YEAR LONG VARIABILITY OF GROUND ELECTRICAL CONDUCTIVITY IN THE SANDY CLAY SOIL OF AKURE AREA, SOUTHWESTERN NIGERIA

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Abstract

Ground electrical conductivity was measured continuously on a soil type in Nigeria for one year using the Model R-50 Soil Test Resistivity Meter Equipment. The Wenner arrangement of electrodes, which is one of the probe methods of ground resistivity measurement, was employed for the measurement. About 67% of all the values for the year lie within $\pm\delta$ of the mean. The mean ground electrical conductivity for the wet season is 5.98 mS/m with a standard deviation of 0.28 mS/m. The mean for the dry season is 5.60 mS/m with a standard deviation of 0.33 mS/m. The mean ground electrical conductivity for the year is 5.78 mS/m with a standard deviation of 0.36 mS/m. Soil moisture appears to be the only major factor responsible for the variations.

1. Introduction

Electrical conductivity of remote materials and bodies, as well as those in the immediate vicinity, have been measured or estimated by many workers (Tozer, 1959; Noritomi, 1961; Bradley *et al.*, 1962; Eckhardt *et al.*, 1963; 1964;Mizutani and Kanamori, 1967; England *et al.*, 1968; Schult and Schober, 1969; Volarovich *et al.*, 1970; Duba, 1972; and Malicki and Walczak, 1999). This property of materials is useful. A lot of useful information about the nature and behaviour of materials could be obtained and quantities estimated or evaluated from this electrical characteristic of material and bodies.

For example, Duba (1972) showed that the temperature *T* at a depth in the mantle could be estimated from the data on electrical conductivity of olivine single crystal. Although, subject to large uncertainties (Tozer, 1959; England *et al.*, 1968), such estimates from data are still useful. Malicki and Walczak (1999) evaluated soil salinity status from measured bulk ground electrical conductivity. Nadler and Frankel (1980) determined soil solution electrical conductivity from bulk soil electrical conductivity measurements. Ground electrical conductivity is useful for broadcast planning in the medium frequency (MF) band, geophysical exploration, planning transmitter network short wave links, etc.

Some of the factors that determine the soil electrical conductivity include the nature of the soil, its moisture content, temperature, tortuosity and general geological structure (Gupta and Hanks, 1972; CCIR, 1986; Rhoades *et al.*, 1989; Mualem and Friedman, 1991; Van Loon *et al.*, 1991). This soil constant can be measured either in the field or laboratory and some of the methods that have been employed in its measurement include: laboratory measurement of soil sample, probe methods of ground resistivity, wave-tilt method, measurement of ground-wave attenuation and measurement of reflection coefficient (CCIR, 1970; Ajayi and Owolabi, 1975; Koskenniemi and Laiho, 1975; Ajayi and Owolabi, 1981; Dasberg a Dalton, 1985; CCIR, 1986; Ajewole and Arogunjo, 2000)

Data regarding ground electrical conductivity of soils in Nigeria are available (Ajayi and Owolabi, 1975 and 1981, Ajewole and Arogunjo, 2000) but sparse despite its usefulness in broadcast planning, geophysical exploration, and planning antenna installations. This study presents the profile of ground electrical conductivity variability in a typical tropical soil over a period of one year. The data obtained will add to the few existing ones in Southwestern Nigeria and will be useful to the Broadcasting Organisation of Nigeria (BON).

2. Study area

Akure is located slightly east of longitude 5° 20'E and just north of latitude 7° 20'N at an altitude of about 480 m within the Precambrian Basement Complex of Southwestern Nigeria (Fig. 1). This study area has two distinct seasons. While April marks the end of the dry season, June is the month

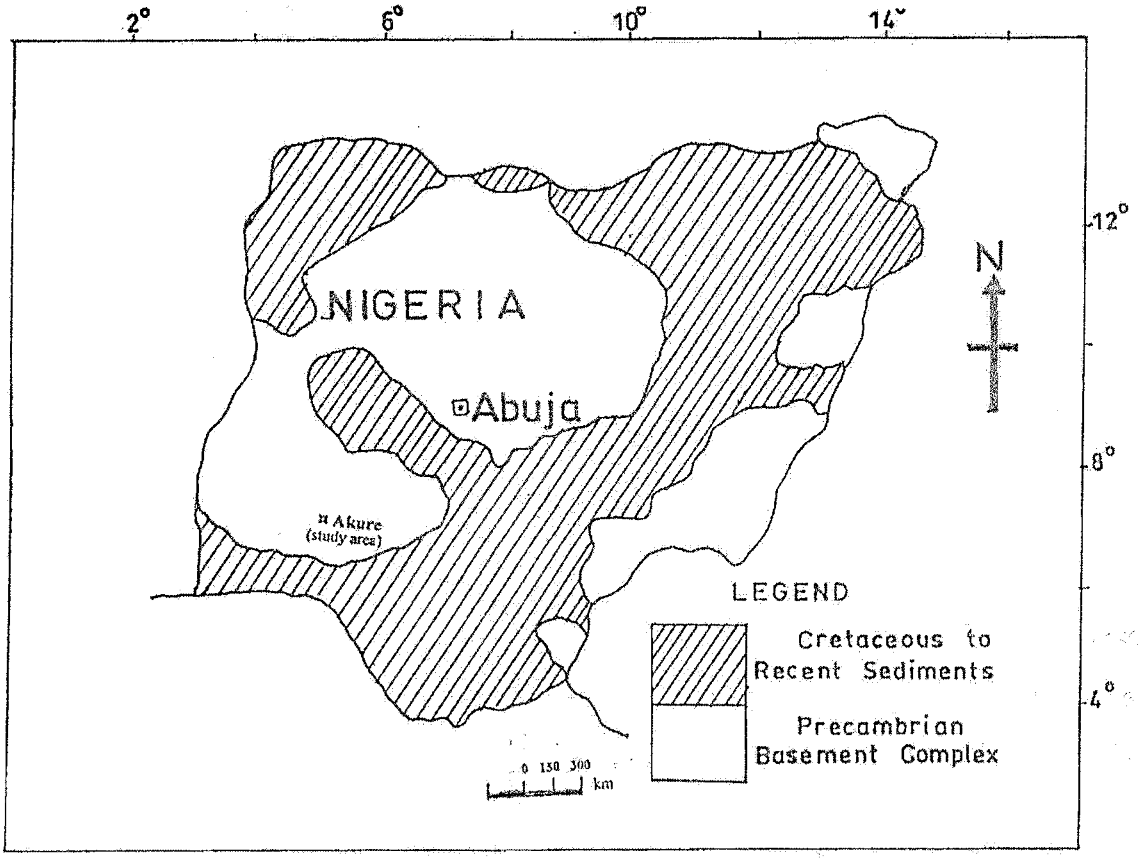

Fig. 1: Map showing generalised geology of Nigeria and the location of the study area (after Reyment, 1965)

of almost daily rains. Rain ceases in August, giving rise to what is popularly called "August break". Metamorphic rocks within the Precambrian Basement Complex underlie the sandy clay soil selected for this study. This soil has a clayey texture with clayey sand within 10 cm of topsoil surface and sandy clay below 25 cm to 40 cm (Smyth and Montgomery, 1962). Studies on profiles have revealed that only about 8 cm to 17 cm of available water are held in the top 1.50 m of the soil (Wessel, 1969). The soil profiles are characterized by low base-exchange capacity. It was selected for the study because it is representative of soils derived from several of the commonest parent rocks found in the belt and also to reduce logistic problems.

3. Materials and Methods

Measurements for calculation of ground electrical conductivity were done at least 2 weeks of each month on a continuous basis for 1 year (January 1999 to December 1999). Weekly measurements were done in the months of April, June and August. More measurements were done during the wet season than during the dry season to investigate the effect of soil moisture content on ground electrical conductivity.

One configuration of the probe methods used in soil resistivity surveys – the Wenner arrangement of electrodes was employed in the measurements. This method was chosen because of easy access to measurement points, validity of measurement values for both small and large areas and the depth of soil to be probed (being below 60 m). The measurement system used for the work consists of a portable Soil Test Resistivity Meter equipment Model R-50 which drives the current into the ground through a pair of electrodes, and a receiver that measures the potential difference developed between another pair of electrodes (Fig. 2).

Thirty-five sets of measurement were made on each day. A set of measurement consists of the electrode separation a (in metres), current I (in ampere), and potential difference ΔV (in volts). Ground temperature during measurement was noted and recorded. Ground electrical resistivity ρ, was evaluated from each set of measurements by using the relation

$$\rho = \frac{2\pi a \Delta V}{I} \; (\Omega - m) \quad \ldots \quad (1)$$

where,

a = electrode separation in metres
ΔV = potential difference between the electrodes
I = current driven into the ground.

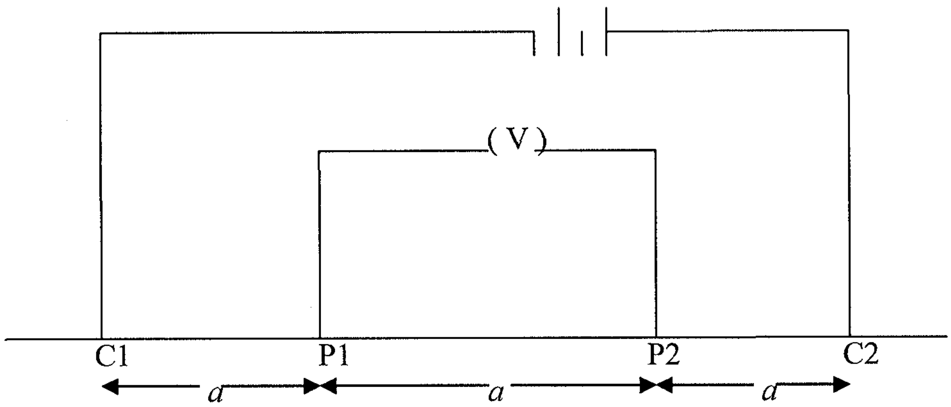

Fig. 2: Experimental set-up

The ground electrical conductivity σ was estimated by using

$$\sigma = \frac{1}{\rho} \ (S/m) \qquad \ldots \qquad (2)$$

The weighted arithmetic mean, geometric mean and standard deviation from the arithmetic mean, were calculated for each set of measurements. The weekly and monthly arithmetic mean ground electrical conductivity was calculated. The arithmetic mean ground electrical conductivity for the whole year was estimated from the monthly arithmetic means. The arithmetic mean ground electrical conductivity for the whole year was used, along with standard wave propagation formulae, to estimate the field strength of a ground wave propagated on the soil type under study. Propagation curves were plotted from the estimated values of the field strength.

4. Calculation of the ground-wave field strength

The field strength E (in mV/m) attained by a radio transmitter at a given distance from the transmitter is needed to determine the adequacy of the radio signal strength for a given service area and for the practical determination of equipment requirement. For a homogeneous terrain, this quantity is given by

$$E = \frac{3x10^5}{d} A\sqrt{PG_s} \qquad \ldots \qquad (3)$$

where $3x10^5/d$ is the value of the field strength dependent on the distance d in the case of free space propagation, A is an attenuation factor given by the ground losses; P is the output power of the transmitter in kW and G_s is the gain of the transmitting antenna directed at the remote receiving point. The factor A depends on the frequency, the ground electrical constants and the radio path length and can be expressed in terms of the "numerical distance" p and the phase constant β. While the numerical distance p is given by

$$p = 1.75x10^{-4} \frac{f\cos\beta}{\sigma} \frac{dx10^3}{\lambda} \qquad \ldots \qquad (4)$$

the phase constant β is given by

$$\beta = \arctan \frac{(\varepsilon+1)f}{1.8x10^4 \sigma} \qquad \ldots \qquad (5)$$

where f is the frequency in MHz, σ is the electrical conductivity of the ground in S/m, ε is the dielectric constant of the ground, λ is the wavelength of the wave in metres and d is the distance between the radio stations in metres. For value of $\beta \leq 90°$, the attenuation factor A may be expressed with sufficient accuracy (Braun, 1986) by

$$A = \frac{2+0.3p}{2+p0.6p^2} - \sqrt{\frac{p}{2}} e^{-1.44p.\log\varepsilon} \sin\beta \qquad \ldots \qquad (6)$$

The arithmetic mean ground electrical conductivity σ for wet season (5.98 mS/m), dry season (5.60 mS/m) and the whole year (5.78 mS/m) were used, along with dielectric constant $\varepsilon = 4$ (representative value for an average soil (CCIR, 1986)) in equations (3) to (6) for a computer program, to estimate the field strength of a ground wave propagated on the soil type under study. Propagation curves (Fig. 7) were plotted from the estimated values of the field strength.

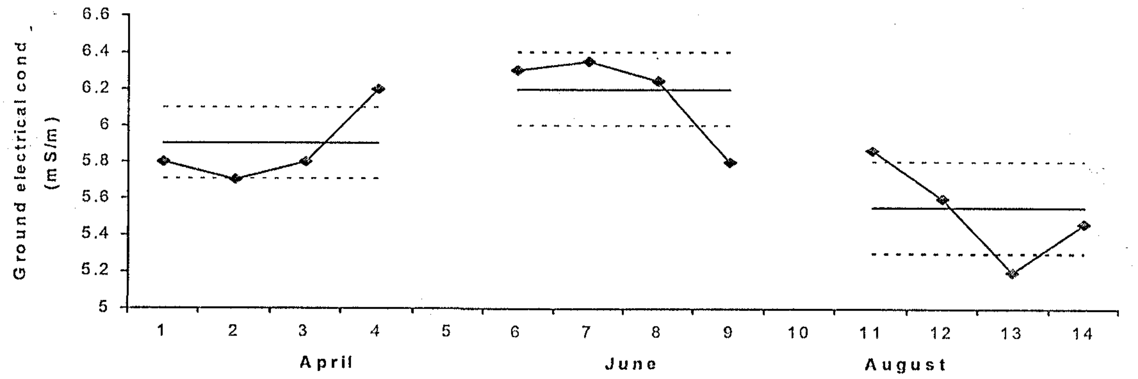

Fig. 3: Arithmetic means of ground electrical conductivity for April, June and August 1999

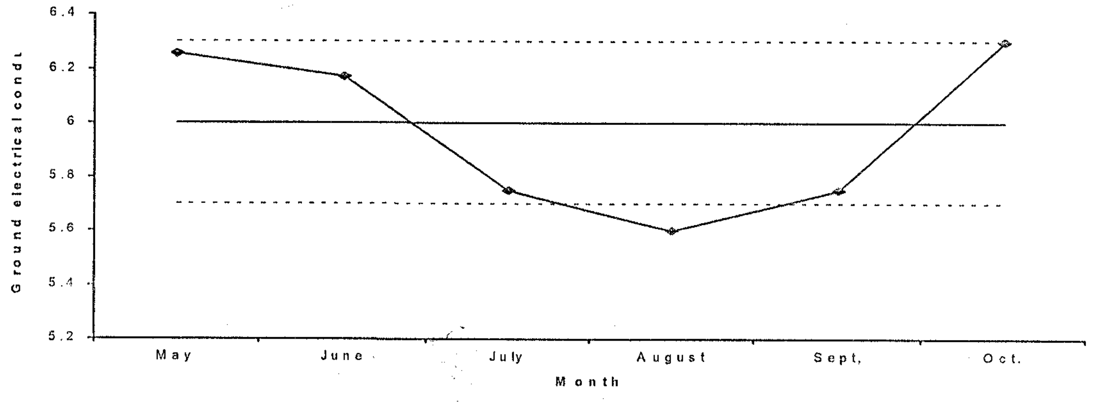

Fig. 4: Wet monthly arithmetic means of ground electrical conductivity for Akure area in 1999

5. Results and Discussion

The time series of ground electrical conductivity from weekly readings of April, June and August (Fig. 3) shows no consistent weekly variations. The arithmetic mean ground conductivity for these months (5.88 mS/m, 6.19 mS/m and 5.55 mS/m respectively) is shown by the solid horizontal lines while the dashed line above and below the solid line shows the arithmetic mean plus and minus the standard deviation δ (0.19 mS/m, 0.20 mS/m and 0.24 mS/m for April, June and August respectively). The maximum departure from the arithmetic mean during these months is 1.58δ higher than the arithmetic mean in April; 1.75δ lower than the mean in June and 1.46δ lower than the arithmetic mean for August. Sixty-seven percent of the weekly arithmetic means lie within $\pm\delta$ in August. The arithmetic mean for June is higher than that for April and August. This may be due to more rainfall in June than in April (the end of dry season) and August (when there was an August break) in the study area. In April, 75% of the weekly values lie below the arithmetic mean value, 75% of the values lie above the arithmetic mean value in June and 50% of the values lie above and below the mean value in August. The time series of ground electrical conductivity for the two distinct seasons, wet and dry, are shown in Figs. 4 and 5 respectively. The arithmetic mean for the wet season (May to October) is 5.98 mS/m with a standard deviation of 0.28 mS/m while the arithmetic mean for the dry season (November to April) is 5.60 mS/m with a standard deviation of 0.33 mS/m. Eighty three per cent of values for each of the seasons fall within $\pm\delta$ of the mean. While 50% of the wet season values fall below and above the arithmetic mean value, only 33% fall below the arithmetic mean during dry season. The maximum departure from the mean during the wet season is 1.36δ lower than the arithmetic mean while the maximum departure from the mean during the dry season is 1.82δ below the mean. The minimum departure from the mean during wet season is 0.82δ lower than the arithmetic mean while it is 0.15δ higher than the mean in the dry season. Comparing the two seasons, ground electrical conductivity appears to increase a little and be more stable during the wet season. The standard deviation is just 5% of

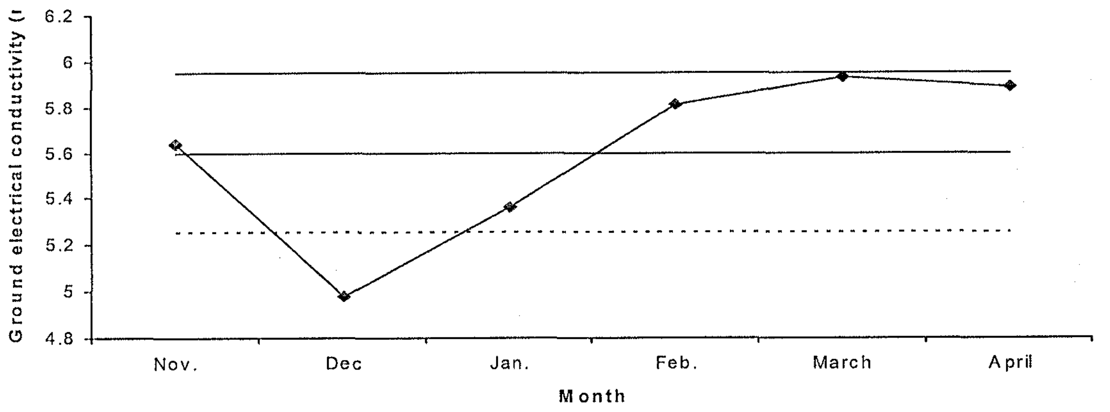

Fig. 5: Dry monthly arithmetic means of ground electrical conductivity for Akure area in 1999

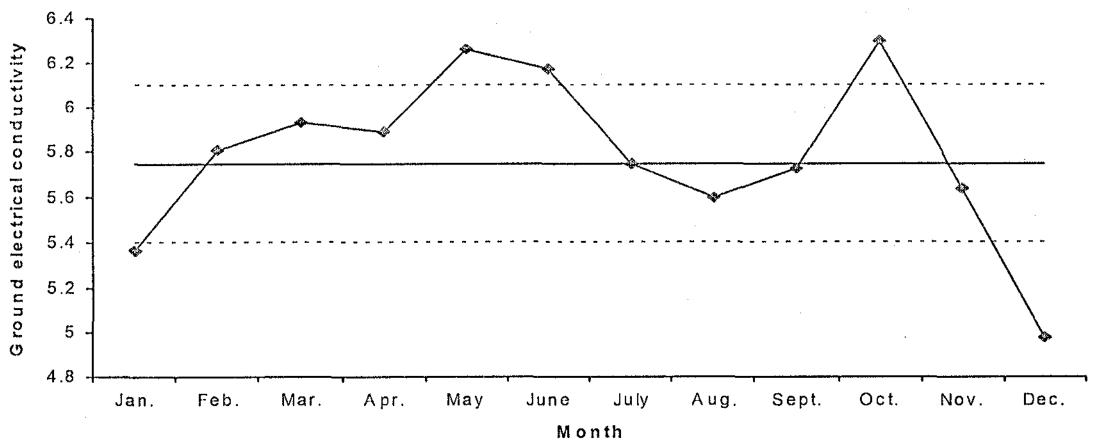

Fig. 6: Wet monthly arithmetic means of ground electrical conductivity for Akure area in 1999

the arithmetic mean during the wet season while it is 6% during the dry season.

The time series of ground electrical conductivity from monthly arithmetic means for the whole year is shown in Fig. 6. The arithmetic mean for the whole year is 5.75 mS/m while the standard deviation δ is 0.36 mS/m (just 6% of the mean). About 67% of all values lie within $\pm\delta$ around the mean. The maximum departure from the arithmetic mean during the year is about 2.08δ lower than the mean and this occurred at about the middle of the dry season of 1999. The minimum departure from the mean is about 0.14δ below the mean and this occurred in the wet season. While the highest ground electrical conductivity was obtained in October (6.40 mS/m), the lowest value was obtained in December (4.98 mS/m). These two values are about 3.9δ apart. These variations may be due to variations of the underground water, the ground moisture content, the ground temperature, season and general geological structure. Since the range of temperature variation during the year decreases rapidly with depth, (the soil is in the tropics), temperature effects on the ground conductivity are not likely to be important. Also, since this study was done on a soil type, the ground is taken as being homogeneous and the effects of other types of soil on the ground conductivity of the one being studied are not important. Therefore, the variations observed in the ground electrical conductivity are due to variation in the ground moisture content.

The ground-wave propagation curves for frequency 531 kHz (Ondo State Radiovision Corporation broadcasting station at Irese, Akure) are shown in Fig. 7. The curves are drawn for distances to be covered by a transmitter of 1.0 kW-normalized power. The electric field strength of the radio signal from this broadcasting station attenuates rapidly at distances below about 50 km from the transmitter. This is the reason for the establishment of booster stations around the state. The curves show that no significant seasonal variation in the field strength of ground wave propagating on the soil under investigation should be expected.

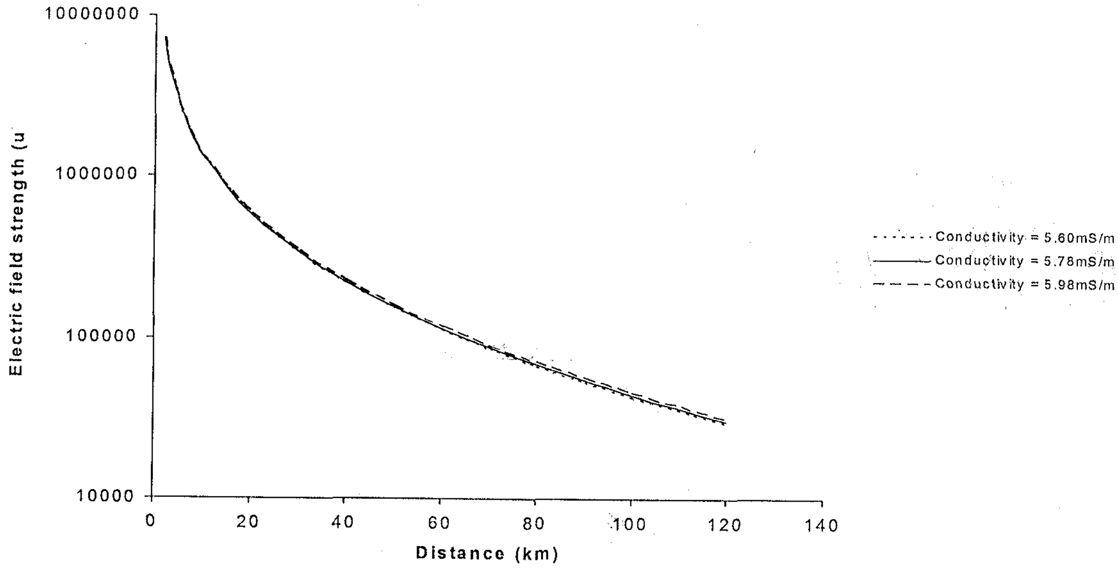

Fig. 7: Ground wave propagation curves for 531 kHz.

6. Conclusion

Ground electrical conductivity has been monitored using one of the methods employed in field resistivity survey. The mean ground electrical conductivity for wet season is 5.98±0.28 mS/m while it is 5.60±0.33 mS/m for dry season. The mean for the whole is 5.78±0.38 mS/m. The variations are generally of the order of $\pm\delta$ around the mean. Moisture content of soil is found to be the most important factor causing variations in the ground electrical conductivity for an undisturbed sandy clay soil on Precambrian Basement Complex of Nigeria.

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