



Investigation of Variation in Resistivity with Depth and Soil Dielectric Constant in Parts of Rivers State, Southern Nigeria

C. N. Nwankwo^{1*}, D. O. Ogagarue² and F. O. Ezeoke³

¹Department of Physics, University of Port Harcourt, P.M.B. 5323 Port Harcourt, Nigeria.

²Department of Earth Sciences, Federal University of Petroleum Resources, P.M.B. 1221 Effurun, Nigeria.

³Seplat Petroleum development Company Lagos, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author CNN designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors DOO and FOE managed the analyses of the study. Author FOE managed the literature searches. All authors read and approved the final manuscript.

Research Article

Received 17th July 2012
Accepted 25th February 2013
Published 17th March 2013

ABSTRACT

The behaviour of the subsurface soil upon application of a low potential field has been investigated utilizing Schlumberger configuration of Electrical resistivity survey. The characteristics of three different soil types which include sandy clay, sand-clayey loam and loamy sand were also investigated through laboratory analysis. The aim was to determine the variation in the subsurface electrical properties such as resistivity and dielectric polarization with the soil texture and structure, density, soil moisture, and mineralogy. The results show variation in electrical resistivity for the different soil types at different depth range points as 1.33 Ω -m to 9.77 Ω -m for sandy clay, 2.09 Ω -m to 23.06 Ω -m for sandy clay loamy and 3.26 Ω -m to 128.0 Ω -m for loamy sand while apparent resistivity increases from 125 Ω -m for sandy clay to 1.448×10^3 Ω -m for loamy sand. The interpreted VES results indicate a variation of resistivity with depth and lithologic units. There is a general increase in both the electrical resistivity and dielectric constant 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. However, the magnitude of variation of the dielectric constant with compaction are in the order Sandy

*Corresponding author: E-mail: cyrilnn@yahoo.com;

Clays > Sandy Clay Loamy > Loamy sand. Soils with higher dielectric constants such as Sandy Clay should be more suitable for agricultural farming in tropical areas especially during dry season. The laboratory and field survey studies of rock electrical properties show that both the dielectric constant and soil resistivity increases with depth and density.

Keywords: Resistivity; dielectric constant; soil structure; density.

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 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 [1]. 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 of texture, structure, water content and water salinity of the subsurface material. In most rocks near the earth's surface, the electrical conduction is dominated by electrolytic conduction in aqueous solution of common salts distributed through the pores of the rock and/or at the rock-water interface. The changes in hydraulic properties, structure and soil contents 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 [2]. Soil electrical resistivity depends on the physical and chemical properties of the soil, water content, fluid composition, seasonal variation and current magnitude [3,4,5,6]. In clay rich soils the moisture, structure and compaction are intimately associated. The Archie law may be applied to the soil structure [7]. In clayey soil, the electrical charges located at the surface of the clay particles induce a "surfacic conductivity" in addition to the electrolytic conductivity. The "surfacic conductivity" can be taken into account in the Archie law via the C.E.C. of the clay material [8].

The objective of the soil compaction for the road construction is to obtain dry density of the compacted material greater than 95% of the dry density obtained at the optimum proctor. That implies a "thin" range of water content for working to avoid the inefficient compaction of too dried or too wet material.

The main objective of this study is to investigate how the moisture, texture and mineral contents 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 density for various soil types. The result can be used to calibrate our near surface geophysical measurements for delineating which soil types are most suitable for seasonal agricultural farming. It will also assist in giving insights on the depths of the various soil types that are appropriate for building foundations to avoid incessant collapsing of structures in the study area in recent times.

Since electrical measurements are sensitive to water content and the ionic concentration, spatial and temporal variability of soils 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 [9]. 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 [10]. Electrical variability is closely linked with crop yield at the field scale [11]. Besson [12], outlined the link between the soil structure and electrical resistivity values in an agricultural context.

2. METHODOLOGIES

2.1 Experimental Area

The study area, Choba, houses the University of Port Harcourt and 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 [13]. The average annual temperature and precipitation are 29°C and 150 mm respectively. The area is generally covered by fresh water swamp, lagoonal marshes, tidal channels and sand bars. Choba and nearby towns are richly endowed with oil and gas. The underlying sediments in Choba forms part of the stratigraphic sequence in the Niger Delta. They consist of unconsolidated fresh water bearing continental sands and gravels with occasional interbedded shales of the Benin Formation, deposited during the late Tertiary to early Quaternary period with an average thickness of about 2100m [14].

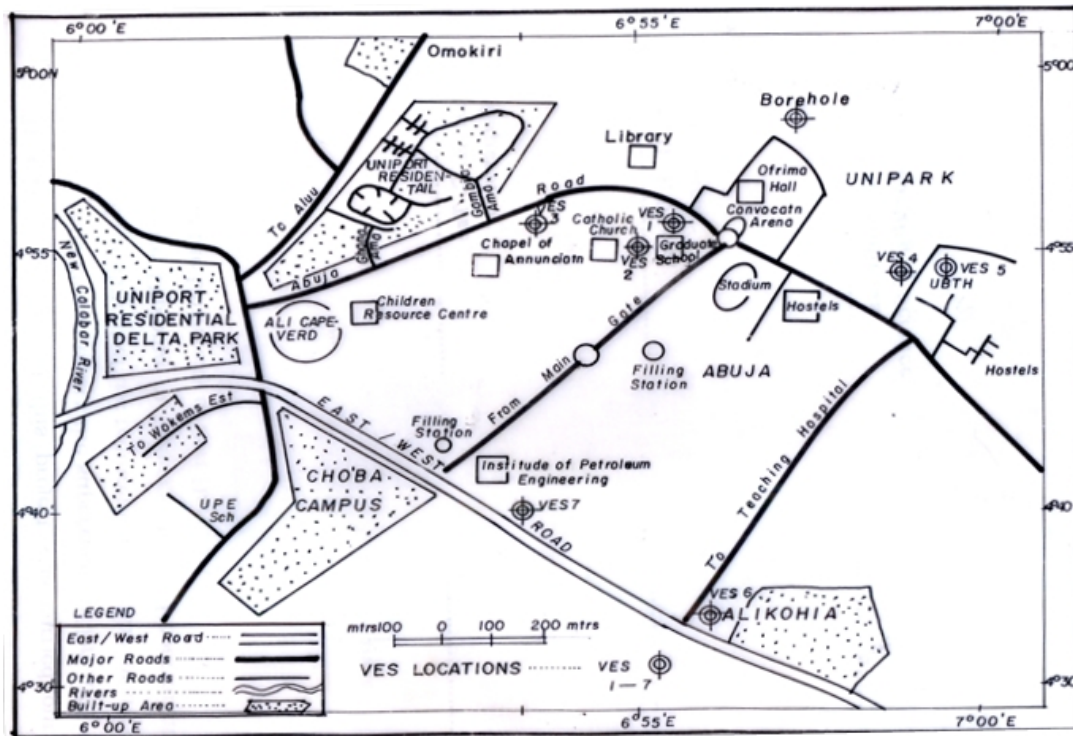


Fig. 1. Location map of the study area showing the 7 sounding points (VES 1-to-7; from Ehirim and Nwankwo [15])

2.2 Electrical Resistivity Measurements

The vertical variation of resistivity with depth was investigated from surface Vertical Electrical Sounding (VES) geophysical survey (Schlumberger electrode configuration) using the Abem Terameter 1000C, aided with a 2000C booster for better penetration. A total of seven vertical electrical sounding stations were occupied, with one of the stations sited near an existing borehole. 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 [16].

The current electrodes separation AB were increased gradually while the potential electrode separation MN 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 [17], to determine the apparent resistivity, depths and thickness of subsurface formations (Table 3).

2.3 Dielectric Constant Measurements

Soil samples were collected at shallow depths of about one meter from three sites at VES locations 3, 4 and 7 respectively. The different soil samples which varied in texture, grain size and moisture content were studied in order to investigate which type will be more appropriate for dry season farming. All the samples were well preserved in a cellophane bag and taken to the laboratory for analysis within 48 hours. At the laboratory, all the samples were mixed with fixed volume of distilled water to obtain a uniformity of the materials of the sample, and then oven dried to a temperature of 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 reflects the increase in the density of the soil it becomes possible to measure the degree of compaction by varying the moisture content of the oven dried soil. The compacted state was effectively controlled by the dry density of compacted material: bulk density B_D , is then given as:

$$B_D = M/V \quad (1)$$

where M is mass of the oven dried compacted material in grammes and V is the volume of the soil or of the mould in centimetre cube.

The compacted soil is oven dried at 105°C to reach a constant W content of 3% in weight. The drying to 3% W allows the electrical measurements at W constant and, thus, forces the electrical data to differences in structure for saturation index near 0. By drying effect, the mechanical characteristics of the material increase effectively (compression resistance and shear strength). The permeability thus, evolves following the dried density of the compacted material, so following the W of compaction. It follows the dried density Proctor curve.

In carrying out the measurement of dielectric constant of soil, five parallel plates of aluminium capacitors measuring 70x20x5 mm were constructed. Each of the compartments of the capacitor, separated by a glass sheet of thickness 5 mm were filled with soil samples. As a result of the presence of depolarizing field owing to the dielectric nature of soils, the capacitance of the capacitor is increased when filled with the dielectric soil material. The capacitance in air between two parallel plates is given by:

$$C_o = \frac{\epsilon_o A}{d} \tag{2}$$

If the space between the plates is filled with soil, the capacitance becomes

$$C_{soil} = \frac{\epsilon_r \epsilon_o A}{d} \tag{3}$$

Where ϵ_r is the dielectric constant or relative permittivity, of the soil, ϵ_o is the permittivity of free space, A is the area of the plate, and d is the distance of separation between the plates. 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:

$$\epsilon_r = C_x / C_o \tag{4}$$

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.

2.4 Particle Size Measurements

Particle-size analysis of the different soil samples was carried out in the laboratory using the hydrometer method. Fifty grammes (50 g) 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 hexametaphosphate (Na_2PO_4) 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 shaken. The cylinder was placed on the table and the time taken at that instant. The density of the suspension was measured using the hydrometer at constant temperature and successive time intervals and associated depths. The time intervals, average depths of measurement and average real density of the mineralogical particles are used to calculate the sedimentation rates of aimed equivalent diameters (Table 1).

Table 1. Particle size analysis

Soils	Approximated Percentage of soil separates			Textural Class
	Sand %	Silt %	Clay %	
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

3. RESULTS AND DISCUSSION

The variation of dielectric constant with density for different soil samples having a constant layers separation of 0.5 cm and placed at a drop height of 50 cm are shown in Fig. 2 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. 3).

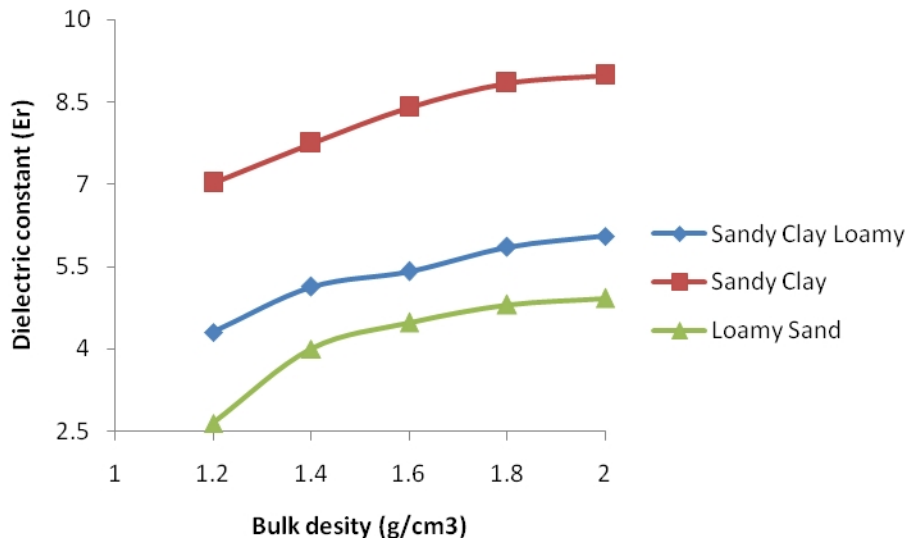


Fig. 2. Variation of dielectric constant with density of different soil samples

The 3 curves (Fig. 2) shift from the lowest dielectric constant values up to the highest dielectric constant value according to the increase in sand percentage or decrease in clay percentage. The curves show a non linear increase of dielectric constant with density for the three soil types. The increase may be due to the 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 density are in the order Sandy Clays > Sandy Clay Loamy > Loamy sand. The computed dielectric constants are in agreement with standard values [18], which are quoted to lie between 2.5 and 110 for dry moist soils. The increase in dielectric constant of the three soil samples with density can also be explained from the view point that reduction in the series capacitance caused by air gap between the plates and sample leads to a larger corresponding layer value for the dielectric constant (Table 2).

Table 2. Variation of dielectric constant with depth

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

Table 3. Geoelectric layer parameters

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

In interpreting VES data, it is usually assumed that the subsurface consists of several horizontal layers [19]; and that the effective depth of investigation depends on the relative

positions of both current and potential electrodes [1]. 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 increase 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 increase in the resistance of the material induces the apparent resistivity increase, and the soil resistivity decreases with increasing water content and associated ion concentration. The variations of dielectric constant with density for different soil samples show a non linear increase of dielectric constant with density for the three soil types. The variations in the apparent resistivity for sandy clay, sand clay loamy shows close similarities between their properties. The depth range of the various soil types corresponding to the electrical resistivity changes is 1.33 m to 9.77 m for sandy clay, 2.09 m to 23.06 m for sandy clay loamy and 3.26 m to 128.0 m for loamy sand.

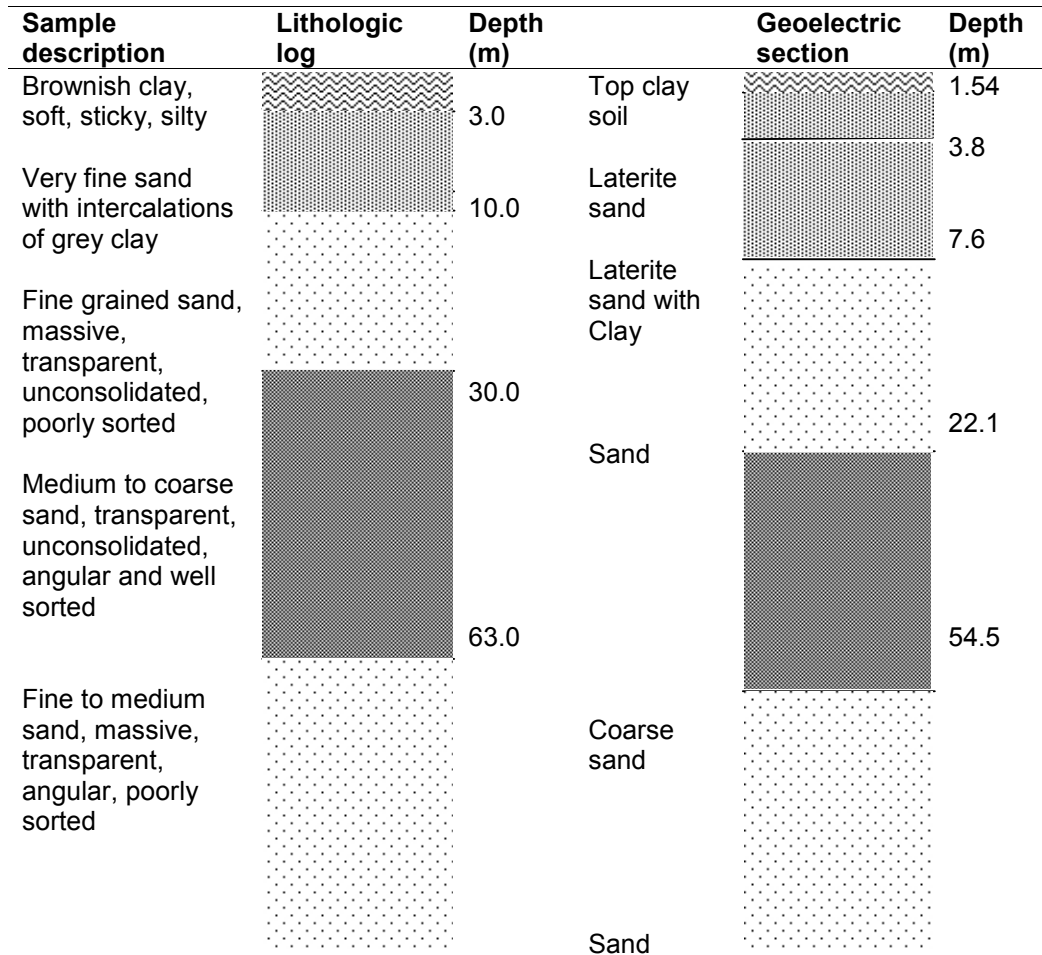


Fig. 3. Lithologic Log and interpreted geoelectric log for the borehole

The study reveals an average soil dielectric constant of 5.35, 8.20 and 4.17 for clayey loamy, sandy clay and loamy sand respectively. Since dielectric constant govern rock formations response to high alternating current (heat) flow, it implies that high conductive samples have higher dielectric constants. Such soils might be more suitable for agricultural farming in tropical areas especially during dry season. The laboratory and field studies of rock electrical properties show that both the dielectric constant and soil resistivity increases with depth and density. Comparing the borehole log data with the generalized geoelectric section from the study area (Fig. 3) confirms the reliability of the field survey in spite of minor differences between the real and apparent depths. Both the borehole log and the geoelectric results indicate a shallow water table of less than 4m, which is in agreement with the geology of the study area.

4. CONCLUSION

The study has shown that soil dielectric constant and resistivity vary non-linearly and at varying degrees with different soil composition. However, the magnitude of variation of the dielectric constant with density are in the order Sandy Clays > Sandy Clay Loamy > Loamy sand. Sandy clay soils which are more conductive will transfer the heat faster and hence will withstand the intensive heat of the sun in dry season farming. Both the resistivity and dielectric constant have generally been observed to increase with depth and by implication with soil density. There is however, no distinct relationship in values of the measured resistivity and soil type. This suggests that the soil composition, porosity and amount of water contained have significant control on resistivity at a particular depth in the subsurface.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Samouelian A, Cousin I, Tabbagh A, Bruand A, Richard G. Electrical resistivity survey in soil science: a review. *Soil and tillage Research*. 2005;83:173-193.
2. Scollar I, Tabbagh A, Hesse A, Herzog I. Archaeological prospecting and remote sensing. 1990;674.
3. Poljak D, Doric V. Wire antenna model for transient analysis of simple grounding systems. Part II: The horizontal grounding electrode. *Prog. Elect. Res. B*. 2006;64:167-189. DOI:10.2528/PIER06062102.
4. Geri A, Veca GM, Garbagnati E, Sartorio G. Non-linear behaviour of ground electrodes under lightning surge currents: Computer modelling and comparison with experimental results. *IEEE Trans. Magnet.* 1992;28:1442-1445. DOI:10.1109/20.123966.
5. Nor NM, Haddad A, Griffiths H. Characterization of ionization phenomena in soils under fast impulses. *IEEE Trans. Power Deliv.* 2006;21:353-361. DOI: 0.1109/TPWRD.2005.852352.
6. Banton O, Seguin MK, Cimon MA. Mapping field scale physical properties of soil with electrical resistivity. *Soil Sci. Soc. Am. J.* 1997; 61:1010-1017
7. Bernard-Ubertosi M, Dudoignon P, Pons Y. Characterization of structural profiles in clay-rich marsh soils by cone resistance and resistivity measurements. *Soil Science Society of American Journal*. 2009;73(1):46-54.

8. Waxman MH, Smith LJM. Electrical conductivities in oil-bearing shaly sands. Journal of the Society of Petroleum Engineering. 1968;8:107-112.
9. Corwin DL, Lesch SM. Application of soil electrical conductivity to precision agriculture: theory, principles, and guidelines. Agro. J. 2003;95:455-471.
10. Freeland RS, Yoder RE, Ammons JT. Mapping shallow underground features that influence site-specific agricultural production. J. Appl. Geophy. 1998;40:19-27.
11. Zanolin A. Irrigation de précision en Petite-Beauce: mesures au champ et modélisation stochastique spatialisée du fonctionnement hydrique et agronomique d'une parcelle de maïs, Paris VI, Paris. 2003;187.
12. Besson A, Cousin I, Samouëlian A, Boizard H, Richard G. Structural heterogeneity of the soil tilled layer as characterized by 2-D electrical resistivity surveying. Soil Till. Res; 2004.
13. Igboekwe MU, Nwankwo CN. Geostatistical Correlation of Aquifer Potentials in Abia State, South-Eastern Nigeria. International Journal of Geosciences. 2011;2:541-548. doi:10.4236/ijg.2011.24057.
14. Reyment RA. Aspects of the geology of Nigeria. University of Ibadan Press, Nigeria. 1965;51-55.
15. Ehirim CN, Nwankwo CN. Evaluation of aquifer characteristics and groundwater quality using geoelectric method in Choba, Port Harcourt. Archives of Applied Science Research. 2010;2(2):396-403.
16. Kearey P, Brooks M, Hill I. An introduction to geophysical exploration. Blackwell Science; 2002.
17. IPI2WIN software. I D- sounding interpretation software. Moscow State University. 2003;3.
18. Park-homenko EI. Electrical properties of rocks. NY. 1967;45-65.
19. Pozdnyakova L, Pozdnyakov A, Zhang R. Application of geophysical methods to evaluate hydrology and soil properties in urban areas. Urban Water. 2001;3:205-216.

© 2013 Nwankwo et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:
<http://www.sciencedomain.org/review-history.php?iid=210&id=5&aid=1113>