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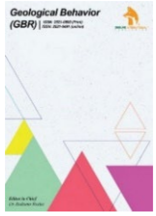

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RESEARCH ARTICLE

INVESTIGATION OF COMPETENCE, CORROSIVITY AND PLASTICITY OF SOILS USING GEOPHYSICAL AND GEOTECHNICAL METHODS IN NARAGUTA AREA, JOS-PLATEAU NORTHCENTRAL NIGERIA

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ABSTRACT

The present study focuses on investigation of competence, corrosivity and plasticity of soils using geophysical and geotechnical methods in Naraguta area. Twenty (20) VES stations were occupied in the study area using Schlumberger array with current electrode separation (AB) varying from 1.5 to 125 m. The VES data acquired in the field were interpreted by curve matching using the Winresist software. Ten (10) soil samples were collected at depth of about 1.5m for geotechnical tests (Liquid limits, plastic limits, plasticity index and linear shrinkage). Resistivity value (23.4-2528.9 Ωm) was used to classify the competence of the soils into three namely: highly competent (>750 Ωm), competent area (350-750Ωm) and incompetent (<100Ω). The soil corrosivity in the area was classified into three namely: moderately corrosive (10-60 Ωm), slightly corrosive (60-180 Ωm) and practically non-corrosive (>180Ωm). The study area is underlain by four (4) geoelectric layers which comprises of Clay, Sandy clay, Clay sand and crystalline rock. The plasticity index (11-270) is classified into medium-plastic (7-17) and highly plastic (>17). The linear shrinkage (7.5-10.7) indicates medium (5-10) and poor-quality soil (10-15). Three (3) degree of expansion zones identified are low, medium and high degree of expansions. Three (3) danger of severity zones were identified namely: non-critical, marginal and critical. Based on the geophysical values the area can be classified into highly competent, competent and incompetent soil for building construction while the geotechnical values indicate medium plasticity/compressibility which suggests medium competence while high plasticity/compressibility suggest low competence.

KEYWORDS

Competence, compressibility, plasticity, quality and shrinkage

1. INTRODUCTION

The ways of construction of buildings vary depending on items used and architectural designs (Giano et al., 2000). Building collapse can occur either by natural elements (hurricanes, tsunamis, tornadoes etc) or by the negligence of man (Andrews et al., 2013). Akinpelu explained that structural failures; soil conditions and wrong interpretations of geotechnical data as major causes of building failure (Akinpelu, 2002). Also, failure of concrete structures could result from corrosion of the reinforcement materials and inappropriate design (Owamah et al., 2018). The frequency of building collapse in Nigeria have become worrisome and places that such had not been heard of decades ago are also beginning to have incidences of building collapse (Adeniya, 2002; Ede, 2010). In the last seven years about five (5) buildings have collapsed in Jos town with consequence loss of lives and properties (Ketkukah et al., 2023).

Geophysical survey methods aid in subsurface mapping providing information crucial for designing foundations and ensuring the stability of the future building; identifying potential hazards such as underground cavities, sinkholes, or old utilities that could pose risks during construction or impact the building's stability and optimizing borehole locations to collect soil samples for further analysis. Popular methods use for site investigation are Ground penetrating radar, electrical resistivity and seismic refraction methods (Oloyede et al., 2010; Odewumi et al., 2022).

Geotechnical engineers employ a suite of methods to assess a building site's subsurface conditions. This information is crucial for safe and cost-effective construction. They are used for site reconnaissance and review; subsurface exploration by physically collecting soil and rock samples for analysis; drilling boreholes to extract soil and rock samples for laboratory testing; laboratory testing of soil and rock samples (Odewumi et al., 2020a).

By using a combination of Geophysical and Geotechnical methods, engineers gain a comprehensive understanding of the subsurface conditions at a building site. This information is critical for safe and cost-effective construction. By using a combination of these techniques, engineers gain a comprehensive understanding of the subsurface conditions at a building site. This information is critical for safe and cost-effective construction Several studies have used electrical resistivity method, geotechnical method and, both resistivity and geotechnical method for soil investigations (Akanbi, et al., 2010; Adukwu and Fadele, 2012; Dauda and Akanbi, 2018; Egbeyale 2019; Ajagbe and Akanbi, 2022; Aghamelu et al., 2011; Akhirevbulu and Ogunbajo, 2011; Habeeb et al., 2012; Sidi et al., 2015; Soupios et al., 2007; Coker 2015: Falowo et al., 2016; Coker et al., 2017).

The study area is located in Naraguta area, situated at the northern fringe of Jos North Local Government Area. The study area lies between latitudes 9° 58'33'' to 9° 57' 47'' N and longitude 8°53'11'' to 8'53'03'' E. The area is

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accessible through Bauchi Junction-Naraguta road. The location map of the study area in Jos, northcentral Nigeria is shown in Figure 1. The aim of this research was to investigate the competence, corrosivity and plasticity of subsurface soils in Naraguta area using the geophysical and geotechnical properties of soil

1.1 Geology of the Study Area

An outline of Geology of the area is similar to that of Jos Plateau and Geological map of the study area is shown in Figure 2. The rock units comprise of Basement Complex which includes: migmatite, aplo-pegmatitic granite gneisses and hornblende biotite granite that are Precambrian to Lower Paleozoic in age. Basic dyke of younger age has been identified cutting across the Migmatite and Aplo-pegmatitic granite gneiss. The Geology, geochemical and magnetic characteristics of rock in Jos and its environs was reported by (Odewumi, 2020b; Oguche et al., 2021; Zumji et al., 2023; Davou et al., 2024)

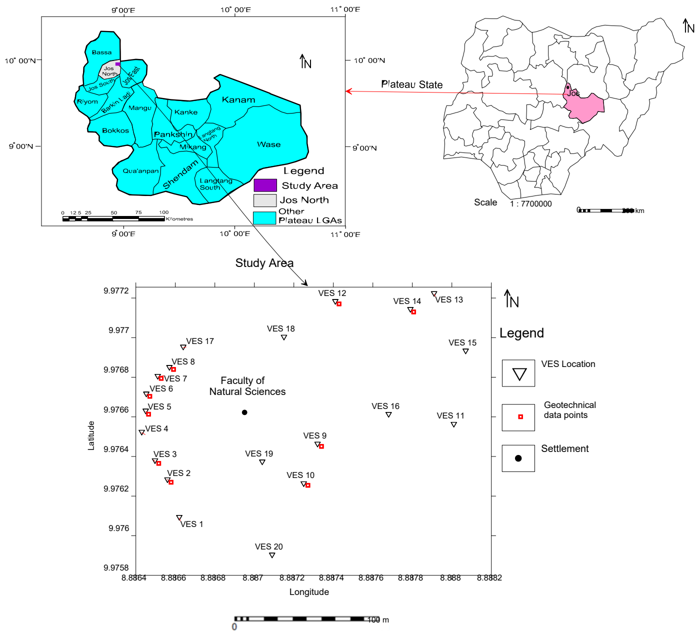

Figure 1: VES and geotechnical data points

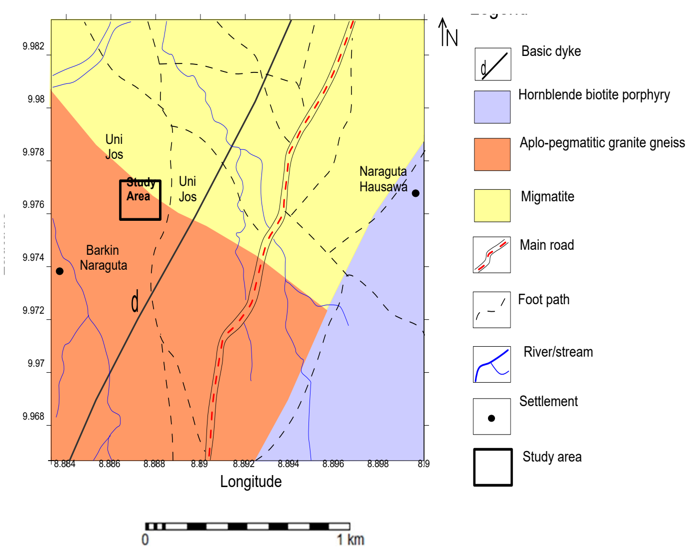

Figure 2: Geological Map of Naraguta area (Odewumi et al. 2024)

2. Materials and Methods

The methodology adopted in the present study is divided into geophysical and geotechnical methods

2.1 Geophysical Measurement

Geophysical measurements were carried out at twenty (20) Vertical Electrical Sounding (VES) points selected in Naraguta area using Campus Ohmega Terrameter and schlumberger array was adopted for field measurements according to (Dobrin, 1976). The data acquired in the field was processed with Winresist software, which was used to generate the primary electrical parameters (resistivity and thickness) in layers models known as curve types, each resistivity represent a layer with its corresponding thickness. Surfer 11 software was used to produce resistivity maps.

The coordinate of each VES points with their corresponding values were imported into the surfer 11 environment according to the data was gridded using Kriging method and the corresponding maps were displayed (Azi et al., 2014). The resistivity values of the study area were compared with some standards for soil competence rating, soil corrosivity rating and iso resistivity depth slice classification (Bulus et al., 2020).

2.2 Geotechnical analysis

Ten (10) soil samples were collected at depth of 1.5m using digger and shovel at different VES stations for geotechnical investigation and labeled with appropriate sample number in plastic bags. The soil samples were taken to Department of Geology, University of Ilorin for determination of liquid limit, plastic limit, plasticity index and linear shrinkage. The results of liquid limit, plastic limit, plasticity index and linear shrinkage were compared with some international standards of soil classification to determine the competence, plasticity, compressibility and quality of soils for building construction.

3. Results and Discussion

The results of resistivity value, thickness, depth and overburden thickness for VES 1 to VES 20 are presented in Table 1. The value of resistivity varies from 24.3 to 2999.5 ohm-m, thickness varies from 0.6 to 35.5m, depth varies from 0.6 to 37.8m and overburden thickness varies from 7 to 43m (Table 1). Figure 3 shows electrical resistivity curve for VES 1, electrical resistivity curve for VES 2 is shown in Figure 4 while Figure 5 shows electrical resistivity curve for VES 3. Table 2 shows the results of the geotechnical analyses of ten (10) soil samples from Naraguta area. The liquid limit varies from 27.0 to 57.0 %, plastic limit value varies from 16.0 to 30.0%, plasticity index value ranges from 11.0 to 27.0 % and linear shrinkage value of 7.5 to 10.7% (Table 2). Table 3 shows a summary of qualitative analysis of curve types of VES readings from the study area carried out for the twenty (20) VES points. The eight (8) major resistivity curves types are KQ, HA, HK, AH, KH, AA, Q, and H type curves (Table 3). Bar chat representation of the qualitative analysis is shown in Figure 6, with HA curve type being the most dominant curve type.

Table 1: The values of resistivity, thickness, depth and overburden thickness from study area

VES Station	Resistivity (Ohm-m)					Thickness (m)				Depth (m)				Overburden Thickness (m)
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	H_1	H_2	H_3	H_4	D_1	D_2	D_3	D_4	
1	314.7	136.5	296.7	34.6		1.3	5.8	26.8		1.3	7.2	34.0		34.0
2	568.1	132.0	200.7	410.5	650.0	0.8	1.2	6.0	23.0	0.8	2.1	8.1	31.1	31.1
3	638.7	282.9	761.8	1420.3		2.1	4.7	16.8		2.1	6.8	23.6		23.6
4	386.6	725.0	1197.6	514.7	3710.0	1.1	4.2	8.3	24.2	1.1	5.3	13.7	37.8	37.8
5	506.6	859.6	582.2	821.5		1.1	3.6	20.6		1.1	4.7	25.3		25.3
6	302.1	360.9	850.8	2535.4	954.9	1.7	2.1	4.1	19.3	1.7	3.8	7.9	27.3	27.3
7	54.5	473.4	3370.4	2999.5	431.2	0.8	0.8	3.8	12.6	0.8	1.6	5.4	18.0	18.0
8	473.7	200.3	315.1			1.7	3.8			1.7	5.4			5.4
9	457.0	191.5	788.2	1934.1		1.7	4.1	10.6		1.7	5.7	16.3		16.3
10	230.5	212.3	130.1			1.4	19.4			1.4	20.8			20.8
11	369.9	459.3	755.6	220.3		1.2	6.5	35.5		1.2	7.7	43.2		43.2
12	578.4	399.6	570.0	918.6	1309.6	0.9	2.8	7.2	20.9	0.9	3.7	10.8	31.7	31.7
13	426.8	366.6	255.0	275.3		1.2	3.2	15.3		1.2	4.4	19.8		19.8
14	1752.5	227.3	812.3	902.8		0.6	1.5	31.2		0.6	2.1	33.3		33.3
15	177.8	507.7	2723.7	1013.3		1.9	3.6	28.0		1.9	5.5	33.5		33.5
16	301.0	471.2	642.9	401.4	218.9	0.9	1.1	6.3	15.9	0.9	2.0	8.3	24.2	24.2
17	322.5	753.7	572.3	2328.9		1.2	2.7	19.9		1.2	4.0	23.9		23.9
18	109.0	665.1	989.7	612.3		1.1	3.1	9.5		1.1	4.2	13.8		13.8
19	694.6	24.3	39.9	916.5		0.8	1.3	16.7		0.8	2.1	18.8		18.8
20	523.1	215.9	437.0	494.8		1.0	2.1	28.5		1.0	3.0	31.5		31.5

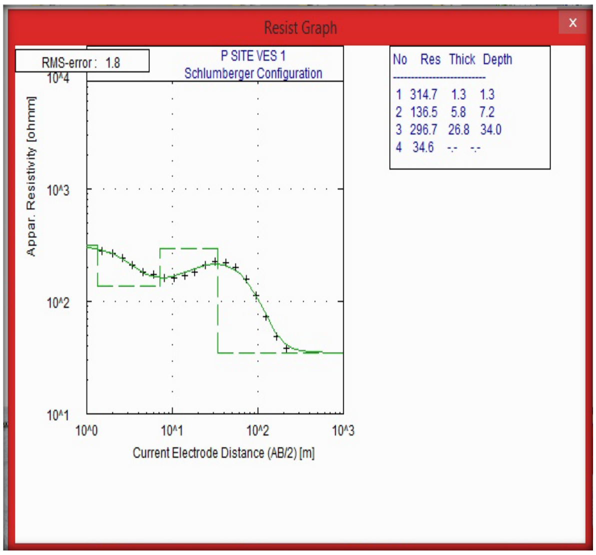

Figure 3: Electrical Resistivity Curve for VES 1

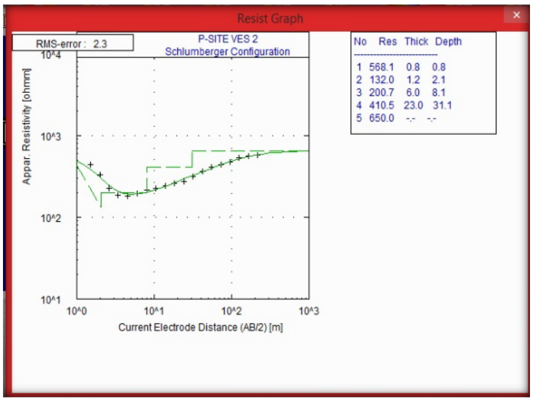

Figure 4: Electrical Resistivity Curve for VES 2

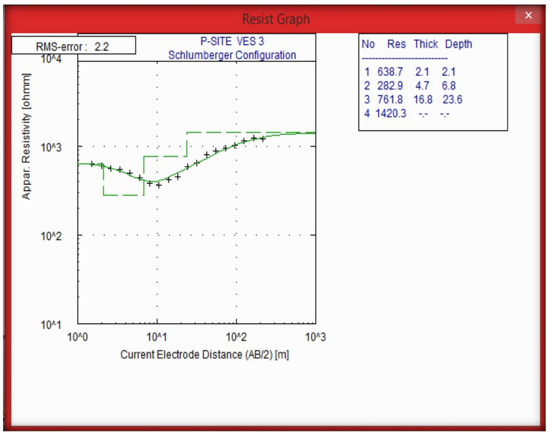

Figure 5: Electrical Resistivity Curve for VES 3

Table 2: Geotechnical results of soil samples in the area

S/N	Sample/ VES Identity	Liquid Limit (%)	Plastic limit (%)	Plasticity Index (%)	Linear Shrinkage (%)
1	VES 2	27.0	16.0	11.0	7.5
2	VES 3	39.0	25.1	13.9	9.1
3	VES 4	43.0	22.4	17.6	9.8
4	VES 6	57.0	30.0	27.0	10.7
5	VES 7	47.0	27.3	19.7	10.2
6	VES 9	35.0	21.5	13.5	8.1
7	VES 10	56.0	29.8	26.2	10.6
8	VES 13	48.0	25.0	23.0	10.4
9	VES 12	39.0	23.2	15.8	8.5
10	VES 16	33.0	20.4	12.6	7.9
	Average	42.4	24.07	18.03	9.28

Table 3: Qualitative analysis of curve types

S/N	Curve types	Frequency	Layer resistivity relationship	Number of geo-electric layers
1	KQ	1	$\rho_1>\rho_2>\rho_3<\rho_4$	4
2	HA	6	$\rho_1>\rho_2<\rho_3<\rho_4$	4
3	HK	1	$\rho_1>\rho_2<\rho_3>\rho_4$	4
4	AH	5	$\rho_1<\rho_2<\rho_3>\rho_4$	4
5	KH	4	$\rho_1<\rho_2>\rho_3<\rho_4$	4
6	AA	1	$\rho_1<\rho_2<\rho_3<\rho_4$	4
7	Q	1	$\rho_1>\rho_2<\rho_3>\rho_4$	3
8	H	1	$\rho_1>\rho_2<\rho_3>\rho_4$	3
Total		20		

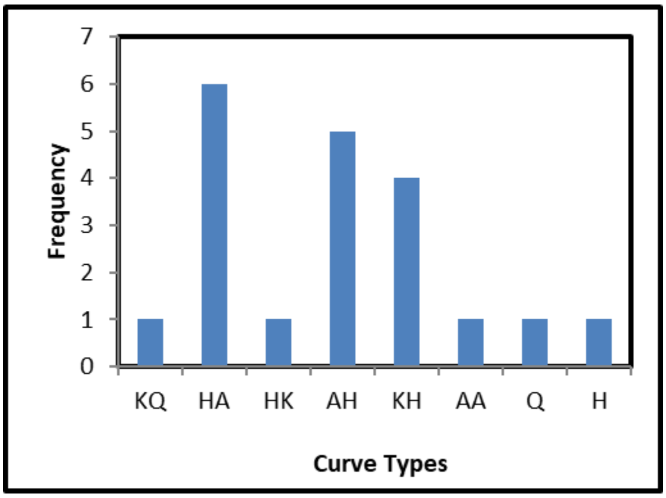

Figure 6: Frequency of curve types in the study area

3.1 Geo-Electric Sections

Four (4) typical geoelectric units identified along A-A' profile (Figure 7). The clay has resistivity values of 34.6 to 54.5 Ohm-m, the sandy clay unit with resistivity values of 132 to 322.5 Ohm-m, clay sand constitutes the third layer of resistivity values of 360.9 to 1197.6 Ohm-m and forth layer is crystalline rock with resistivity values of 725 to 3370.4 Ohm-m. Four (4) typical geoelectric units identified along B-B' profile (Figure 8). The clay layer varies from 24.3 to 39.9 Ohm-m, the Sandy Clay value ranges from 130.1 to 230.5 Ohm-m, Clay Sand layer with resistivity values of 399.6 to 665.1 Ohm-m and crystalline rock with resistivity value of 788.2 to1934.1 Ohm-m.

Three (3) typical geoelectric units identified along C-C' profile (Figure 9). The Sandy Clay resistivity values of 218.9 to 275.3 Ohm-m, the Clay Sand with resistivity values of 309.9 to 642.9 Ohm-m, and Crystalline Rock with resistivity values of 755.6 to 2723.7 Ohm-m. This present study agrees with the occurrence of clay unit within the weathered Basement of the Younger Granite Province on the Jos Plateau reported by (Odewumi et al., 2015; Momoh et al., 2017; Odewumi et al., 2023).

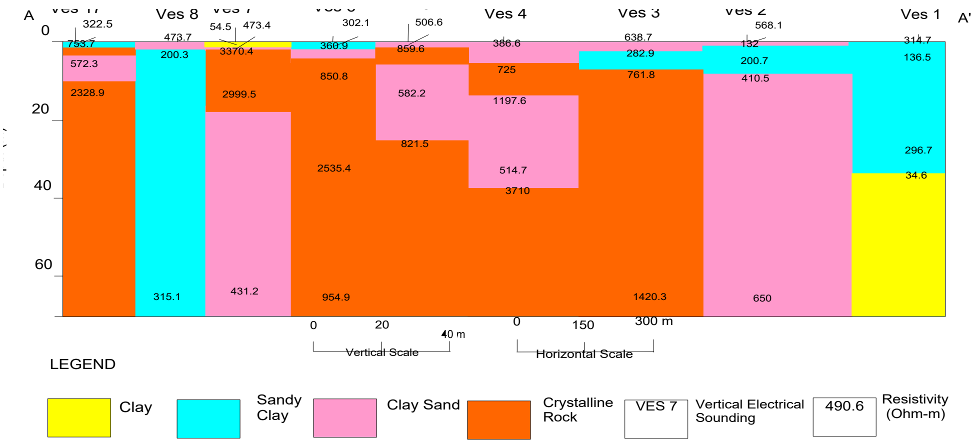

Figure 7: Geo-Electric Stratigraphic Section along Profile A – A' of the Study Area

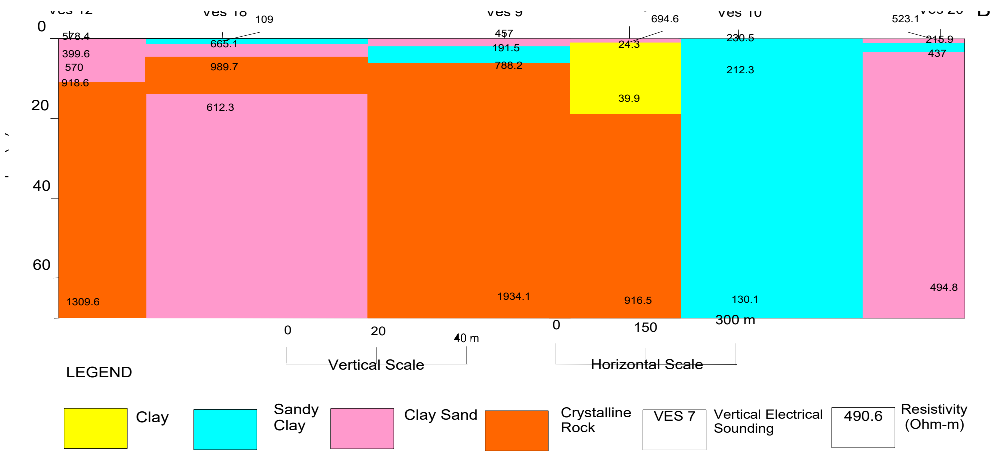

Figure 8: Geo-Electric Stratigraphic Section Along Profile B – B' of the Study Area

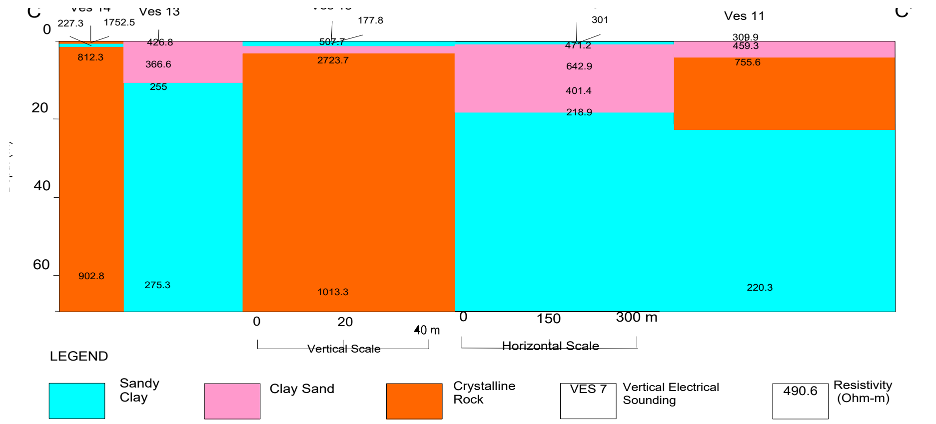

Figure 9: Geo-Electric Stratigraphic Section along profile C – C' of study Area

3.2 Overburden Thickness

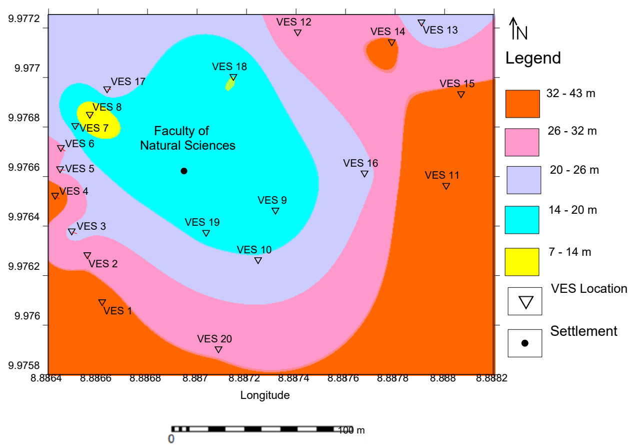

Figure 10: Overburden thickness map of the study area

The overburden thickness map of study area (Figure 10) indicates values varying from 7.0 to 43.0 m. A group researcher suggested that a study area can be categorized into two zones namely: zones of relatively thick overburden of greater than 20 m and zone of relatively thin overburden of <20 m (Satpathy and Kanungo, 1976; Olayinka, et al., 2004). The overburden thickness obtained from Naraguta area shows regions of thick overburden with very thick overburden values of 32 to 43m in the burnt orange colour (Figure 10). These zones are indicative of probable groundwater potential zones in study area. Geophysical studies in southwestern Nigeria also recognized thick overburden regions (>20.0m) as regions of high groundwater potentials (Olorunfemi and Okhue, 1992; Oladapo et al., 2004; Oyedele and Olayinka, 2012).

3.3 Subsoil Rating

The subsoil rating of study area is classified according to on rating of Subsoil Competence using resistivity values (Idornigie et al., 2006). The resistivity value of Naraguta area varies from 24.3 to 2999.5 Ohm-m (Table 1). The value of resistivity less than 100 Ohm-m indicates area with clay deposit, which is incompetent while the resistivity value ranging from 100 to 350 Ohm-m was assessed to be sandy clay and is moderately incompetent. Similarly, area with resistivity values of 350 to 750 Ohm-m is clayey sand which is competent enough to hold structures. Finally, highly competent areas are characterized with sand/laterite/crystalline rocks, and the values are above 750 Ohm-m (Table 4). The competence map of the study area (Figure 11) where four (4) zones were identified which include: highly competent with resistivity value > 750Ωm, competent of resistivity of 350 to 750Ωm, moderately competent of resistivity of 100 to 350Ωm and incompetent of resistivity of <100Ωm.

Table 4: Rating of Subsoil Competence using Resistivity Values (Idornigie et al., 2006)

App. Resistivity Range (ohm-m)	Lithology	Competence Rating
< 100	Clay	Incompetent
100 – 350	Sandy clay	Moderately competent
350 – 750	Clayey sand	Competent
> 750	Sand/Laterite/Crystalline Rock	Highly competent

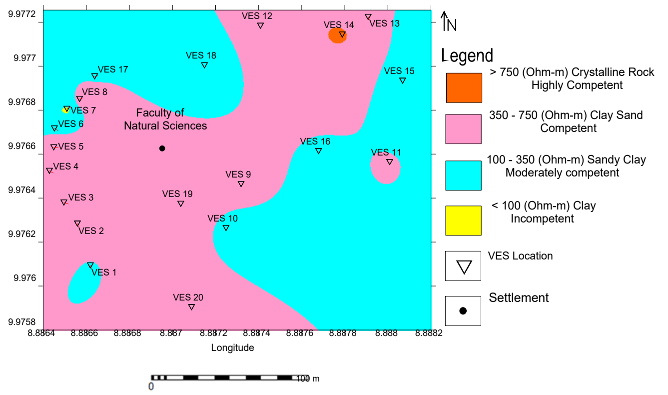

Figure 11: Competency map of the Topsoil

3.4 Soil corrosivity evaluation

Classification of soil resistivity in terms of corrosivity was based on (Baeckmann and Schwenk, 1975; Agunloye, 1984). When pipes are buried in a corrosive subsurface soil, with time the pipes will rust and disintegrate which will create allowance in the subsurface which in turn can cause crack on walls. The resistivity value of the study area ranges from 24.3 to 2999.5Ωm (Table 1). The soil corrosivity in the area can be classified into three namely: moderately corrosive (MC) with value varying from10 to 60Ωm, slightly corrosive (SC) with value ranging from 60 to180Ωm and practically non-corrosive (PNC) with value of 180Ωm and above.

A group researcher determined the corrosivity of soil in Miango area of Jos-Plateau northcentral Nigeria where the resistivity values (105.64 - 2384.30 Ωm) exceeded the resistivity values of moderately corrosive (10 to 60 Ωm) and very strongly corrosive (<10 Ωm) zones (Bulus et al., 2020). The present study in Naraguta area is in contrast to the report in Miango area where moderately corrosive and very strongly corrosive zones were not identified but in Naraguta area, moderately corrosive, slightly corrosive and practically non-corrosive zones were identified (Bulus et al., 2020).

3.5 Expansion and Danger of Severity

The classification for degree of expansion and danger of severity is presented in (Table 5) according to (IS, 2002). The degree of expansion in the study area was categorized based on the value of liquid limit (27 - 57 %) into three (3) namely: low degree of expansion (12-35%), medium degree of expansion (35-50%) and high degree of expansion (50-70%). The danger of severity in the area was classified based on the liquid limit values from the study area which varies from 27 to 57 % (Table 2) and three (3) danger of severity zones were identified in the area namely: non-critical with liquid limit value of 12 to 35%, marginal with liquid limit of 35 to 50% and critical with liquid limit of 50 to 70%.

The plasticity index from the study area varies from 11.0 to 27% (Table 2) and three (3) danger of severity zones were identified in the area which include: non-critical with plasticity index value of <12%, marginal with plasticity index of 12 to 23% and critical with plasticity index of 23 to 32%. Degree of expansion can be classified into three (3) namely: low with plasticity index value of <12%, medium with plasticity index value of 12 to 23% and high with plasticity index value of 23 to 32% (Table 5).

The linear shrinkage from the study area varies from 7.5 to 10.7 % (Table 2) and one (1) danger of severity zone was identified in the area as non-critical with linear shrinkage value of <15% and the degree of expansion is low (Table 5). The Classification of soil according to plasticity index is presented Table 6. The Plasticity index of the study area varies from 11.0 to 27 % (Table 2) and two (2) plasticity index zones were identified in the area which include: medium plastic with plasticity index value of 7 to 17 % while highly plastic with plasticity index value >17

Table 5: International Standard Classification System IS (2002)

Liquid limit (%)	Plasticity Index(%)	Linear Shrinkage %	Degree of expansion	Danger of severity
12-35	<12	<15	Low	Non- critical
35-50	12-23	15-30	Medium	Marginal
50-70	23-32	30-60	High	Critical
70-90	>32	>60	Very high	Severe

Table 6: Classification of soil according to plasticity index

Plasticity	Index Plasticity	Studied Soil (VES)
0	Non Plastic	
<7	Low – Plastic	
7 – 17	Medium – Plastic	2, 3, 9, 12 and 16
>17	Highly Plastic	4, 6, 7, 10, 13

Relationship between the plasticity index and the swelling potential (Table 7), the Plasticity index of the study area varies from 11.0 to 27 % and three (3) swelling potential zones were identified namely: low (0 - 15 %), medium (15 - 25%) and high (25 - 35%)

Clay deposits have been reported within the Precambrian Basement Complex of southwestern Nigeria which were plastic in textures and were suggested to be derived from granitic rocks of Precambrian Basement Complex of Nigerian (Odewumi, 2013; Odewumi and Olarewaju, 2013; Odewumi et al., 2015). The soils in Naraguta area is underlain by crystalline rocks similar to the clay deposits in the Basement Complex and were observed to show medium-plastic and highly plastic textures (Table 6).

Table 7: Relationship between the plasticity index and swelling potential

Plasticity Index (%)	Swelling Potential	Studied Soil (VES)
0 – 15	Low	2,3,9 and 16
15 – 25	Medium	4, 7, 13 and 12
25 – 35	High	6 and 10
>35	Very high	

Classification of soil according to linear shrinkage is shown in (Table 8), The linear shrinkage of the study area varies from 7.5 to 10.7 % (Table 2) and two (2) quality of soil zones were identified in the area which includes: medium good quality of soil with linear shrinkage value of 5 to 10% and poor quality of soil with linear shrinkage value of 10 to 15%.

Table 8: Classification of soil according to linear shrinkage

Linear Shrinkage (%)	Quality of Soil	Studied soil (VES)
<5	Good	
5 – 10	Medium good	2, 3, 4, 9, 12, 13, 16
10 – 15	Poor	6, 7, 10
>15	Very poor	

The Plasticity index of the study area varies from 11.0 to 27 % (Table 2) and two (2) zones was identified which includes: Medium plasticity/medium compressibility/moderate competence with plasticity index ranging from (10-20%) and High plasticity/high compressibility/low competence with plasticity index of >20 (Cassagrande classification index). The plasticity chart classification as shown in Figure 12.

All the samples from the study area plotted above the A line, indicates clayey content. Eight samples (VESs 2, 3, 4, 7, 9, 12, 13 and 16) that plotted on the left side of the vertical line which have liquid limit (LL) values ranging from 27.0 to 48.0% while two VES point locations (VESs 6 and 10) plotted on the right-hand side of the A line with LL >50% signifying high compressibility.

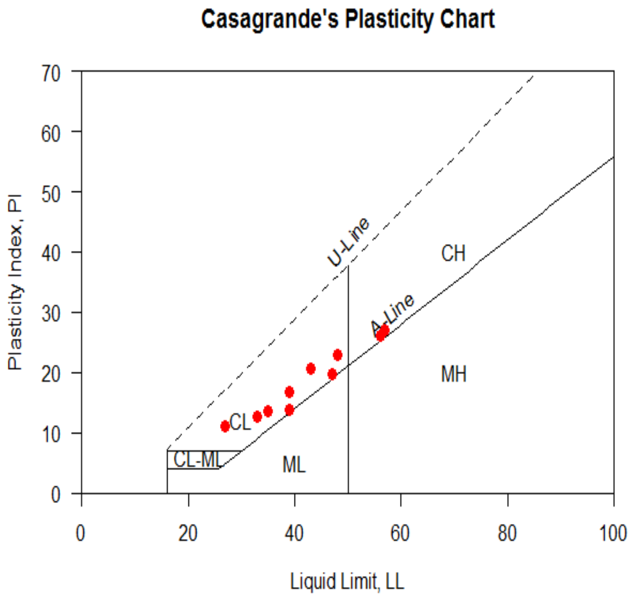

Figure 12: Casagrande chart classification of the studied soils (C-clay, M-silt; Level of plasticity: L-low, H-high; A line- is the boundary between two types of soil; U line- upper limit of the relationship between PL and LL)

4. Conclusion

The study area is underlain by four geoelectric layers of clay, sandy clay, clay sand and crystalline rock units. The soils in the study area are moderately corrosive, slightly corrosive and practically non-corrosive while based on competence, the soils are observed to be highly competent, competent, moderately competent and incompetent zones. Thin overburden and thick overburden zones are obtained from the area which is indicative of probable groundwater potential zone. The linear shrinkage also indicates soils of medium and poor quality which are of low, medium and high degree of expansion. The swelling potential zones and degree of expansion are low, medium and high with medium-plastic and highly plastic textures. The three (3) danger of severity zones based on liquid limit and plasticity index are non-critical, marginal and critical danger of severity.

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