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Geotechnical Investigation of Proposed Site for Building Suitability using Geological and Geophysical Methods in Ughelli Metropolis

Juliet Emudianughe[1], Sunday Utah[1], Jerry Osokpor[1] and Omolemo Omo-Irabor[1]
[1]Department of Earth Sciences, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria.
emudianughe.juliet@fupre.edu.ng

Abstract
Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT) technique have been employed to investigate a proposed building site along Ughelli-Patani Road, Ekiugbo, Ughelli North, Delta state, Nigeria. Subsurface rock(soil) type and bedrock depth with priority to aquifer depth and shallow depth profiling as an index for engineering property of the subsurface. Electrical imaging resistivity survey was carried out along three spreads with maximum spread length of 130m using the 2D-Wenner configuration in N-S dip direction, in addition to five Vertical Electrical Sounding using the Schlumberger configuration with maximum current spread (AB) of 140m. VES points were selected at strategic position with three VES points on the three ERT spreads to integrate all data. Data from 25 sample points and test borehole(14m /45ft deep) were used to support geophysical models. Geophysical models show horizontal and vertical distribution of electrical properties (resistivity values) due to the inhomogeneous subsurface. Models show layers with low resistivity values delineated as silty clay to wet clay, and layers with high resistivity values as silty sand to coarse sand. Delineated layer depth and thickness from geophysical models show high degree with sample analysis results and logs from test borehole.

Keywords: Resistivity, Ughelli South, Bedrock, Tomography.

1. Introduction
News of collapse building and limited access to quality waterwhich has characterized the media, hascalled for deeper play in site engineering, geotechnical, soil and ground water exploration studies. Acquisition of quality geo parameters has become more holistic and technical. These acquired geo data serve as the fundamental input to geo modelling which act as a major guide to site engineering and drilling.

Electrical resistivity method is the most widely used surface geophysical method. It has played and continue to play key role in geoelectric subsurface studies. Resistivity survey in many cases substantially reduces the drilling costs by allowing a more intelligent selection where and how depth must be drilled to reach the target. In most cases, the combination and integration data from different geophysical techniques and drilling will provide the optimal solution for an investigated area (Abu Heen, 2017).

Resistivity surveys are done to ascertain the subsurface electrical properties distribution by making surface measurement. True resistivity values are estimated from the measurements. Resistivity is a function of geological parameters such as porosity, water saturation and minerals of the rock (Niwas et al., 2003; Akintorinwa et al., 2011).

Geophysicists have also used resistivity method to determine the thickness of bedrock, clay aquitards, saltwater intrusion, the vertical extent of certain types of soil and the spread of groundwater contamination(Anomoharan,2013). The electrical resistivity method can be used in a wide range of geophysical investigations, such as exploration for minerals, engineering investigation, geothermal studies, archaeological surveys, and geological mapping (Anomoharan,2013). The method has been used extensively in Nigeria and other parts of the world to investigate the subsurface. (Majumdar and Das ,2011) used it to estimate the aquifer properties of Sagar Island Region in India, where they observed that the results correlated significantly with borehole data from the area.

This research employs the electrical resistivity geophysical investigation (2D and VES) of a proposed site in Ekiugbo in Ughelli North to delineate depth and characterization of layers, rock beddings, and the suitability of the proposed site for building with priority to the hydrogeology.

1.1. Location of the Study Area

Thestudy area is located along the Ughelli-Patani Road bordering Ekiugboin Ughelli North local government area of Delta state, Nigeria.

The site is an open land with a gentle sloppy terrain (almost) flat with elevation range of 5m-8m above sea level. The study area lies between longitudes 5^{0}59 03.0” E and 5^{0}30’59.03. E, and Latitudes 5^{0}30’ 53.06 and 5^{0} 30.52.3.N. The study area was accessible from the major road, [Ughelli – Patani Road], with an adjoining minor road that leads to the study area by foot paths road

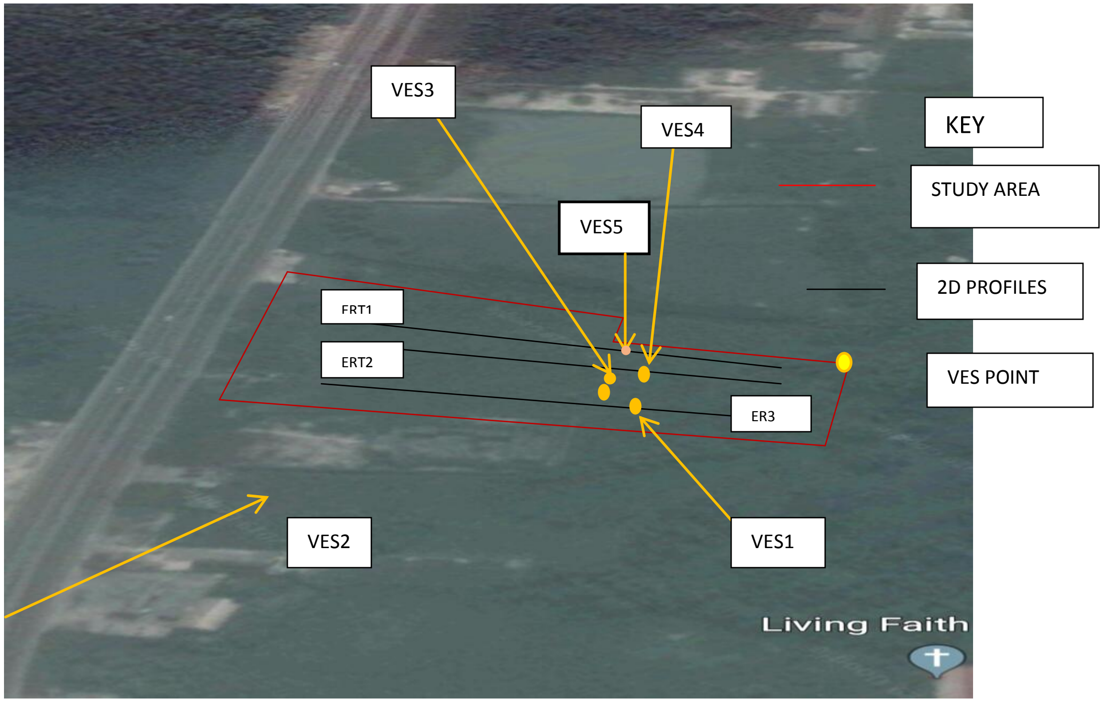


Fig 1. Location of the study area, VES points and 2D survey lines

2. Method

Soil samples were collected using a soil auger, from the various points in the study area (See table 1) and prepare for grain size analysis. Borehole was drilled and soil sample collected at intervals of 1.5m / 5ft.

Table1 Showing coordinates of sample location.

SN	NAME OF LOCATION	DEPTH	LATITUDE	LONGITUDE
1	UA1	1FT	05030’53.6N’’	005059’03.0’’E
2	UA2	2FT	05030’52.8N’’	005059’03.8’’E
3	UA3	2FT	05030’52.2’’N	005059’03.01E
4	UB1	1FT	05030’52.5’’N	005059’02,6’’E
5	UB2	1.5FT	05030’52.9’’N	005059’01.5’’E
6	UB3	1.5FT	050 30’52.6’’N	0050 59’01.8’’E
7	UB4	1.5FT	050 30’51.9’’N	0050 59’01.5’’E
8	UC1	1FT	050 30‘52.7’’N	0050 59’ 00.9’’E
9	UC2	0.5FT	050 30’51.I’’N	0050 59’01.1’’ E
10	UC3	1FT	050 30’51.3’’N	0050 59’ 00.4’’E
11	UC4	1.5FT	050 30’50.7’’N	0050 59’00.5’’ E
12	UC5	1FT	050 30’50.8’’N	0050 59’00.8’’E
13	UD1	1FT	050 30’51.6’’ N	0050 59’ 003’’E
14	UD2	1.5FT	050 30’50.4’’N	0050 59’59,4’’E
15	UD3	1.5FT	050 30’50.3’’N	0050 59’59.0’’E
16	UD4	0.5FT	050 30’50.5’’N	005059’59’02’’E
17	UD5	1.5FT	050 30’51.2’’N	005059’ 00.6’’E
18	UD6	1FT	05030’ 51.8’’N	0050 59’01.1’’E
19	UE1	1FT	05030’52.3’’N	0050 59’01.4’’E
20	UE2	1FT	05030’51.3’’N	0050 59.12.3’’E
21	UE3	1.5FT	050 30’51.3’’N	0050 59’02.1’’E
22	UE4	1FT	050 30’51.6’’N	005 59’ 02.3’’E

23	UE5	1.5FT	050 30’51.9’’N	0050 59’02.6’’E
24	UE6	2FT	05030’52.0’’N	0050 59’02.9’’E
25	UF1	1.5FT	05030’ 52.3’’N	005059’03.6’’E

The geophysical investigation for the study area involved the Vertical electrical sounding (VES) and Electrical Resistivity Tomography (2D ERT).Measurement procedure for the ERT was taking across 3 spreads using the 2D Wenner configuration for all the survey with 130m in length and at different spacing (see Fig 1).

The 2D survey data were acquired using the Omega resistivity equipment with a dipole spacing of 5m. This gives a penetrating depth of about 25m. The data were processed and inverted using the Diprowin software, a computer programme that determines the subsurface layer parameters and true depth-resistivity model for each of the survey. The Vertical Electrical Sounding

technique was employed for further study. A total of 5 VES (3VES along the 3 profiles(2D Survey lines) were conductedwith a current spread, AB, range of 1m-140m. Acquired and computed data (AB/2, MN/2, R,Rho) for the electrical sounding are tabulated below (see table2). All acquired VES data were inverted using the RESIST WINRES software.

Table2. Showing acquired and computed statistics for the 5 VES

AB/2	MN/2(m)	VES1		VES2		VES3		VES4		VES5	
		R(Ω)	RHO(Ω.m)	R(Ω)	RHO(Ω.m)	R(ohm)	RHO(Ω.m)	R(ohm)	RHO(Ω.m)	R(ohm)	RHO(Ω.m)
1	0.2	56.42	425.587	66.61	502.45	92.63	698.727	58.89	444.2191	95.05	716.9812
2	0.2	10.96	341.028	11.77	366.23	17.97	559.149	9.57	297.7772	14.42	448.6884
3	0.2	4.001	281.683	3.676	258.80	4.833	340.259	2.884	203.0428	3.584	252.3251
4	0.2	1.411	176.947	1.117	140.08	1.462	183.343	0.8987	112.7021	1.127	141.3322
6	0.2	0.351	99.262	0.218	61.597	0.3188	90.0788	0.2102	59.39321	0.3462	97.8208
6	0.8	1.37	95.161	0.8164	56.707	1.025	71.1968	1.137	78.97636	1.147	79.6710

8	0.8	0.713	88.717	0.3808	47.395	0.461	57.3774	0.5666	70.52062	0.6357	79.1210
10	0.8	0.334	65.190	0.2741	53.499	0.34	66.3613	0.4214	82.24898	0.4837	94.4087
12	0.8	0.300	84.343	0.2284	64.320	0.276	77.7251	0.3473	97.80412	0.3932	110.7302
15	0.8	0.300	131.998	0.1868	82.328	0.227	100.045	0.3371	148.5691	0.9937	437.9506
15	2	0.390	67.706	0.4691	81.460	0.553	96.0289	0.7006	121.6597	0.7805	135.5344
18	2	0.345	86.797	0.4021	101.10	0.487	122.451	0.5768	145.0306	0.6326	159.0609
21	2	0.304	104.248	0.3615	124.13	0.4	137.349	0.4955	170.1412	0.4988	171.2743
25	2	0.262	127.794	0.3046	148.63	0.355	173.223	0.411	200.5477	0.4053	197.7664
30	2	0.220	155.098	0.2528	177.98	0.295	207.689	0.334	235.1467	0.2936	206.7038
35	2	0.368	352.676	0.2274	218.17	0.237	227.378	0.3615	346.8234	1.126	1080.2852
40	2	0.158	198.643	0.1878	235.51	0.22	275.893	0.2234	280.1563	0.2142	268.6190
40	3	0.485	404.542	0.2538	211.52	0.3027	252.276	0.3269	272.4446	0.3046	253.8594
45	3	0.755	796.788	0.2213	233.70	0.263	277.741	0.2796	295.2710	0.2538	268.0250
50	3	0.949	1238.84	0.1959	255.62	0.2274	296.727	0.2544	331.9586	0.2163	282.2431
55	3	0.773	1220.77	0.1706	269.53	0.1939	306.339	0.2142	338.4106	0.1797	283.9047
60	3	0.327	614.927	0.1492	280.66	0.1665	313.201	0.186	349.8819	0.175	329.1900
65	3	0.286	632.288	0.133	293.73	0.1411	311.617	0.1639	361.9700	0.1558	344.08139
70	3	0.547	1402.2203	0.1198	306.936	0.1279	327.68860			0.1478	378.6738

4. Result and Discussion

Table3.Particle Size Distribution (Psd) Data Results

Sieve size(mm)	Ua1% passing	Ua2 %passing	Ua3 % passing	Uc4 % passing	Ua4 % passing	Ub1 % passing	Ub2 % passing	Uc1%passing	Uc2% passing	Uc3 %passing
1.18	-	-	-	-	-	-	-	-	-	-
0.85	-	-	-	-	-	-	-	-	-	-
0.6	73.84	81.07	82.11	79.92	86.02	91.96	83.40	79.25	66.54	68.35
0.425	68.5	75.60	77.42	71.10	81.67	87.57	78.10	73.59	66.42	59.72
0.30	67.87	70.65	73.16	66.56	77.19	82.69	73.12	67.35	66.29	51.10
0.21	57.07	65.17	66.65	60.12	70.74	74.45	68.53	61.15	58.27	43.15
0.15	41.35	51.27	50.23	55.21	59.39	54.87	55.78	50.94	45.64	30.15
0.075	14.32	19.90	22.82	33.00	29.79	23.12	41.80	18.10	22.70	7.94
0.063	10.77	11.60	17.02	20.10	10.48	15.01	21.10	8.08	17.04	2.58

Sieve size (mm)	Ud1% passing	Ud2 %passing	Ud3 % passing	Ud4 % passing	Ud5 % passing	Ud6 % passing	Ue1%passing	Ue2% passing	Ue3% passing
1.18	-	-	-	-	-	-	-	-	-
0.85	-	-	-	-	-	-	-	--	-
0.6	84.32	69.49	65.24	82.04	88.02	80.01	95.85	76.24	85.39
0.425	80.14	61.85	59.94	78.01	80.64	75.05	91.59	71.12	81.32
0.30	64.45	55.40	55.91	72.70	77.12	70.28	86.05	66.33	75.66
0.21	59.72	49.71	49.18	66.34	70.78	63.67	79.94	59.93	54.91
0.15	45.53	42.22	40.62	47.28	59.39	52.26	64.60	51.35	51.36
0.075	33.51	23.88	13.14	33.56	29.78	25.42	28.40	19.13	41.06
0.063	22.97	18.46	4.82	23.90	10.48	13.05	14.65	10.45	10.34

Sieve size (mm)	Uf1 %passing	Uf2% passing
1.18	-	-
0.85	-	-
0.6	74.38	81.01
0.42	70.27	77,20
0.30	66.57	70.31
0.21	60.35	67.23
0.15	44.98	58.12
0.075	17.44	49.03
0.063	12.21	21.12

LOCATION	% OF SAND	%OF FINEST	Unified Soil CLASSIFICATION system (USCS)	SUB-GRADE RATING
UA1	>50	>-10.77	SP-SM	Poorly graded sand with silt and clay
UA2	>50	<15	SP- SM	Poorly graded sand with silt and clay
UA3	>50	>15	SM	Silty sand
UB1	>50	15	SM	Silty sand
UB2	>50	>15	SM	Slty Sand
UC1	50	<15	SP-SM	Poorly graded sand with silts
UC2	<50	>15	SM	POOLY Graded sand with silt
UC3	<50	<15	SM	Poorly graded sand
UB4	<50	<15	SM	Poorly graded sand with clay &silts
UD1	<50	>15	Sp- sm	Poorly graded sand with clay
UD2	<50	<15	SP-SM	Poorly graded sand with clay
UD3	<50	>15	SM	Poorly graded sand with silt
UD4	<50	>15	SM	Poorly graded sand with silts
UD5	<50	<15	SP-SM	Poorly graded sand with clay
UE1	<50	<15	SP-SM	POOLY GRADED SAND WITH CLAY
UE2	<50	<15	SP-SM	POORLY GRADED SAND WITH CLAY
UE3	<50	<15	SP- SM	Poorly graded sand with clay

Table4. Particle Size Distribution Test Classification According to Unified soilClassification scheme(USCS)

4.1 Grain size analysis (Geological analysis).

The result from particle size distribution test shows that all the soil sample are mainly fine sand and silts or silty sand that are poorly graded with an average range of 22% and 34 % respectively. Because of their poorly graded nature they have low permeability with medium porosity.

4.1.1 Challenges / Limitation of the use of Silt with Sand for Engineering Geology Purposes

Sandy silts consist of 22- 34% of fine sand and silts respectively, they are very smooth to touch and retains water for a longer time because its smaller particles and drains poorly and expand against the wall of a foundation and result cracking and failure

4.2.2D ERT Survey

Table 5.Summarizes statistics for the ERT interpretation where minimum and maximum resistivity for the 2D surveys is presented. Results from the table show those minimum and maximum calculated resistivities are 0.12Ωm and 7358 respectively

Table 5. Showing minimum and maximum calculated resistivity

Profile no.	Min. Resistivity (Ωm)	Max. Resistivity (Ωm)
ERT1	22	4326
ERT2	0.12	7358
ERT3	35	1268

4.2.1 2D Resistivity Model of ERT1

Inspection of the inverse models for the 2D surveys (see fig 2-4) revealed horizontal and vertical changes in electrical property distribution as a result of the inhomogeneity of the subsurface. A high resistivity layer on the topsoilindicates dry top or sandy soil. While low resistivity values indicate silty sands to wet clay. 30' 50.4" E005 59' 0.00' El=5m

Profile ERT1 shows increasing changes in resistivity distribution from surface to depth. Silty clay topsoil to silty sands within the depth range of 5m-25m were inferred for the resistivity range of 22Ωm - 4326Ωm. The coordinate of ERT1: N05

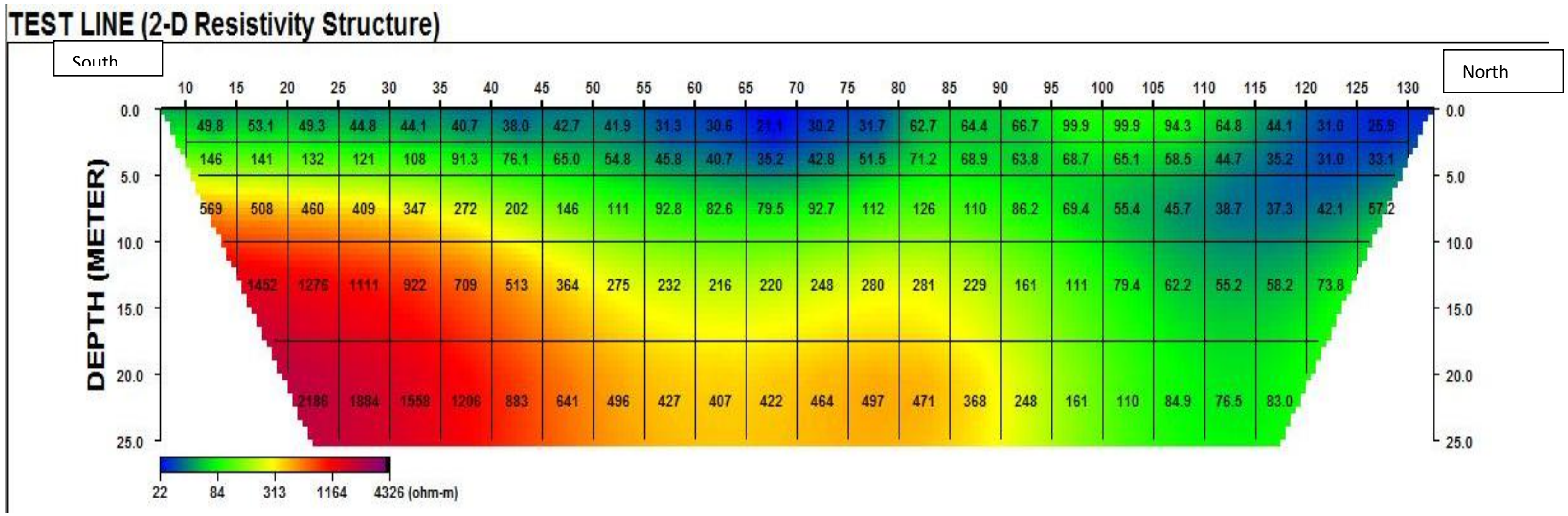


Fig 2. Inverse Model for ERT1

4.2.2 2D Resistivity Model of ERT2

ERT2trends South-North direction along the Dip is parallel and 15m away from ERT1. The inverse model is shown in Fig 3. Resistivity values of this profile ranges from 0.12Ωm-7358Ωm. The layers of this profile is majorly characterized by silty sands to coarse sand. It also contains a relatively small conductivezone of silty clay to wet clay at a depth range of about 7m-25m and horizontal extension of 15m-41m on the south flank. The coordinate of ERT2 is N05 30' 50.5'' E005 59' 00.0'' El=9m

South

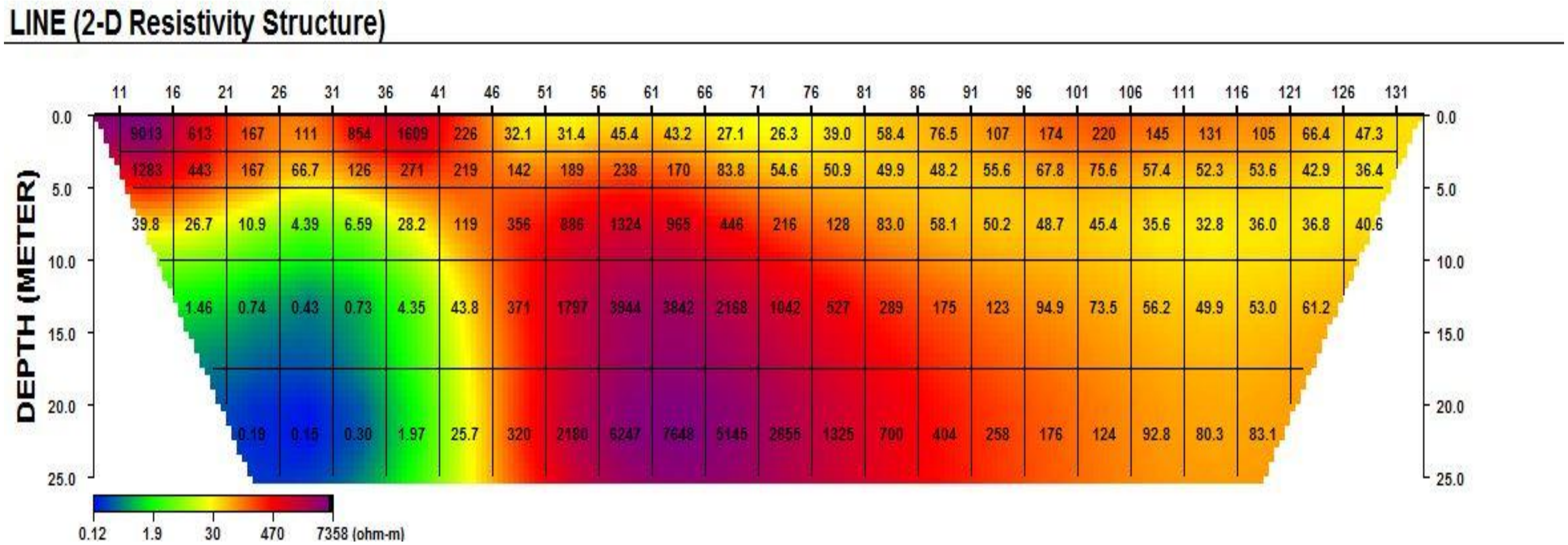


Fig 3. Inverse Model of ERT2

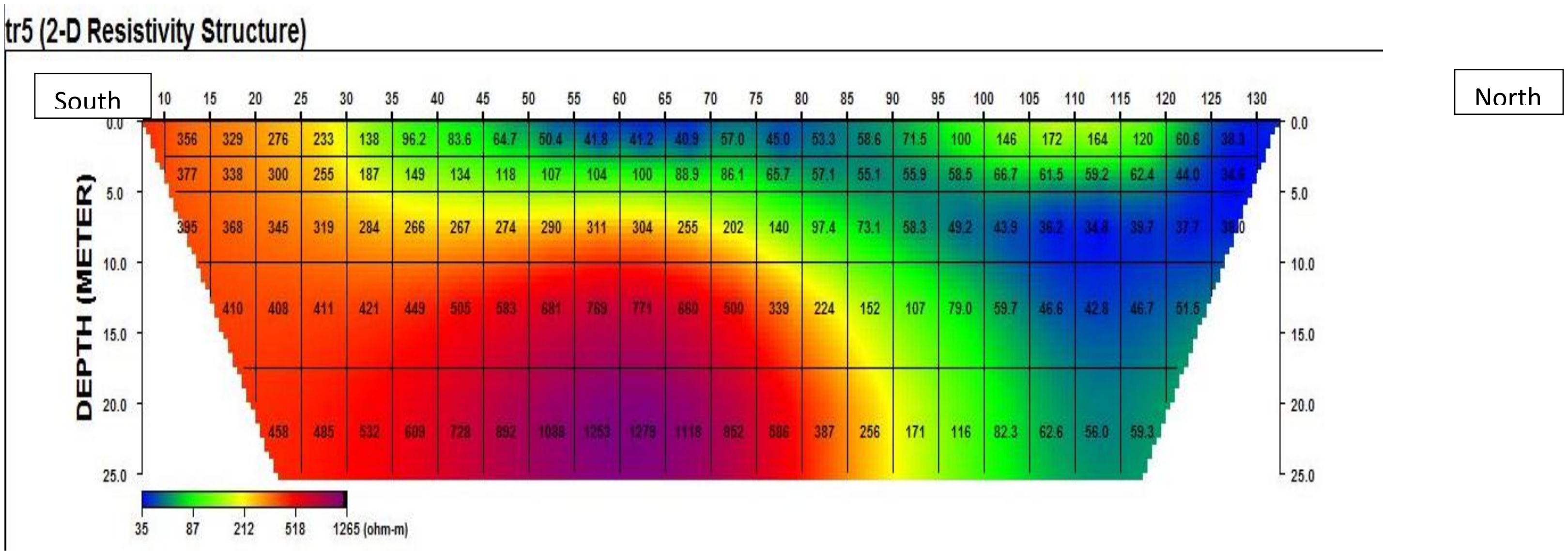


Fig 4. Inverse Model of ERT3

4.2.3 2D Resistivity Model of ERT3

Profile ERT3 is quite similar toERT1 trends North South Direction with resistivity distribution range of 35Ωm-1265Ωm. The inverse Model (see fig 4) unlike. ERT2 present two major layers. While the South part of the profile inferred majorly silty sands with resistivity range of 518Ωm-1265Ωm, the North flank is characterized with silty clay to very wet clay from surface to depth. The coordinate of ERT3: N05 30' 51.0"E005 58' 59.8"El=5m

4.3 Vertical Electrical Sounding (VES) Interpretation

4.3.1 VES1 Results Interpretation

Table 1 and fig 5 present observed and geoelectric model for VES 1. 5 layers were delineated as silty clay topsoil, Clay,Clay, silty Clay, and Sand with resistivity values of 455.5Ωm, 31.3Ωm, 84.5Ωm,539.9Ωm and 3183.39Ωm respectively. VES 1 acquisition was conducted along profile (60m point on ERT3) to integrate the results. From the result we can see a strong agreement With ERT3. 3183.39Ωm was the inferred aquifer of depth over 8.7m. Transverse coordinates TR1: N05 30' 52.2"E005 59' 01.9" E l=7m

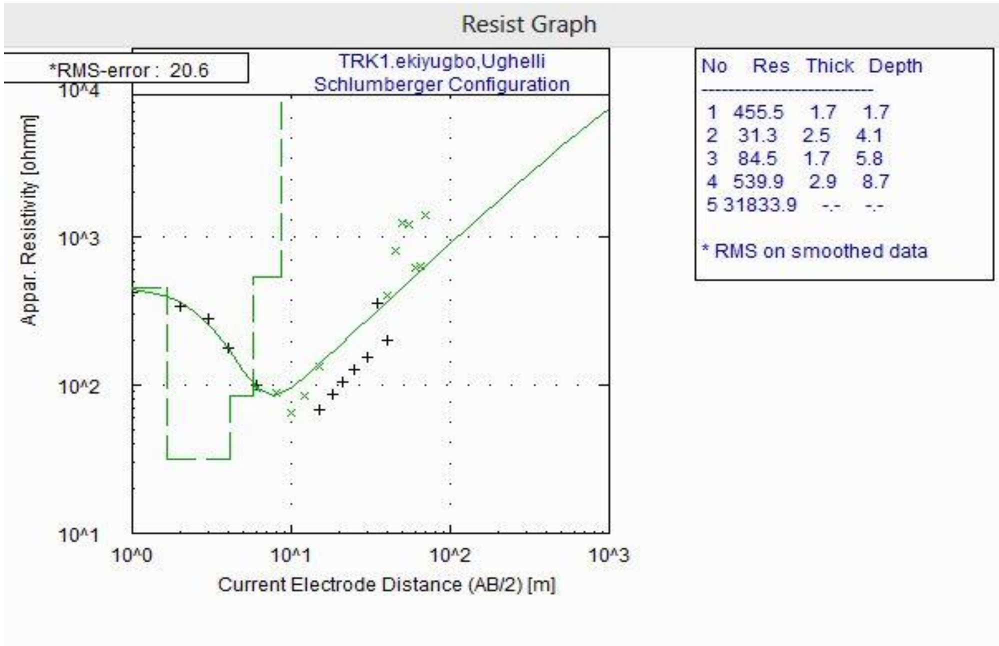


Fig.5. Geoelectric model of VES1

4.3.2VES2 Results Interpretation

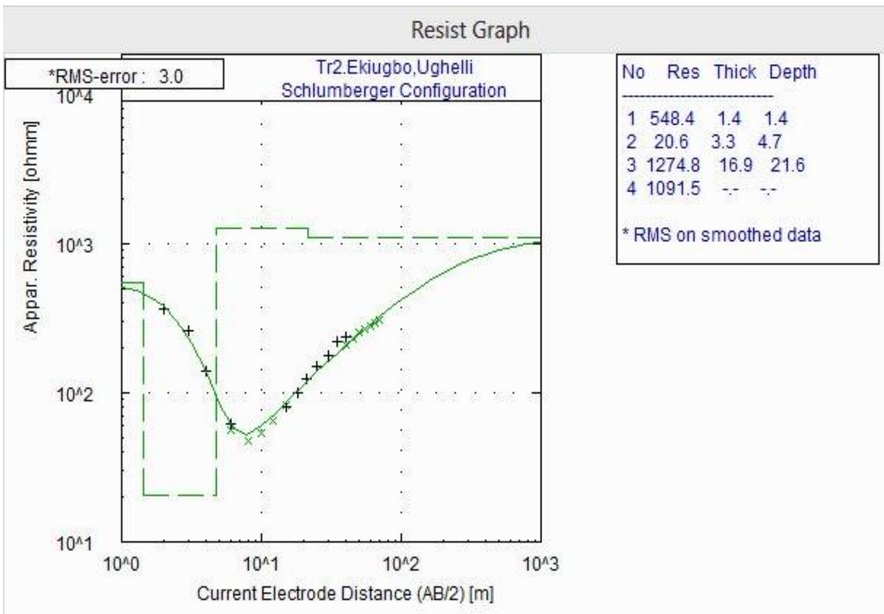
Fig.6 Present 1D model results for VES2, with 4 geoelectric layers of resistivity values of 548.4Ωm, 20.6Ωm, 1274.8Ωm(Shallow confined aquifer with appreciable thickness of 16.9m) and 1091.5 at their corresponding depth from surface of 1.4m,4.7m, 21.6m and > 21.6m. The geoelectric layers were delineated as silty clay topsoil, clay, to Sand and silty Sand. Transverse coordinates TR2: N05 30' 52.0" E005 59' 50.1" El=7m

4.3.3 VES3 Results Interpretation

1 dimensional Model results are presented in Fig7, with four geoelectric layers delineated as Silty or Clayey sand topsoil, Clay, Sand and silty sand at corresponding depth of 1.3m, 6.0m, 24.2m and >. The third layer with resistivity value of 1191.2Ωm at a depth of 24.3m is the inferred shallow aquifer with an appreciable bed thickness of 18.1m. Transverse coordinates TR3: N05 30' 50.5" E005 59' 27.3" El=6m

4.3.4 VES4 Results Interpretation

Location of VES 4 along profile ERT2 is shown in Fig1 ,5m away from VES5. VES4 results are presented in Fig 8 with four (4) geoelectric layers of resistivity values 478.4Ωm as silty Clay topsoil, 33.7Ωm as clay, 1151.7Ωm as Sand and 565.9Ωm as silty clay at corresponding depths from surface of 1.3m, 4.8m, 24.1m and above respectively. The First and third layers correlate clearly with the layers on ERT2 at 60m(VES point). The third layer (Sand) bed with resistivity value of 1151.7Ωm was the inferred confined aquifer. Transverse coordinates TR4: N05 30' 50.5" E005 59' 43.1" El=6m



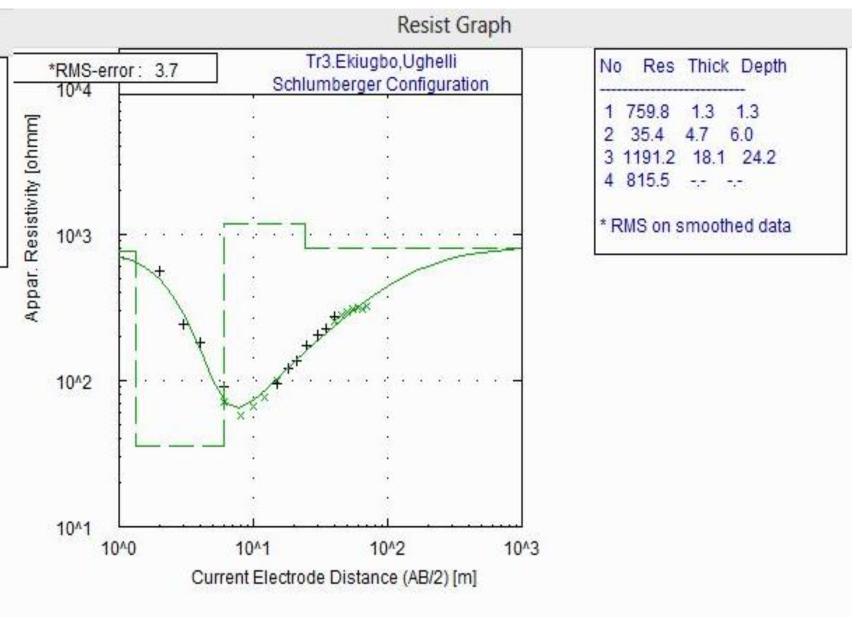


Fig 6. 1D model for VES2Fig.7. 1D Model for VES3

4.3.4 VES4 Results Interpretation

Location of VES 4 along profile ERT2 is shown in Fig1 ,5m away from VES5. VES4 results are presented in Fig 8 with

four(4) geoelectric layers of resistivity values 478.4Ωm as silty Clay topsoil, 33.7Ωm as clay, 1151.7Ωm as Sand and 565.9Ωm as silty clay at corresponding depths from surface of 1.3m, 4.8m, 24.1m and above respectively. The First and third layers correlate clearly with the layers on ERT2 at 60m(VES point). The third layer (Sand) bed with resistivity value of 1151.7Ωm was the inferred confined aquifer. Transverse coordinates TR4:

N05 30' 50.5" E005 59' 43.1" El=6m**4.3.5 VES5 Results Interpretation**

VES5 1D Model results for VES5 is presented in Fig9, with 5 delineated layers of resistivity value 794.9Ωm as silty clay topsoil, 44.5Ωm as clay, 1227.7Ωm as Sand bed(aquifer), 247.2Ωm as clay and 210.0Ωm as clay at the corresponding depths of 1.2m, 4.7m, 18.5m, 24.2m respectively. The first, second and third geoelectric layers presented in Fig 9 correlate with the layers of ERT1 within the depth range of 1m- 18m. Transverse coordinates TR5: N05 30' 51.9" E005 59' 01.5" El=7m

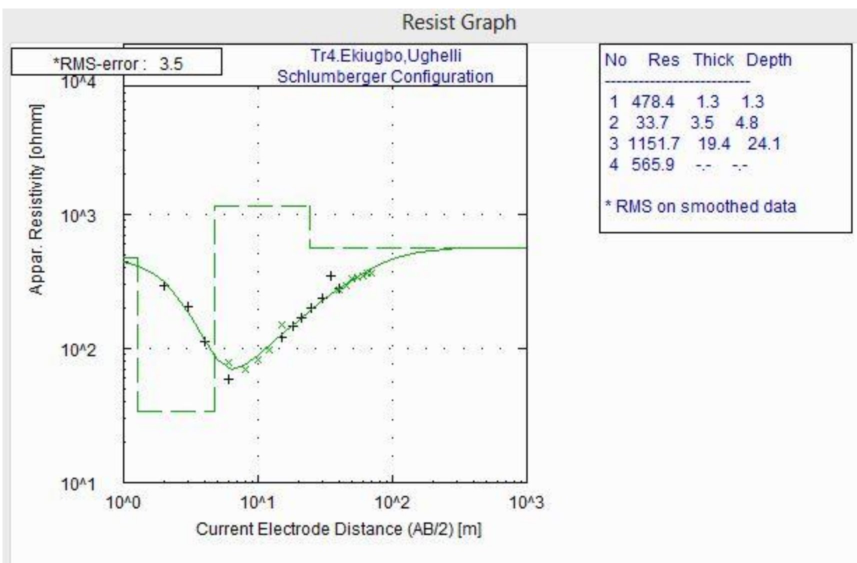


Fig.8. 1D Model for VES4

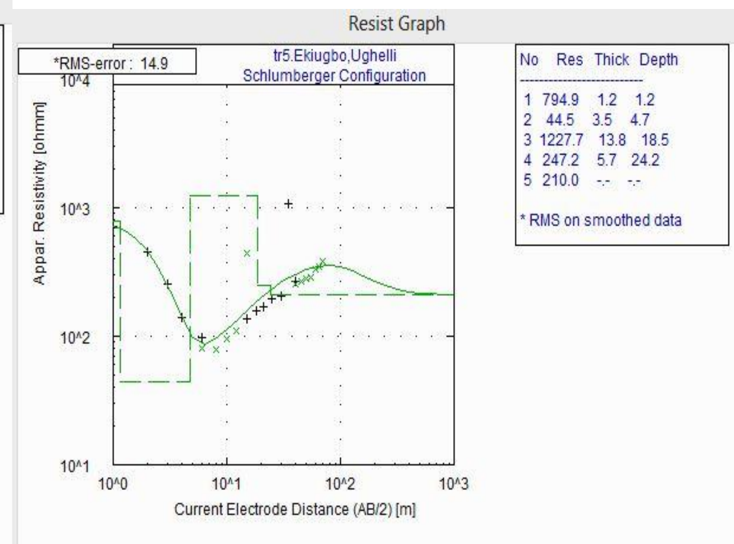


Fig 9. 1D Model for VES5

4.4 Borehole soil samples at different depth

Table 6: Results for clays from 3ft to 16ft.

Depth in fts	**Results (L.L Liquid Limit, P.L Plastic Limit, P.I Plasticity Index)**	**USCS Symbol**	**USCS Name**	**Features**
3	L.L =26% P.L=0 P.I=26%	CL or OL	Lean Clay	Medium to High Dry strength. Low permeability Low to Medium Plasticity.
5	L.L=41% P.L=19.72% P.I=21.28%	CL or OL	Lean Clay	Medium to High Dry strength. Low Permeability Low to Medium Plasticity.
8-10	L.L=90% P.L=33.36% P.I=56.64%	CH or OH	Fat Clay	Medium to High Dry strength. Very Low Permeability Medium to High Plasticity.
10-16	L.L=68% P.L=24.75% P.I=43.25%	CH or OH	Fat Clay	Medium to High Dry strength. Very Low Permeability. Medium to High Plasticity.

Table 7: Results for sediments from 18ft to 45ft.

Depth in ft	**Coefficient of Uniformity (Cu) Coefficient of conformity (Cc)**	**USCS Symbol**	**USCS Name**
18	Cu=2.61 Cc=1.10	SP	Poorly Graded Sand
20	Cu=2.36 Cc=0.72	SP	Poorly Graded Sand

25	Cu=2.13 Cc=0.89	SP	Poorly Graded Sand
30	Cu=3.77 Cc=1.07	SP	Poorly Graded Sand
40	Cu=2.17 Cc=1.07	SP	Poorly Graded Sand
45	Cu=3.57 Cc=1.20	SP	Poorly Graded Sand

From 18ft down to 45ft the soil samples contained high concentration of silt than clay making it difficult to determine the plastic limit of the soils from those depths, particle size distribution test indicate a poorly graded soils showing high percentage of silt than sand from 18ft to 30ft and high percentage of sand to silt from 30ft to 45ft.

Conclusion

The study area which is covered with swamp grass and mangroves trees at the south flank, is part of the Greater Ughelli depobelt of Niger Delta basin,Nigeria. The area has been examined by the application of Electrical Resistivity Tomography(ERT) and Vertical Electrical Sounding techniques. A total of 3 ERT spreads with maximum profile length of 130m and 5 VES with maximum current electrode spread of 140m were conducted, in addition to 25 geological test pits (0.6m

Fat Clays are clays that have very high plasticity Lean Clays are clays that have slight or low plasticity

depth) to back the geophysical models. Geophysical results showed a charistic QH curve type, with the layer resistivity, thickness, and depth well defined. Geophysical results also show good ground water exploration potential. The inferred lithologies from geophysical studies which are mainly silty clay to silty sands correlate with geological results from grain size analysis. By implication the subsurface have high water retention ability and this can cause swelling and shrinking effect as temperature changes across the seasons, which can create shock effect to building foundations.

Recommendation

We recommend the following to be put into consideration before or during building. A raft foundation may be needed. There are certain requirements that need to be considered during the **raft foundation** in order to produce adequate design of minimum depth of 0.5m, required excavation depth of approximately 2.5m, and rebar cover of 50mm. The geological soil analysis should be considered by the Architect or Civil Engineers for depth of foundation.

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