Investigation of Variation in Resistivity with Depth and Soil Compaction in parts of River State, Southern Nigeria.

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ABSTRACT

The behaviour of the subsurface soil upon application of a low potential field has been investigated. The aim of the study was to determine the variation in the electrical properties of resistivity and dielectric polarization in relation to soil compaction, type and chemical constituents. Three different soil types which include sandy clay, sand-clayey loam and loamy sand were investigated. The near-surface geophysical technique of vertical electrical sounding and proctor compaction methodology were employed to measure the electrical properties of the soil investigated. The results show variation in electrical resistivity with depth from 1.33 Ω to 9.77 Ω for sandy clay, 2.09 Ω to 23.06 Ω for sandy clay loamy and 3.26 Ω to 128.0 Ω for loamy sand while apparent resistivity increases from 1.251 x 10^2 Ω-m for sandy clay to 1.448 x 10^3 Ω-m for loamy sand. The higher the apparent resistivity, the greater is the resistance of the material to the flow of current, and resistivity increases as water or ion concentration increases. Laboratory investigation of the soil samples shows that dielectric constant ranges from 7.02 Er to 8.98 Er for sandy clay, 3.30 Er to 6.05 Er for sand clay loam and 2.64 Er to 4.92 Er for loamy sand. These variations were suspected to be due to the different mineral compositions of the soils and organic matter content contained.

Key words: resistivity, compaction, depth, subsurface soil.

1. INTRODUCTION

Electrical resistivity offers a very attractive non-destructive tool for describing the subsurface properties over a large range of scales without digging, contrary to classical soil science measurements and observations which perturb the soil by random or regular drilling and sampling. It is a very attractive method for soil characterisation. It has been applied in various contexts like: groundwater exploration, landfill and solute transfer delineation, agronomical management by identifying areas of excessive compaction or soil horizon thickness and bedrock depth, and at least assessing the soil hydrological properties (Samouelian et al., 2005). Variation in the resistivity of the earth materials either vertically or laterally produces distortion to applied current and potential distribution measured on the surface, and when combined with other measurements, can reveal information about the composition, extent and physical properties of the subsurface material. The changes caused on soil by intensive agricultural production are variable in space and time; geophysical methods however, have helped to non-intrusively collect subsurface properties without digging (Scollar et al., 1990). Resistivity of soil depends on the physical properties of the soil, water content, fluid composition, seasonal variation and current magnitude (Poljak and Doric, 2006; Geri et al., 1992; Nor et al., 2006; Banton et al., 1997). Different soil composition gives different average

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resistivity but moisture has a great influence on resistivity of soil (Ab Kadir et al., 2009; Begamudre, 2009; Razevig, 2003). In clay soil, the electrical charges located at the surface of the clay particles lead to greater electrical conductivity than in coarse textured soils because of the magnitude of the specific surface (Fukue et al., 1999).

Soil compaction is one of the most critical components in the construction of roads, airfields, embankments, and foundations. Structural failure of roads and airfields and the damage caused by foundation settlement can often be traced back to the failure to achieve proper soil compaction. Compaction is the process of mechanically densifying a soil. This is accomplished by pressing the soil particles together into a close state of contact with air being expelled from the soil mass in the process.

The main objective of this study is to investigate whether chemical content present in soils can influence variations in resistivity of the soil and dielectric polarization of a heterogeneous soil medium, and also to determine the general trend or variation in dielectric constant as a function of soil compaction. Since electrical measurements are sensitive to water content and the ionic concentration, spatial and temporal variability of plant nutrient can also be estimated. This information can be useful in precision farming for the management of irrigation to both optimise production and minimise nitrate leaching (Corwin and Lesch,2003). It also provides an efficient, economical, and rapid way of identifying areas of excessive soil compaction due to wheel traffic; identifying soil horizon thickness and bedrock depth, and assessing soil hydrological properties over vast agricultural production regions (Freeland et al., 1998). Electrical variability is closely linked with crop yield at the field scale (Zanolin, 2003). Besson et al., (2004) outlined the link between the soil structure and electrical resistivity values in an agricultural context.

2. GEOLOGICAL DESCRIPTION

The study area, part of which houses the University of Port Harcourt lies within the Nigerian coastline facing the Atlantic ocean, between latitude 4° to 5°E and longitude 6° to 7° N (Fig. 1). The area enjoys an equatorial climate consisting mainly of two major seasons: Rainy season, (March-October) and Dry season (November-February) each year (Igboekwe and Nwankwo, 2011). The average annual temperature and precipitation are 29°C and 150 mm respectively. The area is generally covered by fresh water swamp, lagoonal mashes, tidal channels and sand bars. Choba nearby towns is richly endowed with oil and gas.

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Figure 1. Map of Nigeria showing the study area.

3. METHODOLOGY

The vertical variation of resistivity with depth was investigated using Schlumberger electrode configuration for geophysical resistivity measurement, while modified proctor compaction method was utilized in measuring dielectric constant of the soil in the area. This was aimed at analyzing the soil composition, homogeneity, texture, porosity, density and soil moisture content of the area. Soil samples were collected from three different sites within the study area. Sample 1 (greenish soil) was collected from the river; Sample 2 (reddish brown) is top soil while Sample 3 (white) was collected while drilling water borehole. All the samples were tied in a cellophane bag and taken to the laboratory for analysis. At the laboratory, all the samples were mixed with fixed volume of distilled water to ensure uniformity of the particles of the sample, and then oven dried to a temperature of the 70°C.

Compaction of different degrees were achieved in the laboratory from mechanically applied force whereby a known weight (5kg) was allowed to fall freely from a fixed height (50 cm) on to the surface of the soil in a constructed soil mould measuring 7x2.5 cm. This method gives a very good approximation of a uniform density. A good soil surface finishing was achieved by polishing the sides of the mould parts with a sand-paper. Since compaction refers to the increase in the bulk density of the soil (soil stabilization), it becomes possible to measure the degree of compaction by varying the moisture content of the oven dried soil. The bulk density B_D, is then given as

$$\mathbf{B_D = M/V} \qquad \textbf{(1)}$$

where M is mass of the oven dried soil and V is the volume of the soil.

The soils were oven dried at a 105°C for a regulated period to give a moisture content of 3% by weight of water. Soil stabilization increases the shear strength, reduces permeability and compressibility in the soil.

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The dielectric constant of the soil was measured using the Booton capacitance meter 95B by simply measuring the capacitance of the capacitor with air against the measurements made with the soil compacted at the different degrees separated with slides. The dielectric constant ϵ_r was obtained using the expression

$$\epsilon_r = C_x/C_o \quad (2)$$

where C_x is the capacitance of the capacitor with the compacted soil in between, and C_o is the capacitance of the aluminium capacitor with air as the dielectrics. The measurements were made with a frequency of 50 Hz. A void space capacitance value of 247.8 pF was utilized in the computation of results.

Particle-size analysis of the different soil samples was carried out in the laboratory using the hydrometer method. Fifty grammes (50 Kg) of soil were poured into a dispersing cup and each weighed sample was treated with hydrogen peroxide after it has been oven dried for 24 hours so as to remove the organic matter. The weighed soil in the dispersing cup was filled with distilled water and 10 ml of sodium hexameters phosphate was added. The soils were dispersed after soaking and then poured into a graduated one litre cylinder. Enough water was added to fill the cylinder to the one litre mark. A stopper was placed over the end of the cylinder, and the content vigorously shaked. The cylinder was placed on the table and the time taken at that instant. A hydrometer was carefully introduced into the suspension and readings were taken at a given time and temperature interval. By utilizing different mathematical expressions, the approximate sand, clay and silt percentages were obtained (Table 1).

Table 1: Particle Size Analysis

Soils	**Approximated**	**Percentage of Soil Separates**		**Textural**
	Sand	Silt	Clay	Class
Site 1	15.7	29.4	54.5	Sandy Clay
Site 2	48.0	18.2	33.2	Sandy clay loamy
Site 3	75.4	9.6	14.1	Loamy Sand

The VES survey was carried out using ABEM (SAS 300C) Terrameter, and utilizing Schlumberger electrode configuration method. A total of eleven vertical electrical sounding stations were occupied. A low frequency alternating current was driven into the ground by means of the current electrodes connected to the terminals of voltage source. The resulting potential distributions on the ground mapped by two non polarizing electrodes provided information on the form of subsurface heterogeneities and of their properties (Kearey et al., 2002).

In order to increase the depth of investigation, the current electrodes separation were increased gradually while the potential electrode separation remained constant until the potential difference value become too small to be measured satisfactorily. Similar measurements were made in other selected locations. The field recorded values were processed and interpreted using IPI2WIN resistivity sounding interpretation software version 3.0 (2003), to determine the true resistivity and depths of subsurface formations.

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4. RESULTS AND DISCUSSION

The variation of dielectric constant with depth for different soil samples are shown in figures 2-4 and Table 2. Table 3 illustrates the geoelectric characteristics of selected VES survey sites in the study. The interpreted geoelectric section was correlated with a borehole log data from the study area (Fig. 5).

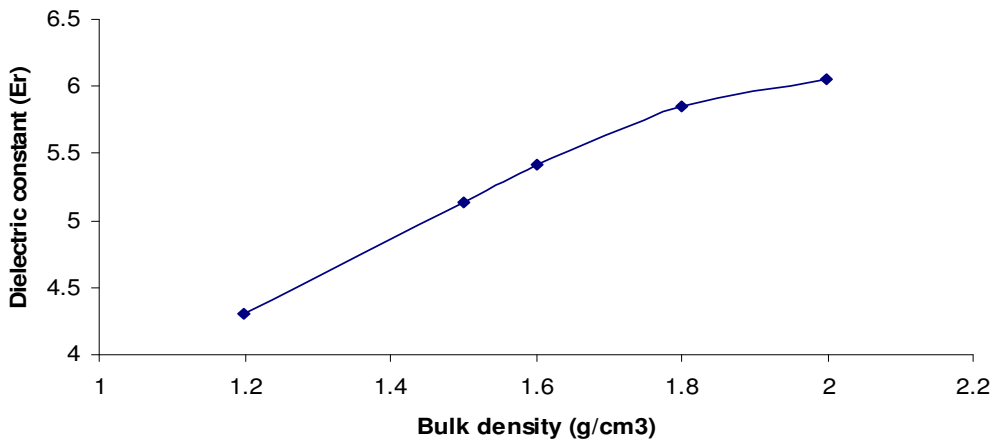

Figure 2. Variation of density with dielectric constant in Sandy Clay Loamy Soil

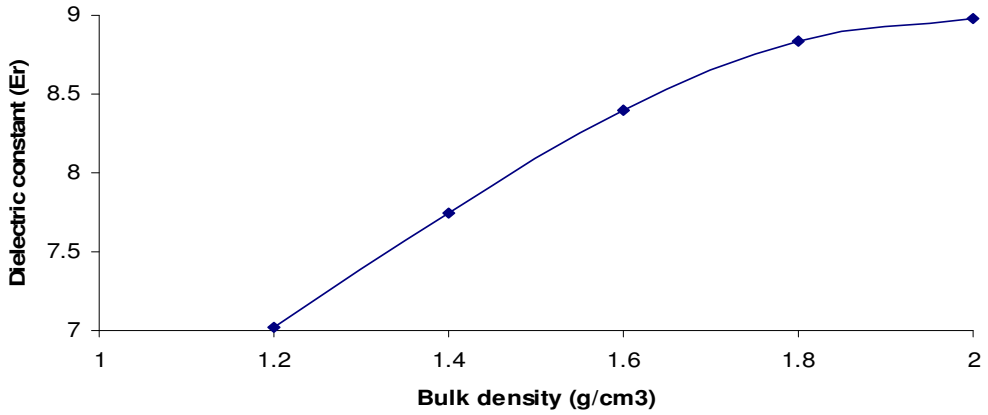

Figure 3. Variation of density with dielectric constant in Sandy Clay Soil

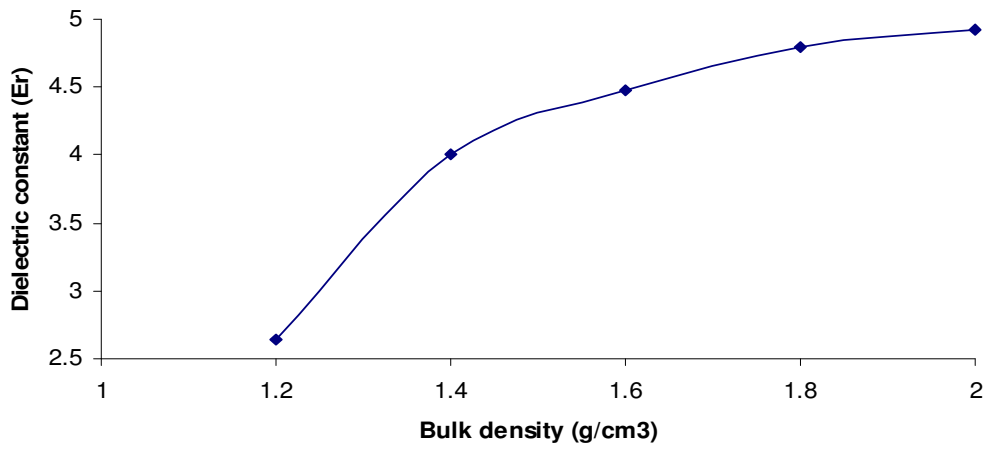

Figure 4. Variation of density with dielectric constant in Loamy Sand Soil

Table 2 : Variation of dielectric constant with depth

Layers separation (cm)	Capacitance of soil sample (pF)	Height of drop (cm)	Bulk density (g/cm^3)	Dielectric constant (Er)	Layers separation (cm)	Capacitance of soil (pF)	Height of drop (cm)	Bulk density (g/cm^3)	Dielectric constant (Er)	Layers separation (cm)	Capacitance of soil (pF)	Height of drop (cm)	Bulk density (g/cm^3)	Dielectric constant (Er)
Clayey Loamy					Sandy Clay					Loamy sand				
0.5	1065	50	1.20	4.30	0.5	1739	50	1.20	7.02	0.5	655	50	1.20	2.64
0.5	1270	50	1.50	5.13	0.5	1919	50	1.40	7.74	0.5	990	50	1.40	4.00
0.5	1340	50	1.60	5.41	0.5	2081	50	1.60	8.40	0.5	1110	50	1.60	4.48
0.5	1450	50	1.80	5.85	0.5	2190	50	1.80	8.84	0.5	1190	50	1.80	4.80
0.5	1500	50	2.00	6.05	0.5	2225	50	2.00	8.98	0.5	1220	50	2.00	4.92

The generated curves for the variations of dielectric constant with compaction for different soil samples (figures 2 - 4), show a non linear increase of dielectric constant with compaction for the three soil types. The increase may be due to the exponential increase in soil density with applied force at given moisture content or the increase in dielectric constant with number of polarizing particles. However, the magnitude of variation of the dielectric constant with compaction seems to be in the order Sandy Clays > Sandy Clay Loamy > Loamy sand. The computed dielectric constants are in agreement with standard values (Park-homenko, 1967), which are quoted to lie between 2.5 Er and 110 Er for dry moist soils. The increase in dielectric constant of the three soil samples with compaction can also be explained from the view point that reduction in the series capacitance caused

Table 3 : Geoelectric layer parameters

VES No	Modeled Layer Resistivity (Ω-m)	Depth (m)	Layer Thickness (m)	Formation type
1	439.4	1.57	1.57	Sandy clay
	1931.0	2.79	1.22	Sandy clay loamy
	247.1	5.39	2.60	Sandy clay
	1448.0	8.14	2.75	sand
	497.1	16.38	8.24	Loamy sand
	1707.0	66.29	49.91	sand
	921.1	----	----	
2	586.0	2.09	2.09	Sandy clay loamy
	1179.0	4.04	1.95	Loamy sand
	2012.0	8.48	4.44	sand
	421.7	19.68	11.20	Loamy sand
	1280.0	53.97	34.29	sand
	610.5	128.0	74.03	Loamy sand
	279.5	----	----	
3	209.6	1.33	1.33	Sandy clay
	372.8	2.57	1.24	Sandy clay loamy
	185.3	7.49	4.92	Sandy clay
	562.3	25.75	18.26	Loamy sand
	3035.0	78.14	52.39	sand
	610.5	----	----	
4	1448.0	2.09	2.09	Loamy sand
	636.2	6.90	4.81	Sandy clay loamy
	247.1	24.71	17.81	Loamy sand
	814.2	84.84	60.13	sand
	3433.0	----	----	
5	237.1	1.85	1.85	Sandy clay
	1179.0	4.57	2.72	Loamy sand
	586.0	9.21	4.64	Sandy clay loamy
	2276.0	81.57	72.36	sand
	921.1	----	----	
6	408.0	2.45	2.45	Sandy clay loamy
	625.8	4.88	2.43	Loamy sand
	125.1	9.77	4.89	Sandy clay
	353.7	23.06	13.29	Sandy clay loamy
	600.9	46.10	23.04	Loamy sand
	783.1	100.00	53.90	sand
	271.4	----	----	
7	480.2	1.33	1.33	Sandy clay loamy
	334.0	2.12	0.79	Sandy clay
	276.9	4.24	2.12	Loamy sand
	239.9	10.96	6.72	Sandy clay loamy
	867.2	37.60	26.64	sand
	379.8	92.18	54.58	Loamy sand
8	283.1	1.54	1.54	Sandy clay
	921.1	3.26	1.72	Loamy sand
	227.6	6.46	3.20	Sandy clay loamy
	343.3	21.1	14.64	Loamy sand
	3262.0	53.67	32.57	sand
	1179.0	----	----	

by air gap between the plates and sample leads to a larger corresponding layer value for the dielectric constant. Also, the organic matter present may have some polarizing effects on the dielectric constant (Ebeniro and Ofoegbu, 1992).

In interpreting VES data, it is usually assumed that the subsurface consists of several horizontal layers (Pozdnyakova et al., 2001); and that the effective depth of investigation depends on the relative positions of both current and potential electrodes (Samouelian et al., 2005). The plot of the variation of the resistivity with increasing electrode spacing represents the variation of the resistivity with depth in a quantitative way.

The interpreted VES results indicate a variation of resistivity with depth and lithologic units (Table 3). There is a general decrease in electrical resistivity with depth for loamy sand, sand clay loamy and sandy clay as the grain size of the soil mineral decrease with decreasing moisture content and pore space distribution with depth. The variations in the apparent resistivity for sandy clay, sand clay loamy shows close similarities between their properties. The electrical resistivity changes with depth from

1.33 Ω to 9.77 Ω for sandy clay, 2.09 Ω to 23.06 Ω for sandy clay loamy and 3.26 Ω to 128.0 Ω for loamy sand.

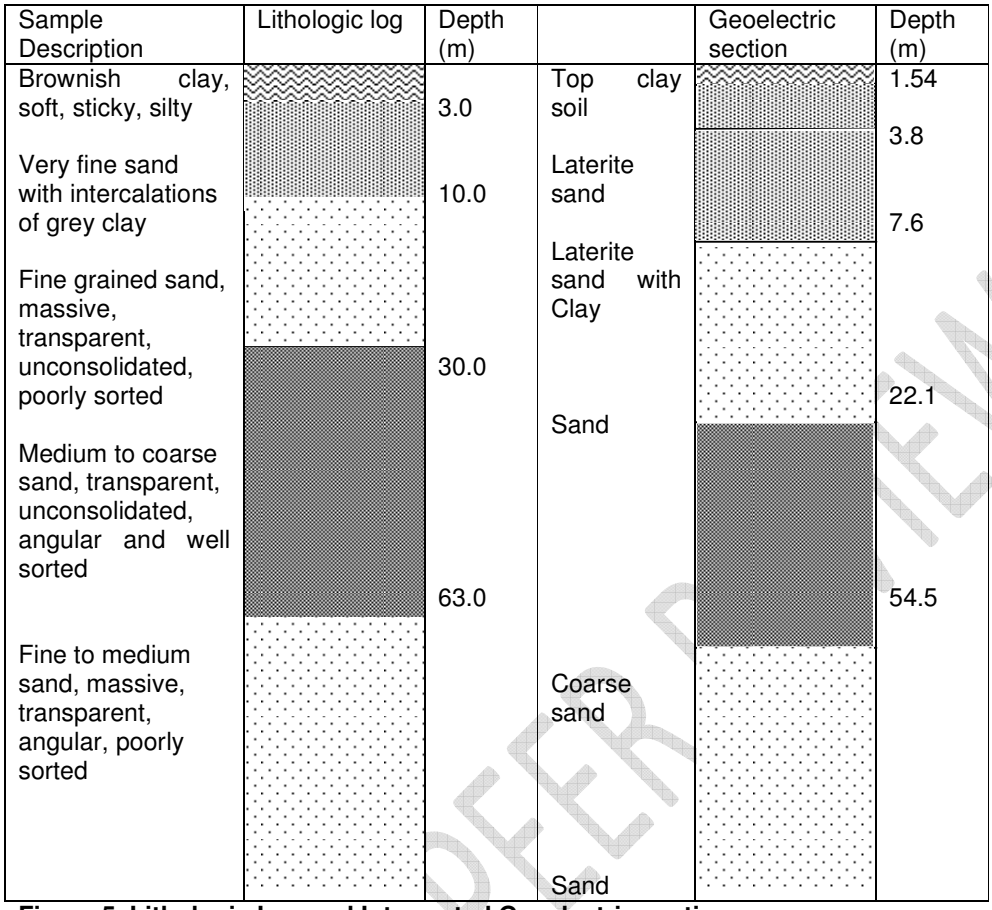

Figure 5. Lithologic Log and Interpreted Geoelectric sections

5. CONCLUSION

The study has shown that soil compaction and resistivity vary non-linearly and at varying degrees with different soil composition. Resistivity has generally been seen to increase with depth and by implication resistivity increases with depth and soil compaction. There is no relationship in values of the measured resistivity and soil type. Therefore, the soil composition, porosity and amount of water contained have significant control on resistivity at a particular depth in the subsurface. Dielectric constant generally increases with depth and/or compaction of soil materials.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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