Characteristics of Soils for Civil Engineering Foundations in Part of North Central Nigeria, Using Electrical Resistivity Method

O. S. Ayanninuola[1*], U. D. Msughter[1], C. O. Ofoegbu[1], E. D. Uko[2]

[1]Department of Physics, Nasarawa State University, Keffi
[2]Department of Physics, River State University, Port Harcourt

ABSTRACT: A geophysical investigation was carried out using Vertical Electrical Sounding (VES) in part of North Central Nigeria to evaluate the subsoil thickness, competence, and corrosivity for civil engineering foundations. A total of 60 VES stations were covered within the study area using the Schlumberger configuration array with half current electrode separation (AB/2) varying from 1m to a maximum of 100m while the half potential electrode spacing (MN/2) varied by 0.3 m to a maximum of 5m. The analysis of data was done using IP2win and Surfer 12 softwares. The first layer has resistivity values between 4.728 Ωm to 4210 Ωm and varied in thickness between 0.15 m to 1.42 m, the second layer has resistivity values between 24.7Ωm to 355000 Ωm and varied in thickness between 0.0355 m to 8.983 m while the third layer has resistivity values ranging between 8.361 Ωm to151,608 Ωm and varied in thickness between 1.05 m to 34.2 m, the fourth layer which is the last of the geoelectric layers has resistivity values between 27.95 m to 77000 m. The subsoil within the study area is composed of clay, sandy clay, clayey sand, sand, and laterite. From the qualitative interpretation of the Isoresistivity and Isopach maps, the Southwestern, Southeastern and Northwestern parts of the study area are moderately corrosive to extremely corrosive subsoil with resistivity values ranging between 4.728 Ωm and 50.48 Ωm. The third layer consists of an incompetent low resistivity soft material that underlain the entire study area except at the central region which is essentially noncorrosive and highly competent. VES curves interpretations revealed the thickness and depths of the geoelectric layers within the study area. The results of this research could enable civil engineers to ascertain the requisite depth of soil evacuation for the sustainability of structures within the study area.

KEYWORDS: Corrosivity, clay, foundation, lithology, resistivity, and, soil competence

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I. INTRODUCTION

The alarming rate of failures or the collapse of civil engineering structures in Nigeria cannot just be attributed to the general perception of poor quality of building materials and inadequate foundation designs, but can also be due to inadequate knowledge of the soils (Ofomola *et al*., 2018, Fadele *et al*., 2012, Coker *et al*., 2013, 2010; Ayolabi *et al*., 2010, Fajana *et al*., 2016, Olorode *et al*., 2016). All civil engineering structures are seated on the earth's geological materials, therefore the knowledge of the soils is very fundamental in foundation planning and management (Bayowa and Olayiwola, 2015, Ofomola *et al*., 2018, Adewuyi and Philips, 2018, Ologo and Augie, 2007).

Soil competence evaluation provides useful information about the ability of the soil to withstand stress and strain that may emanate from the weight of the engineering structures (Ofomola *et al*., 2018, Idornigie *et al*., 2006, Ayolabi *et al*., 2010). There are several factors that determine the competence of soils. These factors include; mineralogy, resistivity, soil particle contact, and the agent of the weathering (Idornigie *et al*., 2006, Bayowa and Olayiwola 2015). Topsoil thickness is also vital in foundation design. The electrical resistivity method involves the measurement of the apparent resistivity of soils and rock as a function of depth or position which helps to determine resistivity distributoin of the sounding soil volume. It is in view of this that the Electrical Resistivity (ER) method is adopted to measure the resistivity and hence the competence and corrosivity of the soil within the study area.

II. STUDY AREA AND ITS GEOLOGY AND SOIL

The study area is located within the Basement Complex of the North Central Nigeria which is part of the Middle Benue Trough. It lies within latitude $8^0$33'30"N to $8^0$35'01"N and longitude $7^0$43'30"E to $7^0$44'03"E (Figure 1). The Basement-Cretaceous Basin consists of faulted contacts which are evident on the magnetic map over the Benue Trough (Ofoegbu, 1986). The Benue Trough originated as the failed arm of an Aulacogen during the separation of the African plate from the South American plate and consists of three major parts; the Upper Benue Trough, Middle Benue Trough, and the Lower Benue Trough (Ofoegbu, 2019). The Basement Complex rocks

*Corresponding author: ayanninuola@gmail.com *doi:* http://dx.doi.org/10.4314/njtd.v18i4.1261

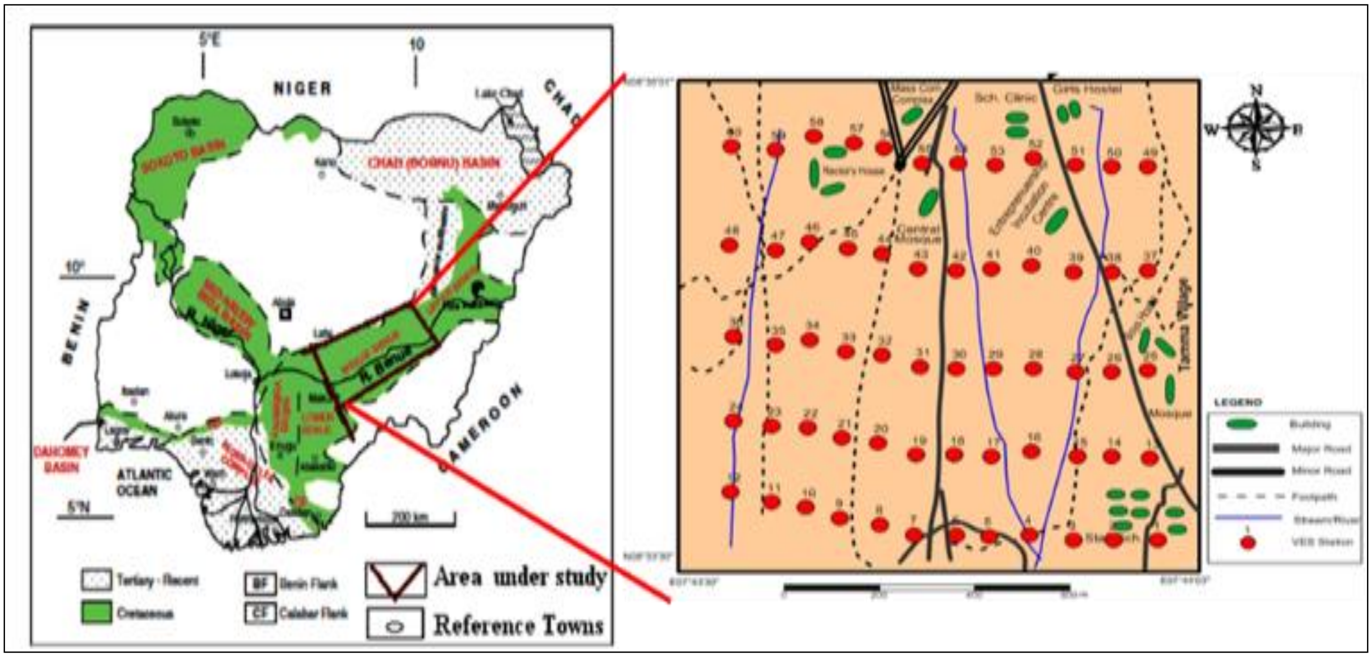

Figure 1: Map of Nigeria showing the Study Area and the VES Stations

within the area are; magmatite, granulitic gneisses, and the older granites with minor traces of pegmatite and quartz (Ayanninuola *et al.,* 2018; Anudu *et al.,* 2012; Rowland and Nur 2019, Ofoegbu, 1986 and Ofoegbu, 2019; Abidemi *et al*., 2022). Figure1 outlines the arrangement of the VES stations within the study area. Within the study area 75%, of the landmass consists of Biotite Gneiss while the remaining 25% is mainly the granite Gneiss. The Biotite Gneiss covered the entire Eastern and Northern region of the study area running through the North-East and South-East regions of the study area with the Granite Gneiss covering only the South-West region as shown in Figure 2. The near-surface soils and rocks consist, predominantly, of sandstones intercalated with calcareous shale, claystone, laterite, and volcanic rocks (Clifford *et al*., 2018; Akpan *et al*., 2020).

III. THEORETICAL BACKGROUND

A. The Schlumberger Array and the Geometric Factor

The Schlumberger array, as shown in Figure 3, consists of two current electrodes and two potential electrodes. The current electrodes are the outer electrodes (A and B) while the potential electrodes are the middle electrodes (M and N). The separation between the potential electrodes is very small, usually less than one-fifth of the current electrode separation.

The apparent resistivity for the Schlumberger array can be determined by using Eqn. (4) which was deduced of Ohms law from the first principle:

$$\frac{\partial V}{\partial r}=\frac{\rho I}{q}=\frac{-\rho I}{2\pi r^2} \tag{1}$$

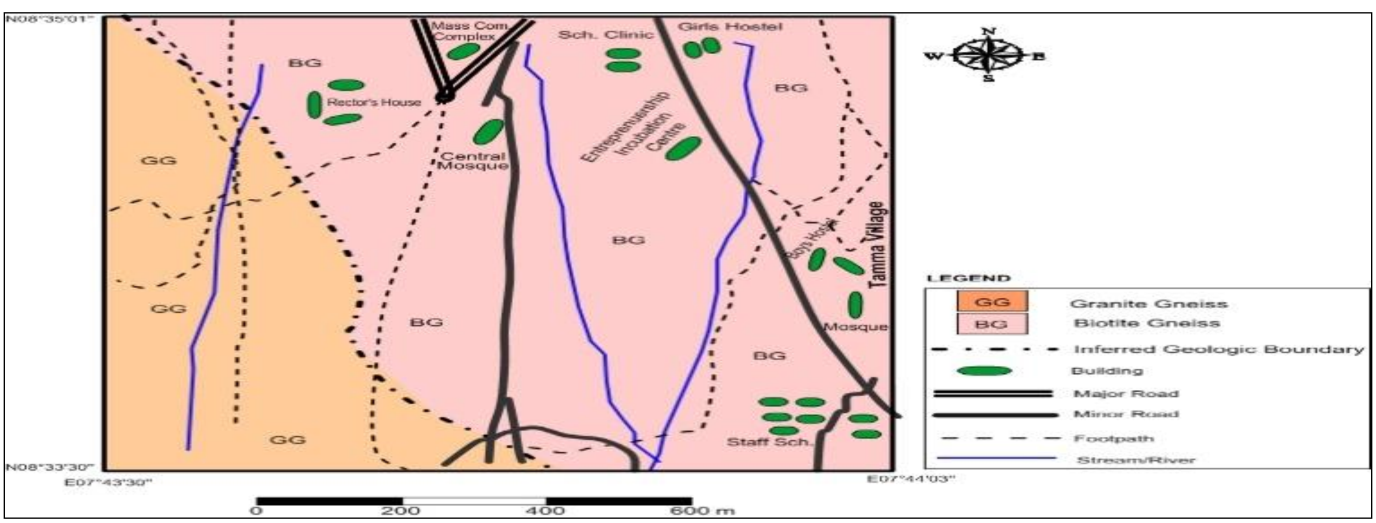

Figure 2: Geologic Map of the Study Area

The potential difference: $\Delta V = P_1 - P_2$

$$\Delta V = \frac{I\rho}{2\pi}\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right] = I\rho G \quad (2)$$

$$G = \frac{1}{2\pi}\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right] \quad (3)$$

where G = Geometric factor, and conversely the apparent resistivity ρ_a is given as:

$$\rho_a = \frac{\Delta V}{I}\frac{1}{G} \quad (4)$$

The soil resistivity guidelines (Bayowa and Olayiwola, 2015; Zoran *et al.*, 2015; Ofomola *et al.*, 2018) on thickness, competence, and corrosivity for interpreting and classifying soils are presented in Tables 1 and 2. The composition of the soil varies from place to place. Corrosive soils are aggressive to concrete and the effect most times is intensive. It is therefore necessary to take into consideration the corrosivity of the soil when designing the building as well as climate factors that influence soil corrosion such as; water content in pores and rate of precipitation and chloride contamination (Falowo and Otuaga, 2020; Miguel *et al.*, 2019).

Table 2: Soil Competence Rating

Apparent resistivity (Ωm)	Lithology	Competence
<100	Clay	Incompetent
100 – 350	Sandy clay	Moderately competent
350 - 750	Clayey sand	Competent
>750	Sand/Laterite/bedrock	Highly competent

IV. MATERIALS AND METHODS

A. Data Acquisition

This research was carried out using the Electrical Resistivity (ER) method for the field data acquisition. The method involves the measurement of apparent resistivity along the earth's surface using Eqn.4. The Vertical Electrical Sounding field procedure was employed to investigate the variation of electrical resistivity of the soil with depth using the Schlumberger electrode array. A total of 60 VES stations arranged along 5 West-East transverses were planned and pegged within the study area (Figure 1). The spacing between each VES station was 100m while the spacing between the transverses was between 80 m – 100 m depending on the terrain. From the data acquired on the field, the values of the apparent resistivity were plotted against the AB/2 values on the bi-log graph for each VES station. Preliminary interpretation of the data was carried out based on the Partial Curve Matching approach and based on the preliminary interpretations, the initial parameters (numbers of layers) of the soil at each VES station within the study area were determined.

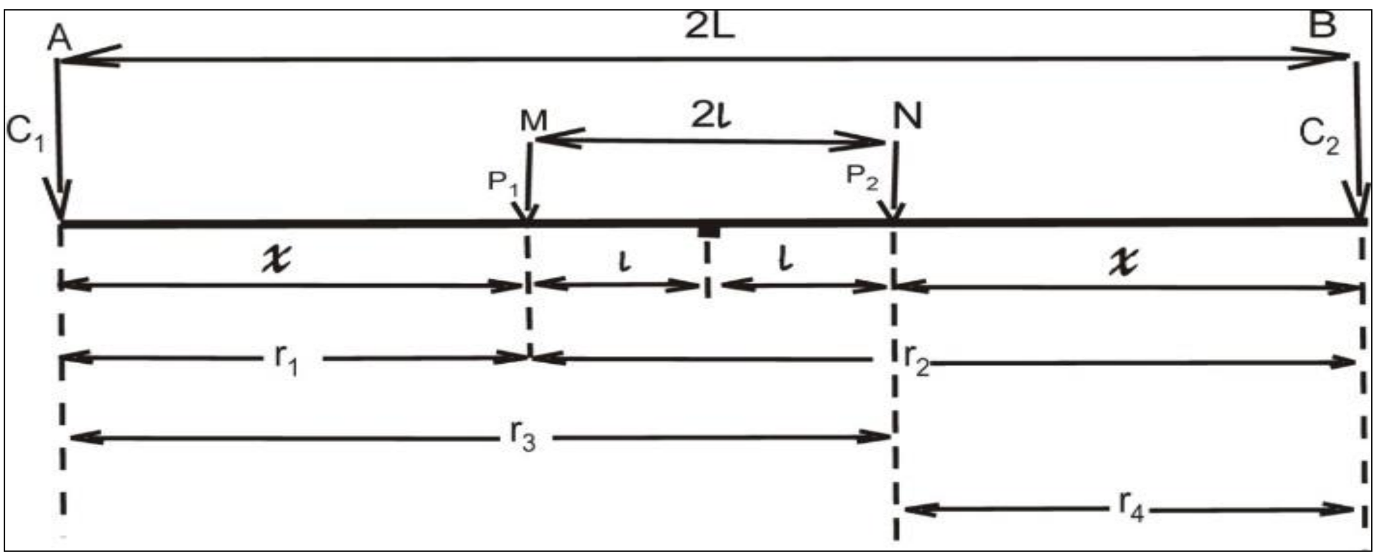

Figure 3: Schlumberger Electrode Configuration Array Setup

Table 1: Soil Corrosivity Rating based on Resistivity Values

Soil resistivity (Ωm)	Corrosivity Rating
> 200	Essentially non-corrosive
100 -200	Mildly corrosive
50 - 100	Moderately corrosive
30 - 50	Corrosive
10 - 30	Highly corrosive
<10	Extremely corrosive

A more detailed graphical analysis of the VES curves (plotted on bi-log graphs) was done using IP2Win software to obtain the thickness, depth, and resistivity values of the different layers. The layer thickness and resistivity values were then analyzed using Surfer 12 software to generate Isopach and isoresistivity maps. The maps were used to categorize the soil within the study area into different soil competence and

Corrosivity zones, which will serve as an important tool for the designs and maintenance of foundation within the study area.

V. RESULTS AND DISCUSSION

A. Result

A total of 60 VES stations were occupied within the study area. The results from the 60 VES stations are tabulated in six tables, each containing the results from 10 VES stations. The thickness of the first layer was qualitatively analyzed to obtain an Isopach map (Figure 7) and the resistivity values of the top layer were also analyzed graphically using Surfer 12 software to obtain the Isoresistivity map (Figure 8) for the first layer. The thickness of all the four geolectric layers were collectively analyzed using Surfer 12 software to obtain the contour map for the depth to basement within the study area (Figure 9).

B. Discussion

The data analysis was done using IP2win to obtain the resistivity, thickness, and depths of the study area while the layer thickness and resistivity values were then analyzed using Surfer 12 software to generate Isopach and isoresistivity maps. The curve types that are identified within the study area are: KH, KQ, QH, QQ, HK, K, and H-Types which are an indication of lithology variations within the study area. The area is mostly underlain by four geoelectric layers of various lithologies with a few cases of three layers at about eight VES Stations.

The first layer has resistivity values ranging from 4.728 Ωm to 4210 Ωm with variations in thickness from one VES station to another within the study area (Jatau *et al.*, 2017).

Table 3: VES Curves Results for VES Stations 1-10

VES Station	Layers	Resistivity Ωm	Thickness (m)	Depth (m)	Probable Lithology	Corrosivity Status	Curve Type
VES 1	1	459	1.42	1.42	Clayey sand	Essentially noncorrosive	
	2	1660	1.12	2.55	Sand	Essentially non corrosive	KH
	3	116	24.7	27.2	Sandy clay	Mildly corrosive	
	4	21,273			Laterite	Essentially noncorrosive	
VES 2	1	278	0.721	0.721	Sandy clay	Essentially noncorrosive	
	2	641	3.82	4.54	Clayey sand	Essentially non corrosive	KH
	3	130	27.8	32.30	Sandy clay	Mildly corrosive	
	4	27,812			Laterite	Essentially noncorrosive	
VES 3	1	349	0.34	0.34	Sandy clay	Essentially non corrosive	
	2	5,137	0.759	1.1	Laterite	Essentially noncorrosive	KH
	3	30.4	3.61	4.7	Clay	Highly corrosive	
	4	1.2E+5			Bedrock	Essentially noncorrosive	
VES 4	1	12.15	0.45	0.45	Clay	Highly corrosive	
	2	31,669	0.57	1.02	Laterite	Essentially noncorrosive	K
	3	116.6			Sandy clay	Mildly corrosive	
VES 5	1	201.1	1.145	1.145	Sandy clay	Essentially noncorrosive	
	2	1707	0.8739	2.019	Sand	Essentially noncorrosive	KH
	3	85.76	2.541	4.56	Clay	Moderately corrosive	
	4	396,966			Bedrock	Essentially noncorrosive	
VES 6	1	272	0.593	0.593	Sandy clay	Essentially noncorrosive	
	2	1380	1.36	1.95	Sand	Essentially noncorrosive	KH
	3	115	34.2	36.2	Sandy clay	Mildly corrosive	
	4	12,801			Laterite	Essentially noncorrosive	
VES 7	1	466	0.32	0.32	Clayey sand	Essentially noncorrosive	
	2	4746	0.609	0.929	Sand	Essentially noncorrosive	KH
	3	146	17.6	18.6	Sandy clay	Mildly corrosive	
	4	57,811			Bedrock	Essentially noncorrosive	
VES 8	1	470	0.323	0.323	Clayey sand	Essentially noncorrosive	
	2	4707	0.613	0.936	Sand	Essentially noncorrosive	KH
	3	146	17.7	18.6	Sandy clay	Mildly corrosive	
	4	66,636			Bedrock	Essentially noncorrosive	
VES 9	1	531	0.323	0.323	Clayey sand	Essentially noncorrosive	
	2	23,958	0.613	0.936	Laterite	Essentially noncorrosive	KH
	3	1035	17.7	18.6	Sand	Essentially noncorrosive	
	4	1.4E+5			Bedrock	Essentially noncorrosive	
VES 10	1	292.5	1.046	1.046	Sandy clay	Essentially noncorrosive	
	2	1666	0.8811	1.927	Sand	Essentially noncorrosive	KH
	3	87.39	1.215	3.142	Clay	Moderately corrosive	
	4	972.4			Sand	Essentially noncorrosive	

Table 4: VES Curves Results for VES Stations 11-20

VES Station	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Probable Lithology	Corrosivity Status	Curve Type
VES 11	1	296	1.177	1.177	Sandy clay	Essentially noncorrosive	
	2	1159	2.167	3.343	Sand	Essentially noncorrosive	KH
	3	110.5	18.92	22.26	Sandy clay	Mildly corrosive	
	4	88,905			Bedrock	Essentially noncorrosive	
VES 1 2	1	27.25	0.4744	0.4744	Clay	Highly corrosive	
	2	7563	4.823	5.298	Laterite	Essentially noncorrosive	K
	3	8.361			Clay	Extremely corrosive	
VES 13	1	1000	0.55	0.55	Sand	Essentially noncorrosive	
	2	173	3.06	3.61	Sandy clay	Mildly corrosive	QH
	3	38.7	8.29	11.9	Clay	Corrosive	
	4	16,975			Laterite	Essentially noncorrosive	
VES 14	1	4210	0.149	0.149	Sand	Essentially noncorrosive	
	2	63.4	1.22	1.37	Clay	Moderately corrosive	QH
	3	8.55	1.35	2.72	Clay	Extremely corrosive	
	4	175			Sandy clay	Mildly corrosive	
VES 15	1	50.48	0.7794	0.7794	Clay	Moderately corrosive	
	2	25.68	2.324	3.103	Clay	Highly corrosive	HK
	3	18,764	12.84	15.94	Laterite	Essentially noncorrosive	
	4	164.2			Sandy clay	Mildly corrosive	
VES 16	1	4.728	0.2844	0.2844	Clay	Extremely corrosive	
	2	1073	0.3467	0.6311	Sand	Essentially noncorrosive	KH
	3	13.21	2.685	3.316	Clay	Highly corrosive	
	4	846.8			Sand	Essentially noncorrrosive	
VES 17	1	581.5	0.7637	0.7637	Clayey sand	Essentially noncorrosive	
	2	287.2	6.686	7.45	Sandy clay	Essentially noncorrosive	QH
	3	55.29	6.54	13.99	Clay	Moderately corrosive	
	4	126,363			Bedrock	Essentially noncorrosive	
VES 18	1	345.1	0.4764	0.4764	Sandy clay	Essentially noncorrosive	
	2	228.9	2.054	2.53	Sandy clay	Essentially noncorrosive	QQ
	3	152	8.776	11.31	Sandy clay	Mildly corrosive	
	4	27.95			Clay	Highly corrosive	
VES 19	1	753	0.397	0.397	Sand	Essentially noncorrosive	
	2	20,245	0.578	0.975	Laterite	Essentially noncorrosive	KQ
	3	1792	7.99	8.97	Sand	Essentially noncorrosive	
	4	545			Clayey sand	Essentially noncorrosive	
VES 20	1	476	0.292	0.292	Clayey sand	Essentially noncorrosive	
	2	32,469	0.466	0.768	Laterite	Essentially noncorrosive	KH
	3	1014	26	26.8	Sand	Essentially noncorrosive	
	4	$3.0 x 10^5$			Bedrock	Essentially noncorrosive	

Based on the Isopach, map the first layer thickness varied between 0.15 m to 1.42 m with a lithology that constitutes predominantly of clayey sand, sandy clay and a little mixture of sand at VES points 1, 13, 14, 19, and 30. This layer is basically competent and noncorrosive except at about 17 VES stations located mostly within the third, fourth, and fifth transverses in the Southeastern, Northwestern, and Southwestern parts of the study area. Based on the Isoresistivity map these regions are the corrosive zones within the study area.

The second layer has resistivity values ranging from 24.7 Ωm to 3.5 x 10^5 Ωm with its thickness varying from one VES station to another between 0.0355 m to 8.983 m. The depth of the second layer as deduced from the results varied between 0.39 m to 11.2 m with a lithology that constitutes majorly of laterite, sand and clayey sand with little mix up of sandy clay and clay at VES stations 14, 15, 25, 37 and 38. The second layer is highly competent and essentially non corrosive except at VES stations (14, 15, 25, 37 and 38) which are characterized by low resistivity values within the second layer. The soils at these VES stations are a potential threat to concretes and steel iron.

The third layer which varied in thickness between 1.05 m to 34.2 m has resistivity values ranging from 8.361 Ωm to 151,608 Ωm. The depth of the third layer as deduced from the results varied between 1.3 m to 36.3 m with a lithology which constitutes predominantly of sandy clay and clay with a little mixture of clayey sand and laterite. The third layer is characterized by low resistivity values except at the central region of the study area which is an indication that the third layer is made of a soft material that is incompetent with corrosivity status ranging from “mildly corrosive” to “extremely corrosive”. However, there are few VES stations within the central part of the study area with very high resistivity values in the third layer. Along the first transverse, VES stations 9 and 12 have high resistivity values and in the second transverse VES stations 19, 20 and 21 also have very high resistivity values in all the four layers. At the third and fourth transverses, VES stations; 31, 32, 33, 35, 42, 43, 44, 45, 46 and 47 are characterized by high resistivity values in the third layer which is an indication that the third layer at these

Table 5: VES Curves Results for VES Stations 21-30

VES Station	Layers	Resistivity Ωm	Thickness (m)	Depth (m)	Probable Lithology	Corrosivity Status	Curve Type
VES 21	1	587	0.288	0.288	Clayey sand	Essentially noncorrosive	
	2	36,538	0.466	0.754	Laterite	Essentially noncorrosive	KH
	3	1018	26.2	26.9	Sand	Essentially noncorrosive	
	4	4.6 x10^5			Bedrock	Essentially noncorrosive	
VES 22	1	146	0.273	0.273	Sandy clay	Mildly corrosive	
	2	4478	0.458	0.732	Sand	Essentially noncorrosive	KH
	3	103	1.38	2.11	Sandy clay	Mildly corrosive	
	4	2822			Sand	Essentially noncorrosive	
VES 23	1	147	0.228	0.228	Sandy clay	Mildly corrosive	
	2	742	2.93	3.15	Clayey sand	Essentially noncorrosive	KH
	3	94.7	16.1	19.2	Clay	Moderately corrosive	
	4	1.0x10^5			Bedrock	Essentially noncorrosive	
VES 24	1	35.9	0.587	0.587	Clay	Corrosive	
	2	50,348	0.664	1.25	Laterite	Essentially noncorrosive	K
	3	223			Sandy clay	Essentially noncorrosive	
VES 25	1	117	0.659	0.695	Sandy clay	Mildly corrosive	
	2	52.6	3.15	3.85	Clay	Moderately corrosive	QH
	3	19	3.61	7.46	Clay	Highly corrosive	
	4	33,811			Laterite	Essentially noncorrosive	
VES 26	1	6.67	0.275	0.275	Clay	Extremely corrosive	
	2	593	0.403	0.677	Clayey sand	Essentially noncorrosive	KH
	3	9.23	1.88	2.56	Clay	Extremely corrosive	
	4	26,834			Laterite	Essentially noncorrosive	
VES 27	1	17.4	0.355	0.355	Clay	Highly corrosive	
	2	3.5x10^5	0.0355	0.39	Rock	Essentially noncorrosive	KH
	3	197	4.32	4.71	Sandy clay	Mildly corrosive	
	4	7361			Sand	Essentially noncorrosive	
VES 28	1	388	0.32	0.32	Clayey sand	Essentially noncorrosive	
	2	9012	0.647	0.966	Sand	Essentially noncorrosive	KQ
	3	179	8.62	9.59	Sandy clay	Mildly corrosive	
	4	53.6			Clay	Moderately corrosive	
VES 29	1	7.061	0.3471	0.3471	Clay	Extremely corrosive	
	2	478	0.4335	0.7806	Clayey sand	Essentially noncorrosive	KH
	3	21.05	2.913	3.694	Clay	Highly corrosive	
	4	68,116			Sand	Essentially noncorrosive	
VES 30	1	3152	0.206	0.206	Sand	Essentially noncorrosive	
	2	299	2.04	2.24	Sandy clay	Essentially corrosive	QQ
	3	173	6.2	8.45	Sandy clay	Mildly corrosive	
	4	61.2			Clay	Moderately corrosive	

Figure 3: A Typical KH-Type VES Curve

Table 6: VES Curves Results for VES Stations 31-40

VES Station	Layers	Resistivity Ωm	Thickness (m)	Depth (m)	Probable Lithology	Corrosivity Status	Curve Type
VES 31	1	743	0.332	0.332	Clayey sand	Essentially noncorrosive	
	2	37,750	0.503	0.835	Laterite	Essentially noncorrosive	KH
	3	1128	24.4	25.2	Sand	Essentially noncorrosive	
	4	1.8E+5			Bedrock	Essentially noncorrosive	
VES 32	1	719.39	0.3144	0.3144	Clayey sand	Essentially noncorrosive	
	2	37,171	0.4690	0.7834	Laterite	Essentially noncorrosive	KH
	3	1186	27.562	28.345	Sand	Essentially noncorrosive	
	4	182,334			Bedrock	Essentially noncorrosive	
VES 33	1	771	0.432	0.432	Clayey sand	Essentially noncorrosive	
	2	25,185	0.664	1.1	Laterite	Essentially noncorrosive	KH
	3	640	23.3	24.4	Clayey sand	Essentially noncorrosive	
	4	1.2E+5			Bedrock	Essentially noncorrosive	
VES 34	1	376	0.722	0.722	Clayey sand	Essentially noncorrosive	
	2	2457	0.75	1.47	Sand	Essentially noncorrosive	KH
	3	122	1.14	2.61	Sandy clay	Mildly corrosive	
	4	1540			Sand	Essentially noncorrosive	
VES 35	1	264	0.291	0.291	Sandy clay	Essentially noncorrosive	
	2	5393	0.439	0.73	Sand	Essentially noncorrosive	KQ
	3	282	5.1	5.83	Sandy clay	Essentially noncorrosive	
	4	54.6			Clay	Moderately corrosive	
VES 36	1	28.7	0.683	0.683	Clay	Highly corrosive	
	2	44,358	0.824	1.51	Laterite	Essentially noncorrosive	K
	3	23.7			Clay	Highly corrosive	
VES 37	1	220	0.753	0.753	Sandy clay	Essentially noncorrosive	
	2	24.7	7.59	8.35	Clay	Highly corrosive	H
	3	44,151			Sand	Essentially noncorrosive	
VES 38	1	173.1	0.5319	0.5319	Sandy clay	Mildly corrosive	
	2	72.33	1.812	2.344	Clay	Moderately corrosive	QH
	3	20.44	2.171	4.516	Clay	Highly corrosive	
	4	29,505			Laterite	Essentially noncorrosive	
VES 39	1	184	0.316	0.316	Sandy clay	Mildly corrosive	
	2	2188	0.451	0.767	Sand	Essentially noncorrosive	KH
	3	70.4	1.41	2.18	Clay	Moderately corrosive	
	4	13228			Laterite	Essentially noncorrosive	
VES 40	1	14.5	0.324	0.324	Clay	Highly corrosive	
	2	56,803	0.277	0.601	Laterite	Essentially noncorrosive	KH
	3	138	6.18	6.78	Sandy clay	Mildly corrosive	
	4	73,364			Laterite	Essentially noncorrosive	

Figure 4: A Typical K-Type VES Curve

Table 7: VES Curves Results for VES Stations 41-50

VES Station	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Probable Lithology	Corrosivity Status	Curve Type
VES 41	1	5.86	0.329	0.329	Clay	Extremely corrosive	
	2	1077	0.464	0.792	Sand	Essentially non corrosive	KH
	3	12.1	3.36	4.15	Clay	Highly corrosive	
	4	14,743			Laterite	Essentially noncorrosive	
VES 42	1	383	0.273	0.273	Clayey sand	Essentially noncorrosive	
	2	6538	0.362	0.635	Sand	Essentially noncorrosive	KH
	3	261	14.1	14.8	Sandy clay	Essentially noncorrosive	
	4	2.9E+5			Bedrock	Essentially noncorrosive	
VES 43	1	687	0.308	0.308	Clayey sand	Essentially noncorrosive	
	2	41,817	0.445	0.753	Laterite	Essentially noncorrosive	KH
	3	1321	26.1	26.8	Sand	Essentially noncorrosive	
	4	7.7E+5			Bedrock	Essentially noncorrosive	
VES 44	1	580	0.296	0.296	Clayey sand	Essentially noncorrosive	
	2	36,296	0.469	0.764	Laterite	Essentially noncorrosive	KH
	3	1298	27.3	28	Sand	Essentially noncorrosive	
	4	6.7E+5			Bedrock	Essentially noncorrosive	
VES 45	1	471	0.282	0.282	Clayey sand	Essentially noncorrosive	
	2	24,181	0.535	0.817	Laterite	Essentially noncorrosive	KQ
	3	823	8.84	9.66	Sand	Essentially noncorrosive	
	4	208			Sandy clay	Essentially noncorrosive	
VES 46	1	489	0.673	0.673	Clayey sand	Essentially noncorrosive	
	2	1963	0.736	1.41	Sand	Essentially noncorrosive	KQ
	3	458	5.51	6.92	Clayey sand	Essentially noncorrosive	
	4	51			Clay	Moderately corrosive	
VES 47	1	551	0.686	0.686	Clayey sand	Essentially noncorrosive	
	2	101	10.5	11.2	Sandy clay	Mildly corrosive	H
	3	1.2E+5			Bedrock	Essentially noncorrosive	
VES 48	1	18.7	0.396	0.396	Clay	Highly corrosive	
	2	40,360	0.611	1.01	Laterite	Essentially noncorrosive	K
	3	117			Sandy clay	Mildly corrosive	
VES 49	1	590.2	0.4684	0.4684	Clayey sand	Essentially noncorrosive	
	2	172.6	0.9721	1.44	Sandy clay	Essentially noncorrosive	QH
	3	32.52	4.478	5.919	Clay	Essentially noncorrosive	
	4	75,241			Bedrock	Essentially noncorrosive	
VES 50	1	227	0.15	0.15	Sandy clay	Essentially noncorrosive	
	2	447	3.4	3.55	Clayey sand	Mildly corrosive	KH
	3	78.3	21.4	24.9	Clay	Corrosive	
	4	73,198			Bedrock	Essentially noncorrosive	

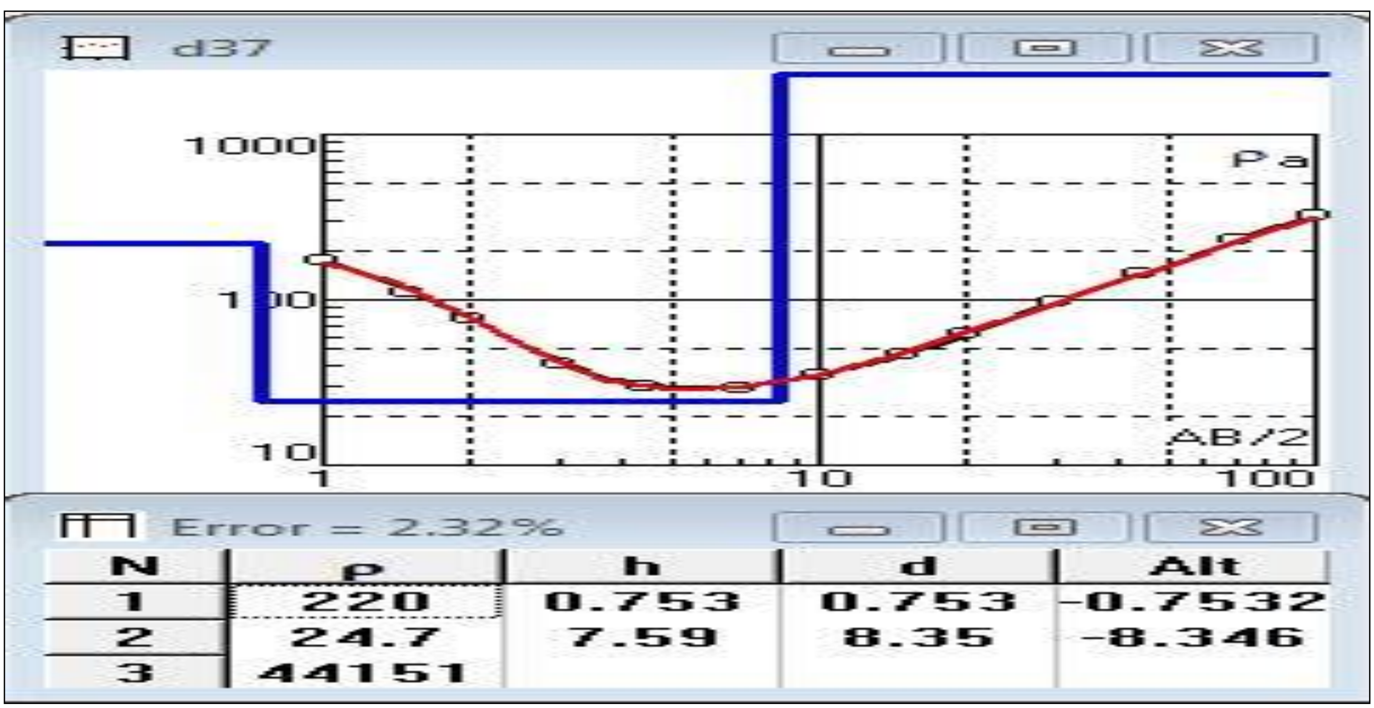

Figure 5: A Typical H-Type VES Curve

Table 8: VES Curves Results for VES Stations 51-60

VES Station	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Probable Lithology	Corrosivity Status	Curve Type
VES 51	1	386	0.641	0.641	Clayey sand	Essentially noncorrosive	
	2	2091	0.564	1.2	Sand	Essentially noncorrosive	KH
	3	77.5	1.05	2.25	Clay	Moderately corrosive	
	4	1535			Sand	Essentially noncorrosive	
VES 52	1	45.11	0.2997	0.2997	Clay	Corrosive	
	2	1321	0.3672	0.6669	Sand	Essentially noncorrosive	KH
	3	62.07	1.409	2.076	Clay	Moderately corrosive	
	4	517,464			Bedrock	Essentially noncorrosive	
VES 53	1	8.08	0.302	0.302	Clay	Extremely corrosive	
	2	426	0.489	0.79	Clayey sand	Essentially non corrosive	KH
	3	14.4	2.8	3.59	Clay	Highly corrosive	
	4	42,378			Laterite	Essentially noncorrosive	
VES 54	1	336	0.276	0.276	Sandy clay	Essentially non corrosive	
	2	2736	1.02	1.29	Sand	Essentially noncorrosive	KH
	3	187	13.1	14.4	Sandy clay	Mildly corrosive	
	4	81,007			Bedrock	Essentially noncorrosive	
VES 55	1	723	0.333	0.333	Clayey sand	Essentially noncorrosive	
	2	35,310	0.491	0.824	Laterite	Essentially noncorrosive	KH
	3	1267	26.7	27.5	Sand	Essentially noncorrosive	
	4	7.4E+5			Bedrock	Essentially noncorrosive	
VES 56	1	615.1	0.334	0.334	Clayey sand	Essentially noncorrosive	
	2	31,946	0.5408	0.8748	Laterite	Essentially noncorrosive	KH
	3	1015	22.3	23.17	Sand	Essentially noncorrosive	
	4	615,775			Bedrock	Essentially noncorrosive	
VES 57	1	529	0.321	0.321	Clayey sand	Essentially noncorrosive	
	2	165,900	0.494	0.815	Rock	Essentially noncorrosive	KQ
	3	1137	7.78	8.59	Sand	Essentially noncorrosive	
	4	194			Sandy clay	Mildly corrosive	
VES 58	1	576	0.85	0.85	Clayey sand	Essentially noncorrosive	
	2	3183	0.694	1.54	Sand	Essentially noncorrosive	KQ
	3	317	7.86	9.41	Sandy clay	Essentially noncorrosive	
	4	79.7			Clay	Moderately corrosive	
VES 59	1	571.1	0.7274	0.7274	Clayey sand	Essentially noncorrosive	
	2	100.2	8.983	9.711	Sandy clay	Mildly corrosive	H
	3	151,608			Bedrock	Essentially noncorrosive	
VES 60	1	6.98	0.276	0.276	Clay	Extremely corrosive	
	2	606	0.467	0.742	Clayey sand	Essentially noncorrosive	KH
	3	12.7	2.64	3.38	Clay	Highly corrosive	
	4	40,566			Laterite	Essentially noncorrosive	

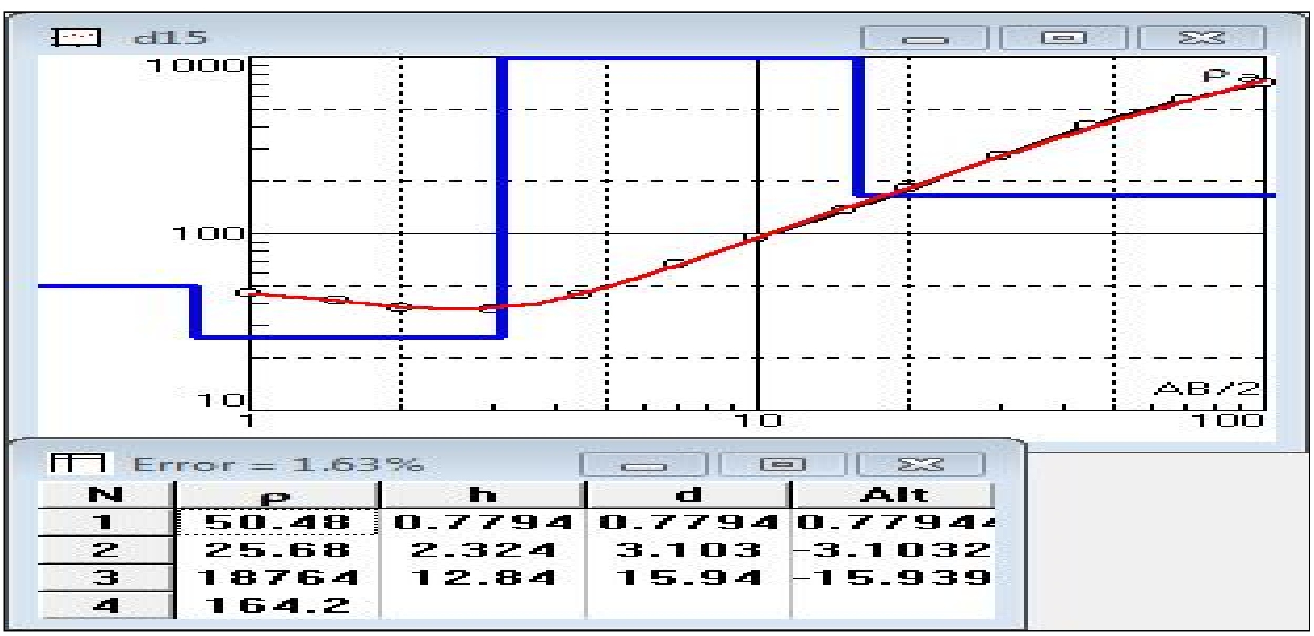

Figure 6: A Typical HK-Type VES Curve

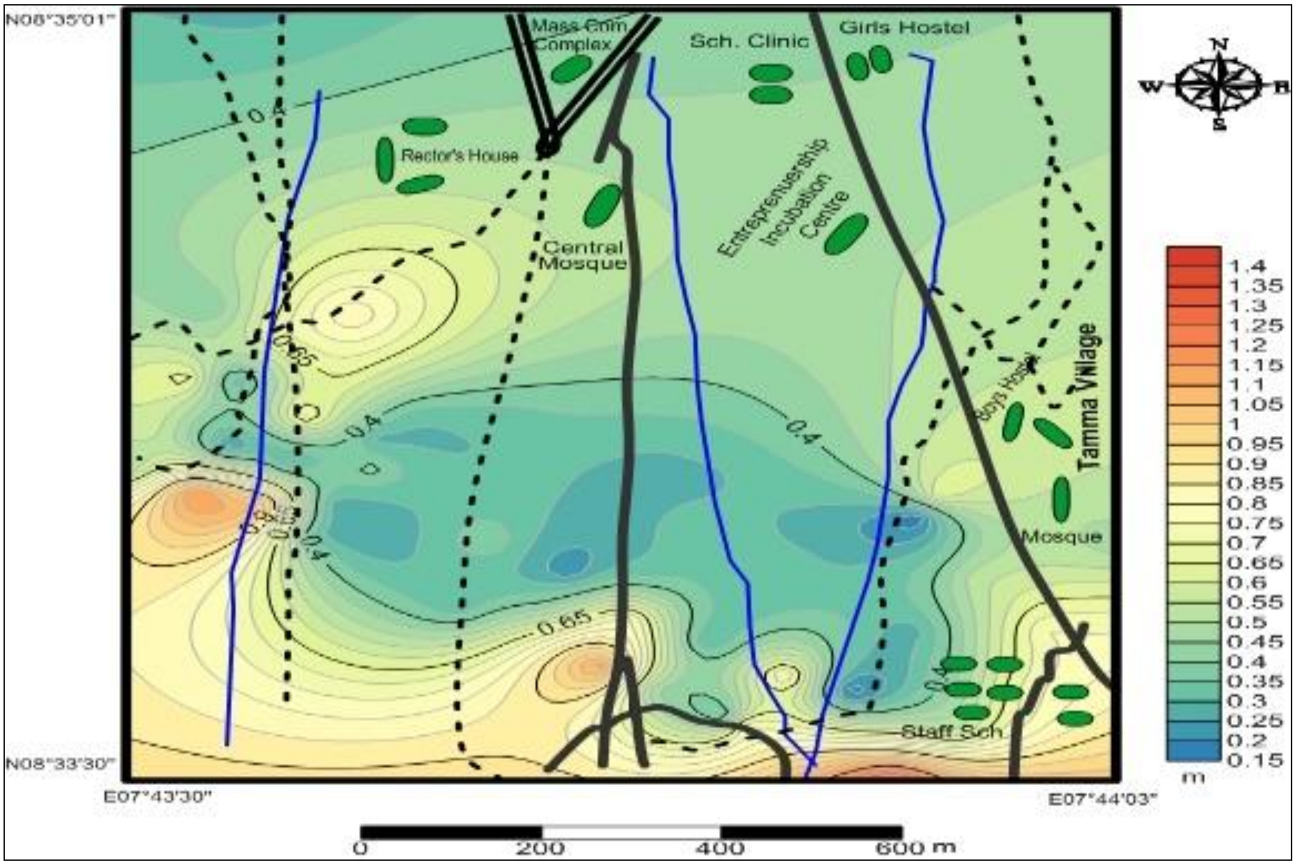

Figure 7: Isopach Map for Soil Thickness

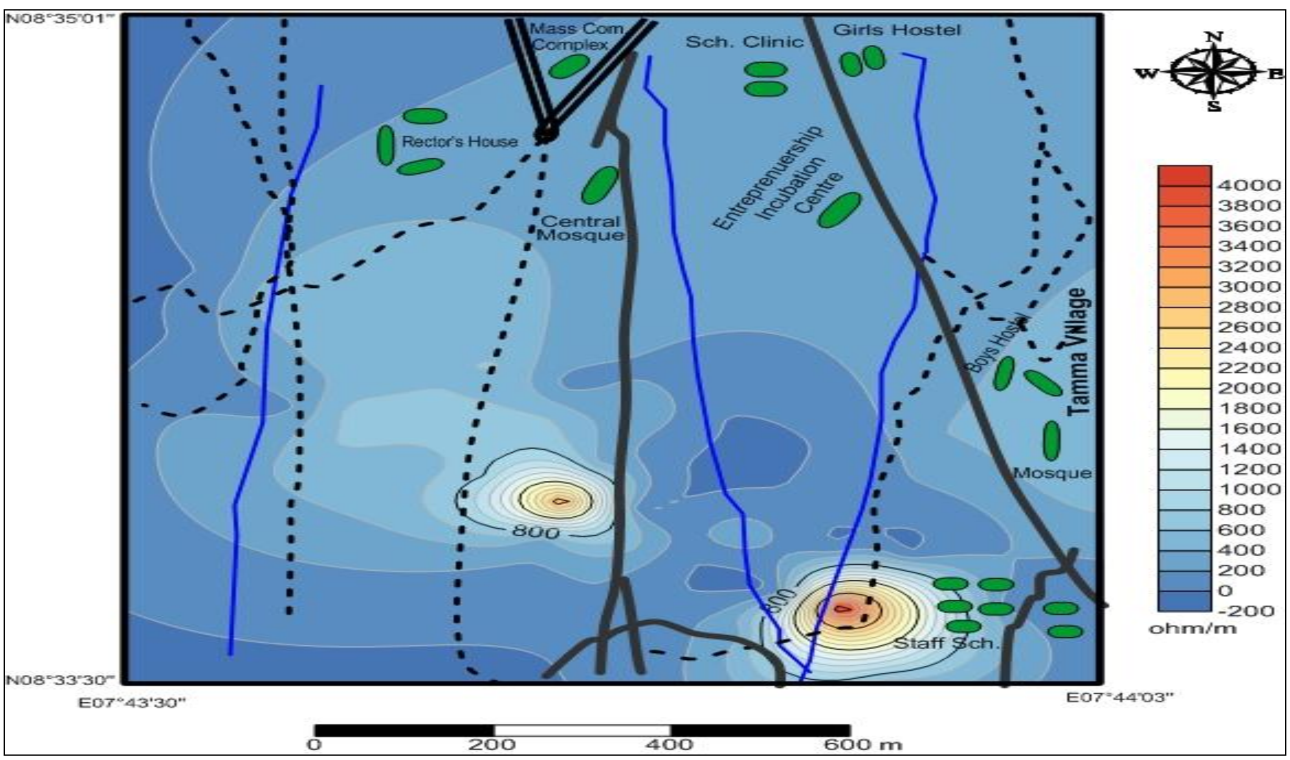

Figure 8: Isoresistivity map for Soil

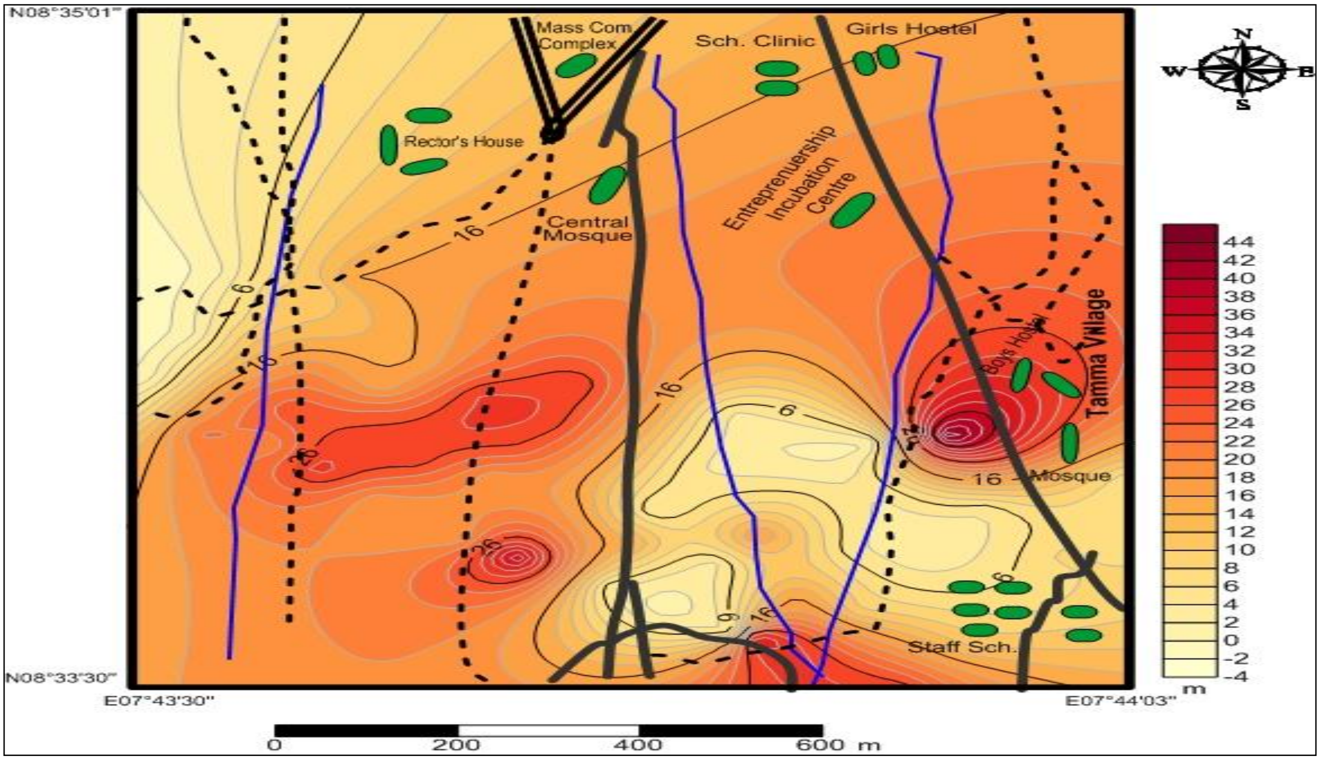

Figure 9: Isopach Contour map for Depth to Basement

VES stations are noncorrosive and highly competent for the construction of high rise buildings.

The fourth layer has resistivity values ranging from 27.95 Ωm to 77005 Ωm and falls majorly within the Bedrock in twenty -five VES stations. The layer also constitutes of laterite, sand, sandy clay and clay at other points. The fourth layer is characterized by high resistivity values and is majorly noncorrosive and competent. There are however a few VES stations (14, 18, 28, 30, 35, 46, 48, 57 and 58) where the fourth layer is mapped by low resistivity values. The depth to bedrock within the study area ranges between 2.076m to 44.5m. The depth to bedrock is shallower at VES 52, 3, and 49 while it is deeper at VES 52.

VI. CONCLUSION

Soil Corrosivity and competence evaluations have been carried out in parts of North Central Nigeria using Electrical Resistivity method. The qualitative interpretation of the Isoresistivity and Isopach maps has provided adequate information regarding the degree of Corrosivity and thickness of the subsoil in the study area. The Southwestern, Southeastern, and Northwestern parts of the study area are characterized as moderately corrosive to extremely corrosive soil with resistivity values ranging between 4.728 Ωm to 50.48 Ωm. The third layer constitute of an incompetent low resistivity soft material that underlain the entire study area except for the central region which is essentially noncorrosive and highly competent. VES curves interpretations revealed the thickness and depths of the geoelectric layers within the study area, the first layer has resistivity values between 4.728 Ωm to 4210 Ωm and varied in thickness between 0.15m to 1.42m, the second layer has resistivity values between 24.7 Ωm to 3.5 $\times 10^5$ Ωm and varied in thickness between 0.0355 m to 8.983 m while the third layer has resistivity values ranging between 8.361 Ωm to151,608 Ωm and varied in thickness between 1.05 m to 34.2 m, the fourth layer which is the last of the geoelectric layers has resistivity values between 27.95 m to 7.7 x 10^5 m. The subsoil within the study area constitutes clay, sandy clay, clayey sand, sand and laterite.

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AUTHOR CONTRIBUTIONS

O.S. Ayanninuola: Conceptualization, writing original draft, data acquisition and interpretation. **U.D. Msughter:** Methodology, data processing and analysis. **C.O. Ofoegbu:** Writing-review and editing. E.D. Uko: Supervision and methodology.

REFERENCES

Abidemi, A. H.; E. D. Uko and O. S. Ayanninuola. (2022). Velocity layering in the Middle Benue Trough Nigeria using seismic refraction method. *Earth Sciences Pakistan,* 6 (1), 27-29.

Adewuyi, O.I. and Philips, O.F. (2018). Integrated Geophysical and Geotechnical Methods for Pre-foundations Investigations. *J. Geol Geophys,* 7, 453. doi:10.4172/2381-8719.1000453.

Akpan, G. G.; E. D. Uko and O. D. Ngerebara. (2020). The Lithostratigraphy of the Near-Surface in part of Sedimentary Kolmani Field in Northern Benue Trough, Nigeria, using Soil Core and Seismic Refraction Data. *Earth Sciences Pakistan,* 4 (2), 58-64.

Anudu, G.K.; B.I. Essien and S.E. Obrike. (2012). Hydrogeophysical Investigation and Estimation of Groundwater potentials of the Lower Palaeozoic to Precambrain Crystalline Basement Rocks in Keffi Area, North-Central Nigeria, using Resistivity method. *Arab J Geosci*., 7, 311-322.

Ayanninuola, O.S.; B.S. Jatau and A.Z. Loko. (2018). Geoelectric Soundings for the Determination of aquifer characteristics in Anjagwa, Nasarawa State Nigeria. *FUW Trends in Science & Technology Journal*, 3 (2B), 938-943.

Ayolabi, E.A.; A.F. Folorunso and A.F. Oloruntola. (2010). Constraining causes of structural failure using Electrical Resistivity Tomography (ERT): A case study of Lagos, southwestern Nigeria. *Journal of Geophysics/mineral wealth*, 156 (210), 7 – 18.

Bayowa, O.G. and Olayiwola, N.S. (2015). Electrical Resistivity Investigation for Topsoil Thickness, Competence and Corrosivity Evaluations; A case Study from Ladoke Akintola University of Technology, Ogbomoso, Nigeria. *2015 2nd International Conference on Geological and Civil Engineering IPCBEE Vol.80(2015)©(2015) IACSIT Press, Singapore* DOI: 10.7763/IPCBEE 2015. V80.11Pp 52-56.

Clifford N. C.; Mbachi, Etim D. Uko, Aminayanasa P. Ngeri and Charles O. Ofoegbu. (2018). Estimation of the Dipping Angles of Refractors in the Middle Benue Trough Nigeria Using Generalized Reciprocal Method. *Asian Journal of Applied Science and Technology, 2 (4), 10 – 22.*

Coker, J.O.; V. Makinde; A.O. Mustapha; J.K. Adesodun. (2013). Electrical resistivity imaging for foundation failure investigation at Remo secondary school, Sagamu, Southwestern Nigeria. *International Science and Investigation Journal*, 2 (4), 40 – 50.

Fadele, S.I.; B.S. Jatau and A. Umbugadu (2012). Engineering Geophysical Investigation Around Ungwan Doka Shika Area within the Basement Complex of North-western Nigeria. *Journal of Environment and Earth Science*, 2 (7), 17-22.

Fajana, A.O.; O.G. Olaseeni; O.E. Bamidele and O.P. Olabode (2016). Geophysical and Geotechnical Investigation For Post Foundation Studies, Faculty of Social Sciences and Humanities, Federal University Oye Ekiti. *FUOYE Journal of Engineering and Technology*, 1 (1), 23-35

Falowo, O.O and Otuaga, M.P. (2020). Engineering Subsoil Exploration for Foundation Design and Planning of a Proposed Filliing Station in Ore Area of Ondo state. *World Academics Journal of Engineering Sciences*, 7 (2), 77-87.

Idornigie, A.I.; M.O. Olorunfemi and A.A. Omitogun. (2006). Electrical Resistivity Determination of Subsurface Layers, Subsoil Competence and Soil Corrosivity at an Engineering Site Location in Akungba-Akoko, SouthWestern Nigeria. *Ife Journal of Science*, 8 (2), 159-177.

Jatau, B.S.; I.Y. Tanko; O.H. Usman; M.E. Yakubu and O.S. Ayanninuola. (2017). Hydrogeological Appraisal of Risha, Part of Akwanga Sheet 209NE, North Cental Nigeria, Journal of Nigerian Association Hydrogeologists 27(1) , 50-67.

Miguel, A. B.; M. M. Jose; C. Rene; G. Citlall; H. Cindy; L. Luis; O. Francisco and A. Facundo. (2019). Corrosion behavior of Galvanized steel embedded in concretes exposed to soil type MH contaminated with Chlorides. Unpublished paper, Mexico.

Ofoegbu, C. O. (1986). Preliminary Results from a pseudogravity study of the Benue Trough, Nigeria. *Journal of African Earth Sciences*, 5 (2), 187-192.

Ofoegbu, C.O. (2019). Structure and Evolution of the Benue Trough. Nigerian Association of Petroleum Explorationist 2019 Technical meeting. Abuja. Nigerian Association of Petroleum Explorationist technical meeting, 1-44.

Ofomola, M.O., Isherhien-Emekeme, R.E., Okocha, F.O. and Adeoye, T.O. (2018). Evaluation of Subsoil competence for Foundation Studies at Site III of the Delta State University, Abraka Nigeria. *Journal of Geophysics and Engineering*, 15 (3), 638-657.

Ologo, O., and Augie, A.I. (2007). Geophysical Investigation for Pre-Engineering Construction Works in Parts of Ilorin, North Central Nigeria. *Journal of Geological and Environmental Engineering*, 14 (11), 341-347.

Olorode, D.O., Adedayo, A.S. and Akintunde, A.O. (2016). Applications of Geotechnical And Geophysical Methods to Investigate Tilt Buildings at Lagos State, Nigeria. *IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)*, 4 (5, Ver.11), 21-28. e-ISSN:2321-0990, p-ISSN:2321-0982.

Rowland, A. A. and Nur, A. (2019). Structural Pattern Deduced from Aeromagnetic Data Over Parts of Nasarawa and Environs North-Central Nigeria. *Global Journal of Geological Sciences*, 17, 85- 95.

Zoran, B., Gordana, T. C., Nebojsa, D. and Jelena, S. (2015). Damage of Concrete and Reinforcement fo Reinforced-Concrete Foundations Caused by Environmental Effects. *Procedia Engineering*, 117, 411-418.