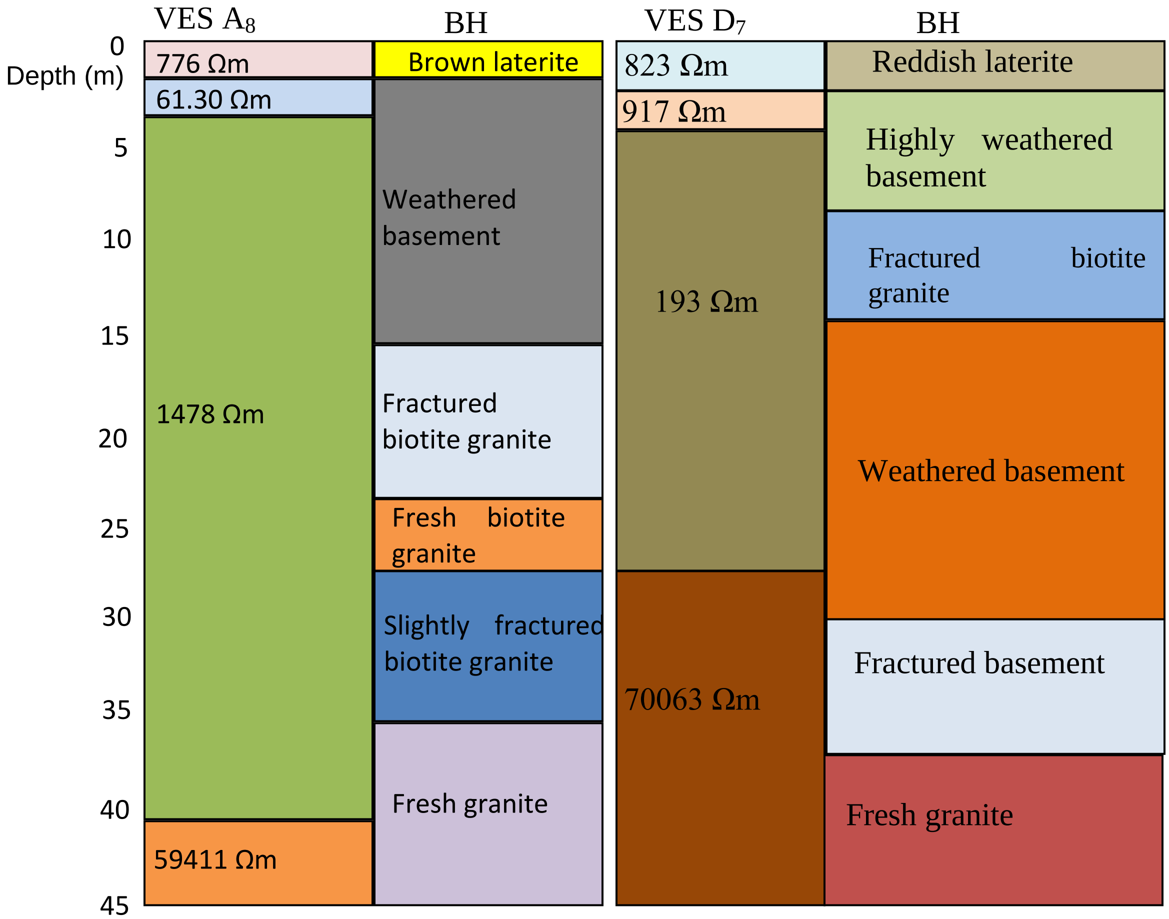


Figure 5: Correlation of VES Lithology with nearby Borehole logs

Table 3: Groundwater Potential Indices

VES Stations	Weathered/fractured resistivity (Ωm)	Weathered/fractured thickness (m)	Overburden depth (m)	Reflection CoefficientRc	Fracture Contrast Fc
A_2	203	11.35	12.50	0.894737	18.0000
A_7	297	10.25	12.60	0.741176	672.7273
A_8	286	23.39	26.70	0.57186	272.381
A_9	237	16.50	23.40	0.996208	526.4304
B_1	174	20.57	22.00	0.99643	559.2471
B_2	309	14.40	25.00	0.42069	245.2381
B_3	113	11.23	16.00	0.67482	194.158
B_5	236	18.75	21.00	0.995051	403.1525
B_6	217	23.22	24.80	0.67828	191.696
B_7	225	21.11	23.90	0.996855	634.9111
B_{10}	143	13.27	20.40	0.80411	108.5800
D_6	145	19.84	23.40	0.997238	723.2414
D_7	193	23.98	24.10	0.65225	210.469
E_8	130	10.30	14.20	0.931866	283.5385
F_4	140	15.18	18.70	0.762511	742.1429
F_7	198	8.42	25.70	0.995231	418.3586
F_8	98	6.94	12.70	0.69085	182.836
F_{10}	280	10.29	18.70	0.872901	147.3571

Table 4: Aquifer Potentials of the Area.

VES Stations	Layer Number	Layer resistivity (Ωm)	Layer depth (m)	Layer thickness (m)	Curve Type
A_2	2	203	12.50	11.35	H
A_7	2	297	12.60	10.25	H
A_8	3	286	26.70	23.39	KH
A_9	2	237	23.40	16.50	H
B_1	2	174	22.00	20.57	H
B_2	3	309	25.00	14.40	H
B_3	3	113	16.00	11.23	HA
B_5	2	236	21.00	18.75	QA
B_6	3	217	24.80	23.22	QA
B_7	2	225	23.90	21.11	H
B_{10}	3	143	20.40	13.27	KH
D_6	2	145	23.40	19.84	H
D_7	3	193	24.10	23.98	KH
E_8	2	130	14.20	10.30	HK
F_4	2	140	18.70	15.18	H
F_7	2	198	25.70	8.42	H
F_8	3	98	12.70	6.94	QA
F_{10}	2	280	18.70	10.29	HK

Table 5: Nearby Boreholes Pumping Test

Parameters	Borehole 1	Borehole 2
Borehole depth	54 m	50 m
Static water level	5.96 m	4.78 m
Pump type and capacity	Franklin1hp	Same
Top of casing above ground level	0.2 m	0.2 m
Pump setting	20 m	40 m
Borehole yield	75 L/min	16 L/min
Water level	37.45 m	37.11 m
Drawn down	31.49 m	32.33 m
Recovery drawn down	31.49 m	32.33 m

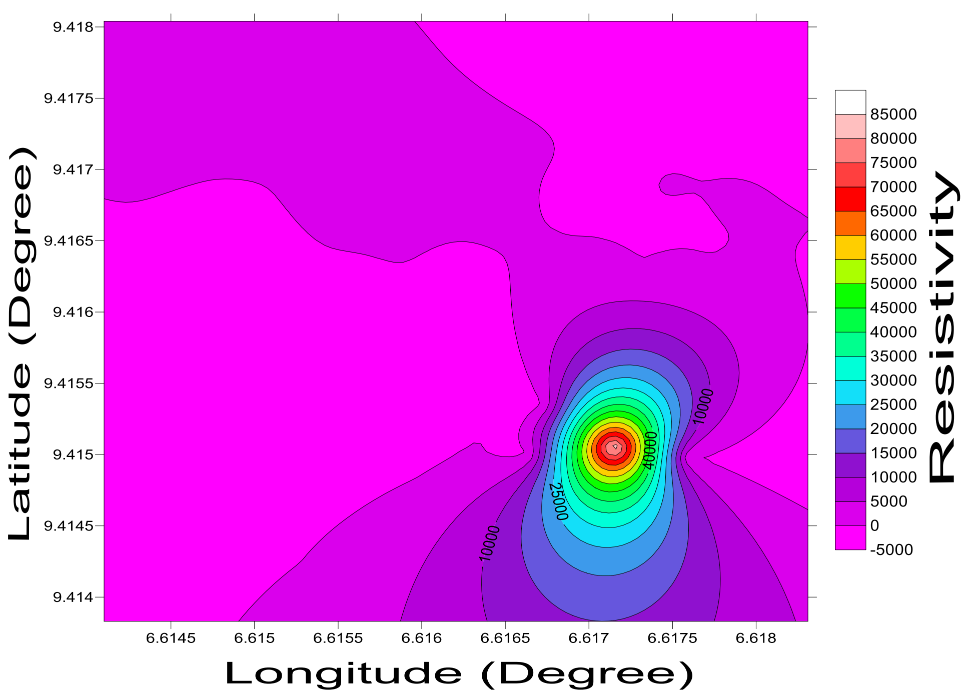


Figure 6: Contour map showing distribution of resistivity in the study area

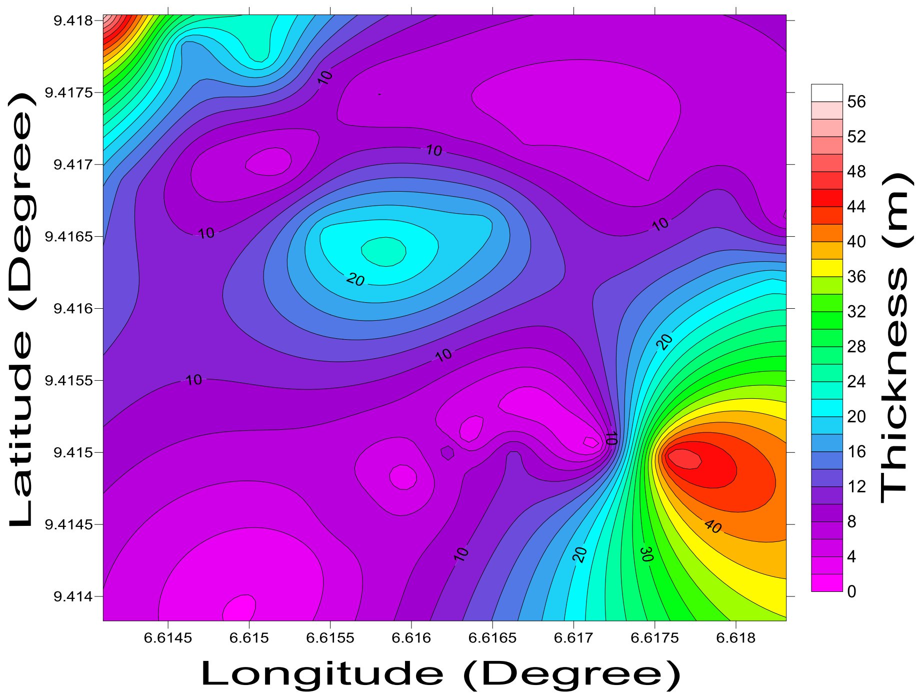


Figure 7: Contour map showing the distribution of thickness in the study area

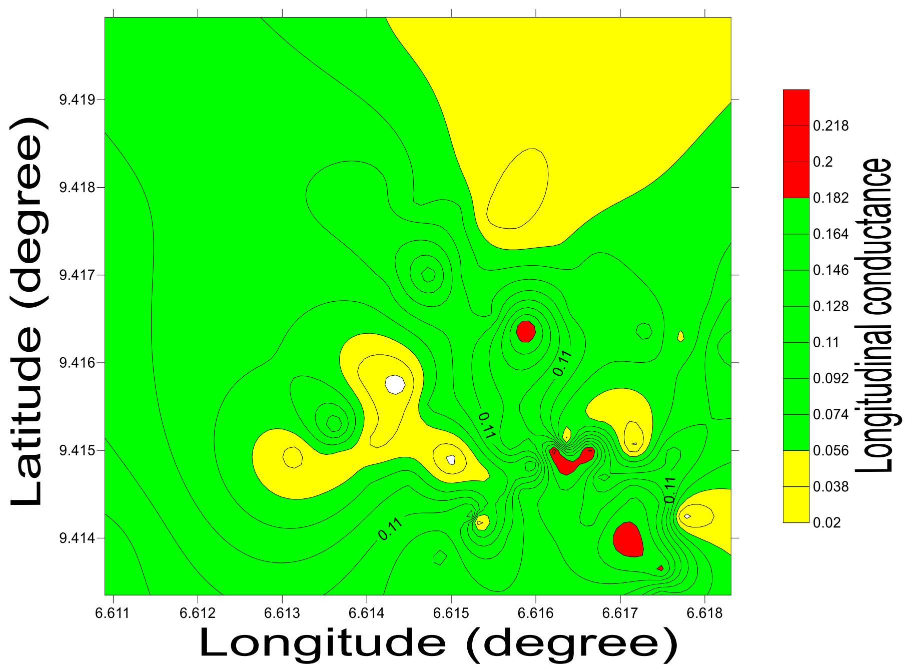


Figure 8: Contour map showing distribution of longitudinal conductance in the study area

Fig. 9 is a contour map showing the distribution of depth to bedrock. The depth to bedrock is high in the southeast and extreme northwest; as such these areas can be delineated for structural development. Table 6 shows the VES stations delineated for structural development having depths to bedrock varying between 0.63m and 3.99m, where bedrock is intruded to the surface. These areas are considered suitable for massive engineering structures with strong base for solid foundation. This study advocates pre-construction foundation survey at any civil engineering site, since it can reliably evaluate the geotechnical competence of the subsurface geologic materials that may pose danger or otherwise favour the design and construction of engineering structures in the area.

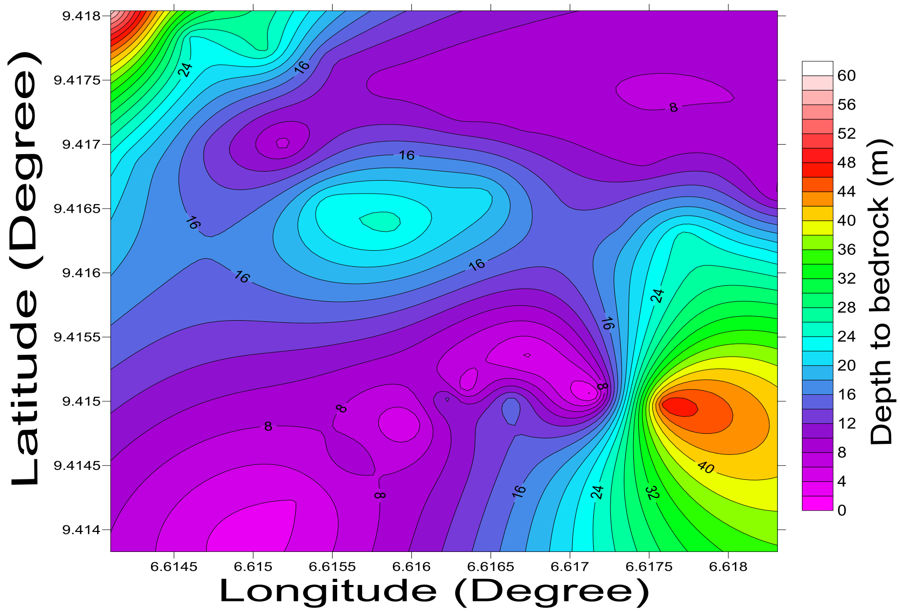


Figure 9: Contour map of depth to bedrock in the study area

Table 6: Areas for Structural Development

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

In investigating the continuous variation of resistivity with depth, isoresistivity map using Golden Surfer 11.0 version was obtained for the layers (Fig. 10a-c). It shows the colour range corresponding to resistivity values of the earth materials. The isoresistivity map of the first layer (Fig. 10a) reveals that blue represents gravels, sky blue represents sand, green corresponds to laterite and yellow represents alluvial deposits (Parasnis, 1986; Milsom, 2003). The isoresistivity map of the second layer (Fig. 10b) shows that blue colour corresponds to clay, sky blue represents laterite and green corresponds to groundwater. Third layer isoresistivity map (Fig. 10c) reveals that blue represents granite, sky blue represents gneiss, green corresponds to igneous rock, yellow represents gabbros rock and red corresponds to ultramafic rock (Parasnis, 1986; Milsom, 2003).

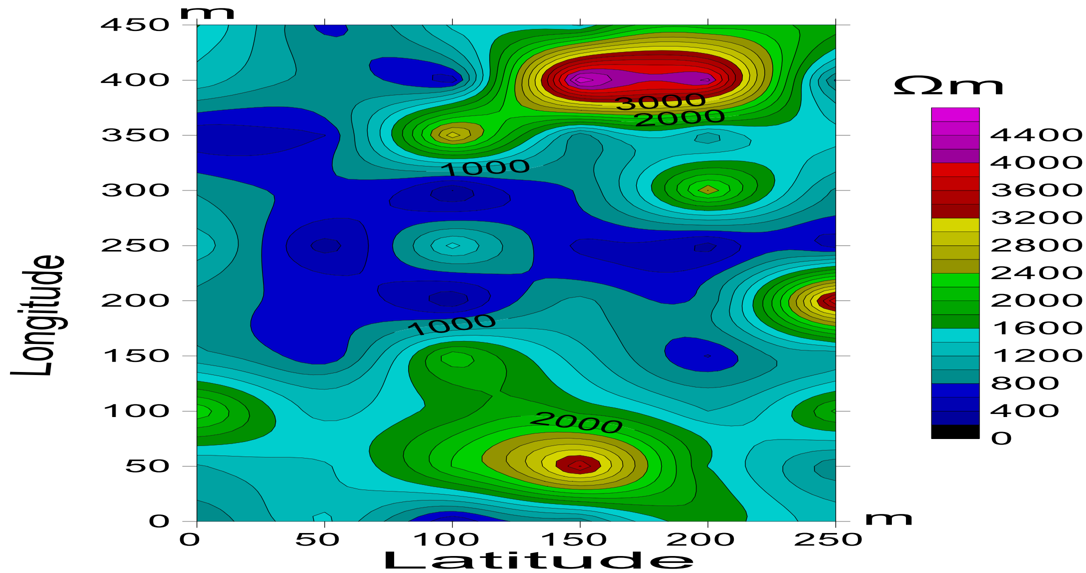


Figure 10a: Isoresistivity Map for Layer One

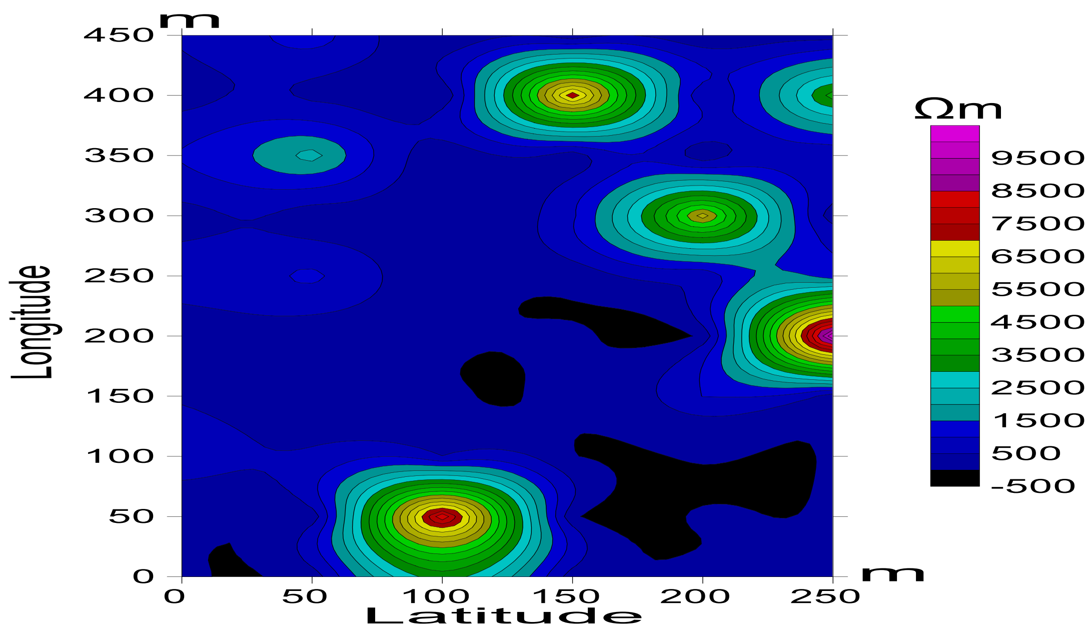


Figure 10b: Isoresistivity Map for Layer Two

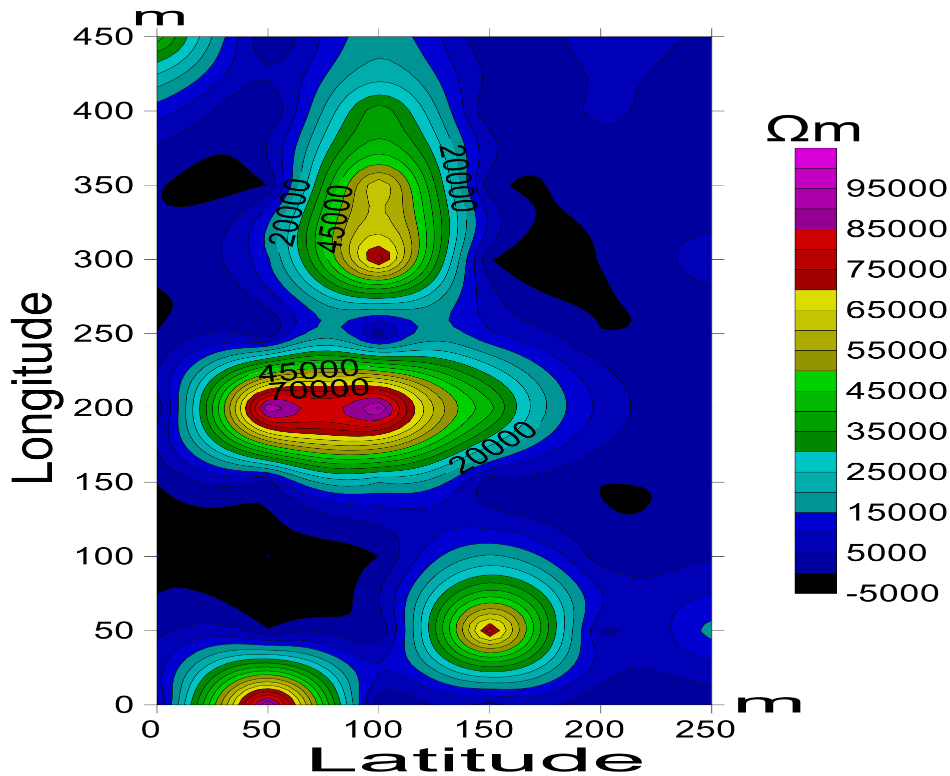


Figure 10c: Isoresistivity Map for Layer Three

CONCLUSION

This study was carried out with a view to determine the subsurface layer parameters (resistivities, depths and thicknesses) that were employed in delineating the groundwater potentials and sites for structural development of southern Paiko. A total of six transverses with ten VES stations along each traverse, having a separation of 50m apart and a maximum current electrode separation (AB/2) of 100m were investigated. Three to four distinct geoelectric layers were observed namely; Top layer, weathered layer, fractured/fresh layer, and fresh basement layer. Eighteen VES stations were delineated as ground water potentials of the area, having third and fourth layer resistivities ranging from 98Ωm to 309Ωm. Depths range delineated are from 12.50m to 25.70m with thickness varying between 6.94m and 23.98m. VES stations A_8, B_1, B_5, B_6, B_7, D_6 and D_7, having fine aquifer with depth ranging from 21.00m to 26.70m and thickness varying between 18.75m and 23.98m are good sites for location of viable boreholes for good potable water. Eight VES stations (C_2, C_5, C_7, C_9, C_{10}, D_1, D_3 and F_5) were delineated as good sites for structural development having depths to bedrock varying between 0.63m and 3.99m. Groundwater developments can be concentrated in the areas of possible groundwater potentials as indicated in Table 4. Government and individuals who wish to site boreholes, construct estate and complex in southern Paiko are encouraged to make use of the results of this study to reduce the problem of borehole failure, building collapse and cracking of building walls and foundations. Most parts of southern Paiko have weak protective capacity, hence are prone to contamination. It is not advisable to locate boreholes in those areas with weak or poor protective capacity. The study area has unconfined aquifer. More research work in this area using other geophysical methods would contribute to solving the water problem and collapse of building completely.

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