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Core Sampling Method: An Ex-Situ Study of Ground Electrical Conductivity of Soil Types in Akure, Nigeria

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Abstract: Results of measurement of ground electrical measurement are usually important to many branches of engineering communication, geophysics, hydrological, mineral explorations and earthling of transformer in the electrical power networks. To achieve this, a better and simpler method-core sampling was employed in this study with objective of detecting smaller intensity of voltage or current that passes through the soil. The measurement was carried out using a direct current on three different types of soil namely, Clay, Loam and Sand soil and this took three different forms of wet, moist and dry. The mean ground electrical conductivity obtained in this study area are from 1.04±0.002 mS m^{-1} for loam soil, 0.99±0.002 mS m^{-1} for clay soil and 0.39±0.001 mS m^{-1} for sand soil, while for the wet soil 1.23±0.002 mS m^{-1} for loam soil, 0.43±0.001 mS m^{-1} for sand soil and 0.52±0.001 mS m^{-1} for clay soil. The results were found to be in agreement with the results of previous researchers.

Key words: Electrical conducting measurement, ex-situ study, soil samples and core sampling

INTRODUCTION

The measurement of ground electrical conductivity is important to many branches of engineering, communications, geophysics, hydrological and Mineral exploration, electrical installations, earthling of transformer in the electric power network. The detection of different type of minerals and rocks present in the earth crust are some of the applications of measurement of ground electrical conductivity. The fact on information and understanding of the inner structure of the earth is based primarily on geological, gravitational and seismic observations, which being examined closely and it gives, rise to a great number of hypotheses about the state of matter. The application of other branches of geophysics to these hypothesis gives full explanation on the structure and the composition of the earth crust and enables us to reject the contradictory ones, one of these branches is the study of artificial and natural electromagnetic fields, the observations of which provide data about electrical conductivity of the ground and indirectly describe other physiochemical parameters of matter under high pressure and temperature (Runcorn, 1967). In the field of communication in which electromagnetic waves are propagated, medium wave transmitting antennas are generally inefficient. Ajayi and Owolabi (1975) explained that the greatest factor contributing to this inefficiency is usually the ground effect. For ground with poor electrical conductivity, the current flowing in the radiating antenna is returned through the ground and this result into attenuation of signal (Mitra *et al*., 1987).

The objective of this study is the design of a simple set up for laboratory measurement of ground electrical conductivity of different soil types at different depth under different condition: wet, moist and dry.

OVERVIEW OF SOME EXISTING MEASUREMENT TECHNIQUES

The possibilities for the study of the structure of the earth's interior with simultaneous observations of variation of magnetic and electric components of the natural, electromagnetic field were demonstrated for the first time in the work of Tikhonov (1950) and Koato, Cagniard and Kukuchi (1953). Synchronous observation at one point of the horizontal $E_{x,y}$ and the magnetic $H_{y\,x}$ component of the field make it possible to express total resistance of the underlying medium by a single ratio (Milton and Carl, 1998).

$$Z_{(\omega)} = \frac{E_{x,y}}{H_{Y,x}} \quad (1)$$

Then conductivity σ, is given by

$$\sigma = \frac{5}{TZ^2_{(\omega)}} \quad (2)$$

Where $E_{x,y}$ is in MV/km, $H_{y,x}$ is in gammas and period T in seconds or frequency in hertz There are various techniques of measuring the ground electrical

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conductivity, which include, Telluric and magneto-Telluric method, Probes method, Wave tilt, Attenuation method etc. but, the electrical resistivity conductivity method is superior because quantitative result are obtained by using a controlled source of specific dimension (Donard and Wayne, 1978). Ajayi and Owolabi (1975) used attenuation method to measure field strength around Oyo transmitter in Ibadan and conductivity value was later derived from the field strength data. Kuhn and Taumer (1974) also used wave- tilt method. Ajayi (2001) used probe method to determine conductivity of soil types throughout Nigeria while Ajewole and Arogunjo (2000) used Wenner array method to determine conductivity around AM-transmitter in three stations in south-west Nigeria. They further suggested that measurement for both wet and dry soil samples should be done and this is the purpose of this research.

This study makes use of the core sampling method to measure the ground electrical conductivity at different locations in Akure (7° 17'N, 5° 18'E) , Ondo State, Nigeria and on various types of soil at different depth and under different conditions.

AN APPLICABLE THEORY

Considering the case of a completely homogeneous isotopic earth, it is necessary to understand the behaviour of current flow in layered media and how this affects the distribution of potential. In dealing with such problems, the starting point is Ohm's law (Griffith and King, 1981).

$$\frac{V}{I} = R \tag{3}$$

where I is the current in a conducting body, V is the potential difference between two surfaces of constant potential and R is the constant called the resistance between the surfaces.

If a conductor carries a current with parallel lines of flow over a cross-sectional area A, then its resistivity ρ is defined by

$$\rho = \frac{RA}{L} \tag{4}$$

where R is the resistance measured between two equipotential surfaces separated by a distance L as presented in Fig. 1. Thus Eq. 3 and 4 can be combined to obtain the total current over the area A as

$$I = \frac{V}{R} = \frac{VA}{\rho L} \tag{5}$$

and that the 'current density' j is given as

$$j = \frac{I}{A} = \frac{V}{\rho L} \tag{6}$$

If the lines of current flow are not parallel, so that the current density varies over the conductor, this argument can be applied to an infinitesimal element of the conductor bounded by equipotential surfaces, which may be curved. The ratio V/L becomes, in the limit, the potential gradient $dV\, dL^{-1}$ and the expression of Ohm's Law becomes

$$j = -\frac{1}{\rho}.\frac{dV}{dL} \tag{7}$$

This shows that the potential increases in the opposite direction to the current flow. The component of the current density in a direction r is

$$j_r = -\frac{1}{\rho}.\frac{\partial V}{\partial r} \tag{8}$$

The potential in a homogeneous medium due to a point source of current, which varies inversely with distance, is therefore given by

$$V = \frac{S}{r} \tag{9}$$

where S is the strength of the source and r is the distance from the source. S depends on the resistivity, the current and the situation of the source. The current flowing through unit area of the surface can be obtained using Eq. 8 and 9

$$j = -\frac{1}{\rho}.\frac{\partial V}{\partial r} = \frac{S}{\rho r^2} \tag{10}$$

Since the current density is the same over the whole surface of area $4\pi r^2$, the total current is

$$I = 4\pi r^2.\frac{S}{\rho r^2} \tag{11}$$

Therefore

$$I = 4\pi S/\rho \tag{12}$$

$$S = \frac{I\rho}{4\pi} \tag{13}$$

However, if the medium is only semi-infinite and is bounded by a plane surface separating it from the air, which can be taken to be of infinite resistivity and the source is located on the interface, the current flow through a hemisphere only. Hence,

$$S = I\rho / 2\pi \qquad (14)$$

Thus Eq. 9 and 14 can be combined to obtain the current strength (the resistivity)

$$V = I\rho/2\pi r \qquad (15)$$

$$\frac{\partial V}{\partial r} = -\frac{I\rho}{2\pi r^2} \qquad (16)$$

$$\rho = -\frac{2\pi r^2}{I}.\frac{\partial V}{\partial r} \qquad (17)$$

The potential gradient $\partial V / \partial r$, in the work is obtained from measurement of the potential difference ΔV between the two closely spaced electrodes ΔL symmetrically placed with respect to the point and in line with the source. Hence the potential gradient is $\Delta V/\Delta L$.

Conductivity σ, which is the most important characteristics of the earth for frequencies below 3MHz, is the reciprocal of resistivity then (ITU-R, P845-2, 1995)

$$\sigma = 1/\rho$$

Therefore,

$$\sigma = \frac{I\Delta L}{2\pi r^2 \Delta V}$$

Where I is the current in Ampere, ΔV is the potential difference in volts; ΔL is the electrode spacing in meters and σ is the conductivity per ohms per meter.

EXPERIMENTAL PROCEDURE

The ground electrical conductivity was determined by laboratory measurement using core-sampling method. The material used are: Different types of soil samples taking from different locations in Akure and at different depth level, two multimeter, PVC pipe, aluminum plate, cells, wires and battery clips, flexible wires and meter rule. The soil sample was taking from three different locations in Akure (7° 17'N, 5° 18'E); clay soil sample from Dandare area along Ilesa road, loam sample from Fayanju Street off Leo road and sandy soil was obtained from Oyemekun Grammar School along Oyemekun road. Each sample was taken from between the depth of 5 and 40 cm.

The wire from the D.C source was soldered to the aluminum plate of 4 cm diameter and 8cm in length, while

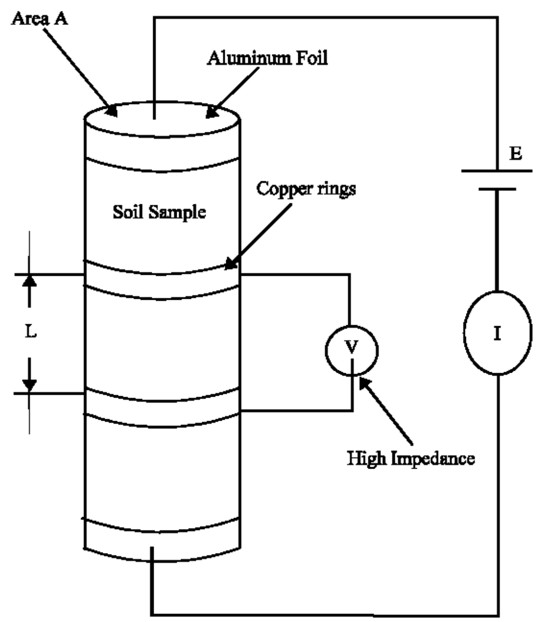

Fig. 1: The arrangement of Core sampling method

the PVC pipe was also cut in the same diameter and length with the aluminum plate. This was used to mold the soil sample in cylindrical shape. For better performance aluminum plate were also used as the electrode while 24V battery was used as a source of the voltage and a multimeter was used for taking the value of the current and voltage respectively. The experiment was performed with the three soil samples collected at various depths in the three different conditions of dry, moist and wet. The results were recorded; the resistivity was obtained using the Eq. 5, the inverse of which gives the conductivity. The whole arrangement is as depicted in Fig. 1.

RESULTS

The results of the measurement for different soil sample of loam, clay and sand soil in different form of dry, moist and wet are summarized in Table 1. The average result of the measurement shows that conductivity of wet loamy soil sample is highest while there is low conductivity in dry form of loam, clay and sand soil sample. The highest level of conductivity for wet loamy soil sample is due to its ability to absorb water, since soil electrical ground conductivity depends on moisture content of the soil among other factors (ITU-R, P 229-5, 1986).

Figure 2 shows the variation of conductivity with depth for dry soil sample (loam, clay and sand). It is

Table 1: Conductivity values σ (mSm) along each depth for the three soil samples

Depth (cm)	Dry soil sample σ (mS m^{-1}) Loam	Clay	Sand	Moist soil sample σ (mS m^{-1}) Loam	Clay	Sand	Wet soil sample σ (mS m^{-1}) Loam	Clay	Sand
0-5	0	0	0	1.37	1.14	0.53	1.53	0.16	0.40
6-10	0	0	0	1.22	1.47	0.58	1.45	0.29	0.35
11-15	0	0	0	1.16	1.14	0.49	1.27	0.58	0.80
16-20	0	0	0	0.96	0.91	0.25	1.17	0.64	0.32
21-25	0	0	0	0.80	0.80	0.25	1.06	0.71	0.32
25-30	0	0	0	0.71	0.50	0.25	0.87	0.71	0.29
Average Value	0	0	0	1.04	0.99	0.39	1.23	0.52	0.43

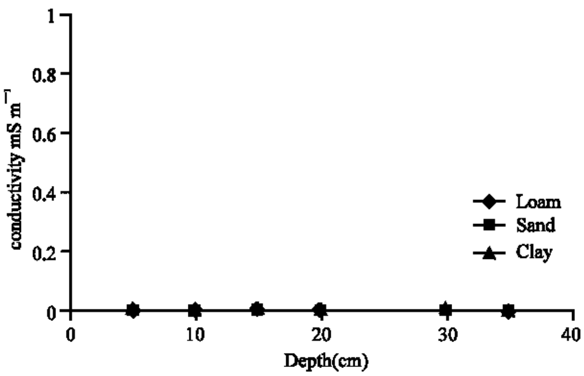

Fig. 2: Graph of Conductivity with depth for dry soil samples

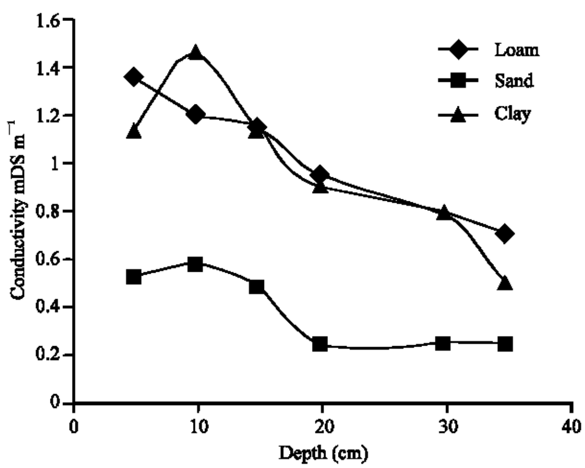

Fig. 3: Graph of Conductivity with depth for moist soil samples

clearly evident that there is low conductivity in the dry soil samples. This is as a result of very large resistance of the dry samples and hence leads to little or no conductivity. Figure 3 also shows the variation of conductivity with depth for moist soil sample (loam, clay and sand). The result shows that moist clay soil sample displays the highest conductivity at the depth of a little above 10 cm when compared with the other soil types

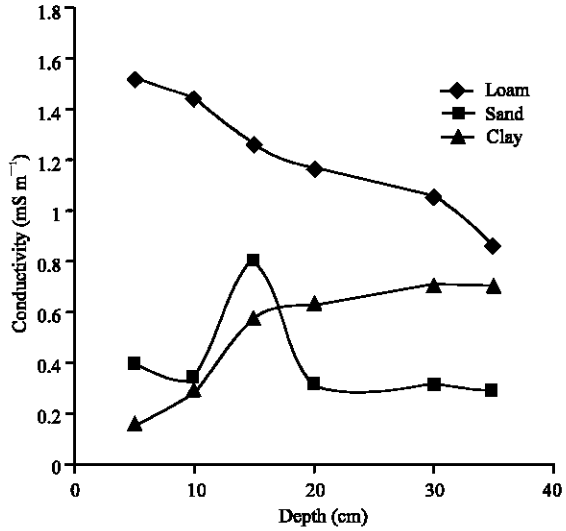

Fig. 4: Graph of Conductivity with depth for Wet soil samples

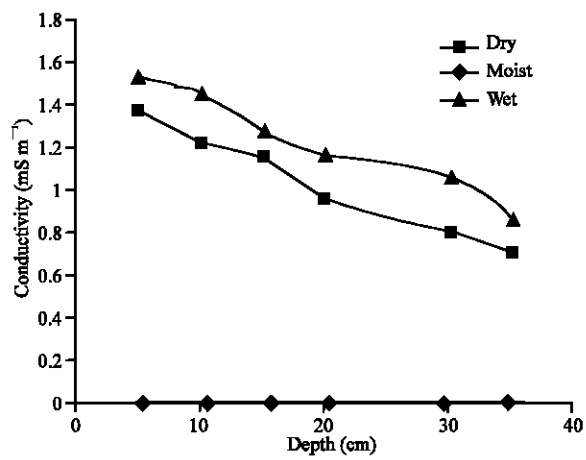

Fig. 5: Typical graph of Conductivity with depth for loam soil sample

because at this depth, the ability to retain moisture content is high. The result of variation of conductivity with depth for wet soil sample is also presented in Fig. 4. From the graph, it could be observed that loam soil display the highest level of conductivity due to its ability to absorb water and contribution from humus top soil content, while clay has the ability to retain the water. Sand soil however will allow the water to pass freely because of its poor water retention ability. Figure 5 is a typical graph of variation of conductivity with depth for loam soil sample under the condition of dry, wet and moist, it was also observed that wet soil sample most especially at the depth above 10 cm has the highest conductivity due to its ability to absorb much water, but when the sample is moist, the moisture contents becomes less hence conductivity is less than wet soil sample. It can therefore be inferred that good electrical conductivity can best be obtained during the raining season most especially at the beginning and towards the end of the rainy season because ground has the highest moisture content during this period. Also, conductivity is at the peak between the depths of 10 and 15 cm because ground can retain much water content at this depth.

CONCLUSION

In this study, electrical conductivity measurement has been carried out in the laboratory using a core sampling method on different soil samples at various depths. The mean conductivity obtained varied from 0.39 ± 0.001 mS m^{-1} to 1.23 ± 0.002 mS m^{-1}. When moist, wet and dry sample's conductivity was varied with depth, the result shows that conductivity for dry soil sample is the lowest and moist soil sample has the highest because its ability to retain moisture is high. Lack of moisture content might have been responsible for the low conductivity variation with depth for dry soil sample. It can also be concluded that the higher the moisture content of the ground the greater the electrical conductivity.

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