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Determination of Soil Electrical Conductivity using Ground Penetrating Radar (GPR) for Precision Agriculture

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Abstract: Non-destructive and high resolution geophysical method ground penetrating radar (GPR) survey was carried out in Ekenkpon, Odukpani, Awi, and Nsan communities of Odukpani and Akamkpa Local Government Areas of Cross River State, Southern part of Nigeria. This survey was carried to determine the electrical conductivity of the soil. MALA professional Explorer control unit (optical module) with antennae of frequency 200MHz instrument was used for the research. Distance based mode was employed for the acquisition of the data at the interval of 1m. Rad-Explorer 1.4 software was used to analyze the data to obtain the velocity of the waves in the ground and dielectric permittivity of the soil.Due to shallow depth of most crop roots, an average depth of 2.075 m was selected for the determination of the velocity of the wave in the soil. The mean value of electrical conductivity at Ekenkpon, Odukpani, Awi and Nzan respectively were 0.61895 $\mathrm{mS/m}$, 0.65205 $\mathrm{mS/m}$, 0.56945 $\mathrm{mS/m}$ and 0.56945 $\mathrm{mS/m}$. The study revealed that the areas are composed of mainly loamy and sandy soil. Hence, for the purpose of precision agriculture, GPR has proven to be one of the most effective methods for the characterization of the subsurface.

Key word: Dielectric permittivity,Electrical conductivity, GPR, Precision agriculture,Salinity velocity, Water content.

1. INTRODUCTION

SOIL electrical conductivity is the ability of the soil to conduct electric current. It depends on the amount of water content in the soil, soil particles and soil texture [7]. Soil electrical conductivity (EC) is a measurement that correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter level, salinity, and subsoil characteristics. When EC measurement is carried out, the data are used to make decisions, predict the value of one or more variables, for instance, in the estimation of spatial soil salinity pattern, soil texture or water holding capacity may be desired [6].

Soil with high water content has high conductivity than dry soil.This shows that moist or wet soil has high conductivity than dry soil. Since, the electrical conductivity depends on the amount of water available in the root zone of the crops because only the nutrients dissolved in the soil water is available for the crop to take in, then soil electrical conductivity can almost be viewed as the quantity of available nutrients in your soil,therefore it serves as one of the very quick, simple and inexpensive method that farmers and home gardeners can use to check the health of their soils and as one of the real time data for farmers practicing precision agriculture.

Soil electrical conductivity is also the viewed as the overall measure of the salinity of the soil. Salinity is the accumulation of salt in the soil to toxic (excess) levels for plants. This excess dissolved salt is readily detected by soil electrical conductivity.In irrigated farmlands, salinity is mostly or predominantly caused by evapotranspiration. This is so because the salt from irrigated water is accumulated in the soil as pure water is returned to the atmosphere through evaporation and through transpiration from the leaves of the plants. The left behind salt prevents water at the root zone to be uptaken by plant because the osmotic potential is lowered. This lowered potential inturns reduces the potential of the total soil water. The adverse effects of salinity are seen in loss of stand of plant, plant growth reduction rate and reduction in yield.This shows thatreduction in salinity of the soil improves the yield of crops which can be predicted, hence precision agriculture. The summaries of the ranges of electrical conductivity for basic soil type, different earth materials, classes of salinity and their effects on cropsare shown on tables 1a, 1b and 2.

Odukpani and Akampka Local Government areas of Cross River State had recently experienced severe flooding in some of their communities which probably may have caused excessive

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quantity of more conducting (saline) water available for the crops thereby impacting negative potential effects on the crops.Soil electrical conductivity depends on this soil water content, therefore it was necessary to investigate the electrical conductivity of the soil of these communities sincefarming is the main occupation of the inhabitants.

TABLE 1a
TYPICAL ELECTRICAL CONDUCTIVITY FOR BASIC SOIL TYPE [4]

Soil type	Electrical conductivity (mS/m)
Sand	0.1 – 1.5
Silt	1.7 – 15
Clay	10 – 1000

TABLE 1b
TYPICAL RANGES OF ELECTRICAL CONDUCTIVITY OF EARTH MATERIAL [8]

Soil Type	ElectricalConductivity (mS/m)	
Gravel and sand	0.1 – 3	
Silt	0.7 – 30	Glacial
Clay	10 – 700	Sediment
Conglomerate	0.1 – 1	
Sandstone	1 – 30	Sedimentary
Shale	50 – 300	Rock
Limestone(dolomite)	0.5 - 50	

TABLE 2
RANGE OF ELECTRICAL CONDUCTIVITY (EC), CLASSES OF SALINITY AND EFFECTS ON CROPS [7].

EC dS/m	Salinity class	Effects on crop
0 < 2	Non saline	effect of salinity is negligible
2 < 4	Very slightly Saline	some sensitive crops yield may be hindered
4 < 8	Slightly saline	many crops yield are hindered
8 < 16	Moderately saline	only tolerant crops will give satisfactory yield
≥ 16	Strongly saline	only a few very tolerant crops yield

1.1 Location and geology of the study areas

The study areas are located in parts of Calabar flank and Oban massif basement complex which lie between latitudes 5^{o}00'N - 5^{o}50'N and longitudes 8^{o}00'E - 8^{o}50'E in the southern part of Nigeria, [4].

The study areas are Odukpani, Ekenkpon, Awi and Nsan. Odukpani is located between longitudes 8.20°E and 8.21°E and latitudes 5.09°N and5.10°N. The area is accessed through Calabar-Ikom Highway [1]. Ekenkpon is along Calabar – Itu high way, immediately after Odukpani junction. It is located between longitudes 8.20°E and 8.21°E and latitudes 5.10°N and 5.11°N. The two locations (Odukpani and Ekenkpon) are all in Odukpani Local Government Area. Awi is located between longitudes 8.21°E and 8.22°E and latitudes 5.14°N and 5.15°N and Nsan is located between longitudes 8.21°E and 8.22°E and latitudes 5.16°N and 5.18°N. Awi and Nsan communities are in Akamkpa Local Government Area, Cross River State. Nsan community is off Calabar - Ikom High way after the State College of Education, Awi, Akamkpa. The Nsan Road leads to Oban which links the Republic of Cameroun.

Geologically, Awi village is located between Oban massif and Calabar flank. Some of its Formation is made up of continental Arkosic sandstone, interbedded with shale. Some areas compose of basement rocks. The study area falls on the Basement area as shown in (Fig. 2). The entire succession sits unconformably on the Basement complex [9].The basal Neocomian-Aptian syn-rift fluvial sand stone of Awi Formation is overlain by the marine Post rift Odukpani group of Albian to Late Cretaceous age which is comprised of Albian Mfamosing limestone, Cenomanian Ekenkpong shale and Turonian to Coniacian New Netim marl.

The Odukpani group is made up of the Mfamosing limestone, the Ekenkpon shale and the New Netim marl. They are all exposed close to Council headquarters of Odukpani. This is unconformably covered by the Nkporo shale. Nsan village is geologically underlain by gneiss which is from metamorphic origin while the rock type in Awi community is mainly granodiorite, which is from igneous origin. (Fig. 1) shows the geology of the Odupkani and Ekenkpon and (Fig. 2) shows the geology of Awi and Nsan.

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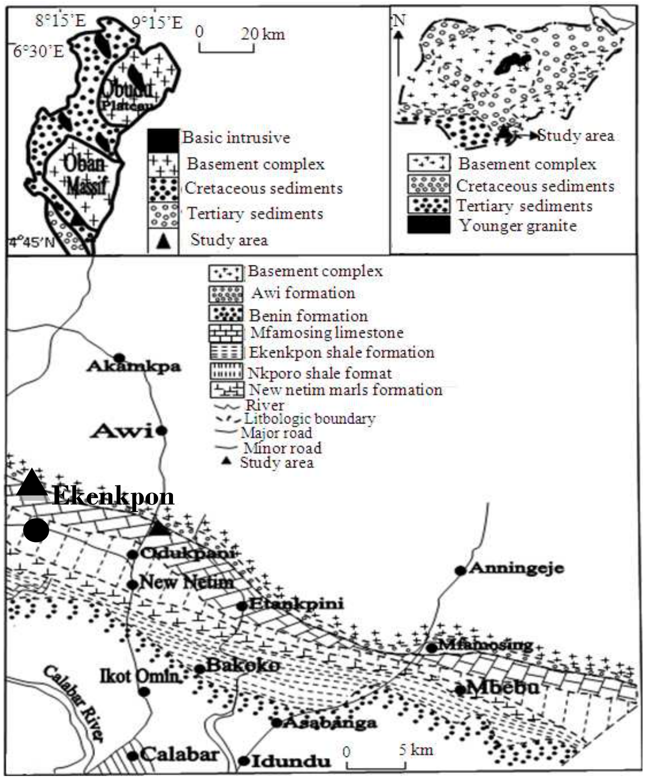

Fig. 1.Geologic map of the study areas (Odukpaniand Ekenkpon).

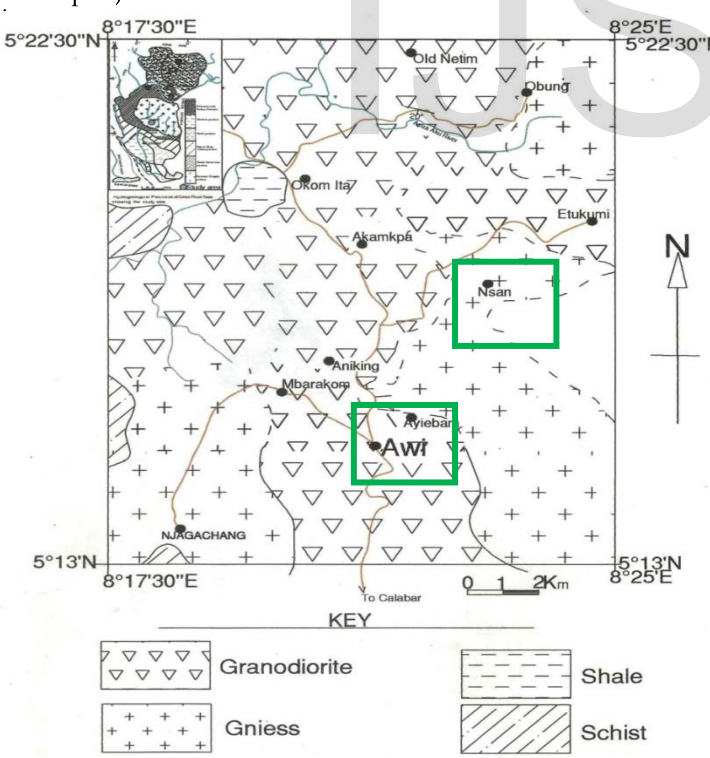

Fig. 2. Geologic map of the study areas (Awi and Nsan), [11]

1.2 Theoretical Background

1.2.1 Velocity determination

The velocity of the wave is related to antenna spacing a, reflector's depth d, and two-way travel time $TWTT$ by:

$$v = \frac{\sqrt{4d^2+a^2}}{TWTT} \quad (1)$$

1.2.2 Dielectric permittivity

Also, the dielectric permittivity k is also related to electromagnetic wave velocity c by:

$$k = \left(\frac{c}{v}\right)^2 \quad (2)$$

1.2.3 Determination of electrical conductivity of the soil

The electrical conductivity σ, according to [12] is related to dielectric permittivity of the medium and attenuation as follows.

$$\sigma = \frac{\propto\sqrt{k}}{1.69} \quad (3)$$

Where $\propto$ is the attenuation in dB/m, σ electrical conductivity in mS/m, and k is the dielectric permittivity obtained from the analysis of GPR field data. Since the soils of the areas are mostly wet soils, attenuation of 0.05dB/m was used [3].

2. MATERIALS AND METHOD

The equipment used for this studyis MALA Professional Explorer GPR system (optical module) with 200 MHz antennae, 5 GPR batteries, 0.6m handle, backpack kits, 30 m field tape and a cutlass, 1 PC (laptop) with window XP operating system and Global Positioning System (GPS). Antennae of frequency 200MHz were chosen due to its suitability for shallow depth of penetration.

Single (constant) offset method was used in the field work. In this method, the two antennae; the transmitter and receiver are separated by a fixed or constant distance *a*, and the whole system is moved at once. The GPR system unit is connected to the antennae through three cables; the data cable (D), the receiver cable (R) and the transmitter cable (T). From then, another cable is connected from here to a Personnel Computer (PC) through universal serial board (USB) port. Two batteries are inserted in each battery section on the antenna to power them. One battery is inserted on the optical module system. Then the system unit is turned on to enable some instrument parameters such as gain, center frequency, time window, etc. to be set on the PC. When the antennae switches are turned on, a beep sound with flash light is given out, meaning the equipment is ready to be used.

The measurement was done along two profiles in each location. The GPR reflection data were collected by moving both antennae across the surface of the ground at a constant or fixed interval of 1m by pressing the ENTER key on the PC when the antennae are well positioned (Fig. 3a and Fig. 3b). To make the survey easier and fast, one of the field crews helped in carrying the antennae while the second helped in holding the cables to avoid cut.

There were eight profiles taken across the entire locations, with two at each of the four locations. Table 3 shows the study areas, profile numbers, lengths and the direction along which the data were collected. All the measurements were carried out at equal distance interval.

TABLE 3
PROFILE LENGTHS AND DIRECTIONS OF THE STUDY AREAS

Study area	Profile number	Profile length	Direction
Odukpani	0006A	55m	N-S
	0007A	130m	N-S
Ekenkpon	0001	100m	N-S
	0002	101m	E-W
Awi	0004	50m	E-W
	0006B	100m	E-W
Nsan	0003	100m	N-S
	0007B	165m	N-S

3. PROCEDURE FOR DATA ANALYSIS

The data processing was done using RadExplorer 1.4 software. Some routines were applied to the raw GPR data, they include DC removal was done to remove the constant components of the signal in case there is one. Here the start time was set at 0 ns and the end time at 100 ns in the mean mode, time adjustment routine was done to adjust the zero point of the vertical time scale to time zero (the moment the wave actually left the antenna). This repacking was done to ensure correct depths in the profile [10]. Others include 2D spatial filtering, Band pass filtering and predictive deconvolution.

Since, most crop roots hardly exceed a depth of 1.8m; the processed data were converted to depth scales so that a mean depth of 2.075m was fixed for each data and the corresponding mean two-way travel time also read off from the radargram.

4. PRESENTATION OF RESULTS AND INTERPRETATION

The results of the velocity and dielectric constant of the study areas are presented in table 4, while table 5 shows the result of the soil electrical conductivity of the areas.

TABLE 4
THE RESULTS OF THE PARAMETERS OBTAINED FROM THE FIELD DATA ANALYSIS.

Study Area	Profile Number	Velocity m/ns	Dielectric Permittivity K
Ekenkpon	0001	0.11	7.4
	0002	0.12	6.3
Nsan	0003	0.13	5.3
	0007B	0.12	6.3
Awi	0004	0.12	6.3
	0006B	0.13	5.3
Odukpani	0006A	0.12	6.3
	0007A	0.10	9.0

TABLE 5
THE RESULTS OF SOIL ELECTRICAL CONDUCTIVITY

Study area	Profile number	Electrical conductivity (mS/m)
Ekenkpon	0001	0.6438
	0002	0.5941
Nsan	0003	0.5448
	0007B	0.5941
Awi	0004	0.5941
	0006B	0.5448
Odukpani	0006A	0.5941
	0007A	0.7100

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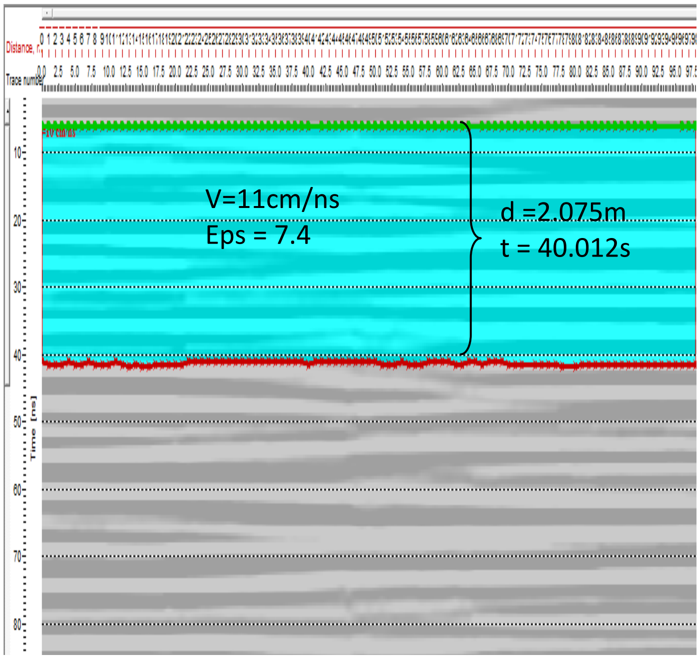

Fig. 4. GPR model of Ekenkpon community(Profile No:0001).

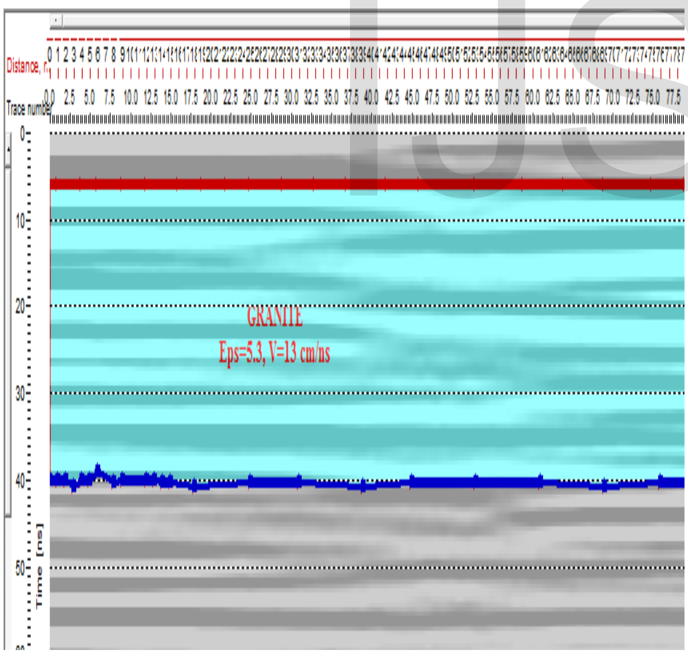

Fig. 5. GPR model of Nsan community(Profile No:0003)

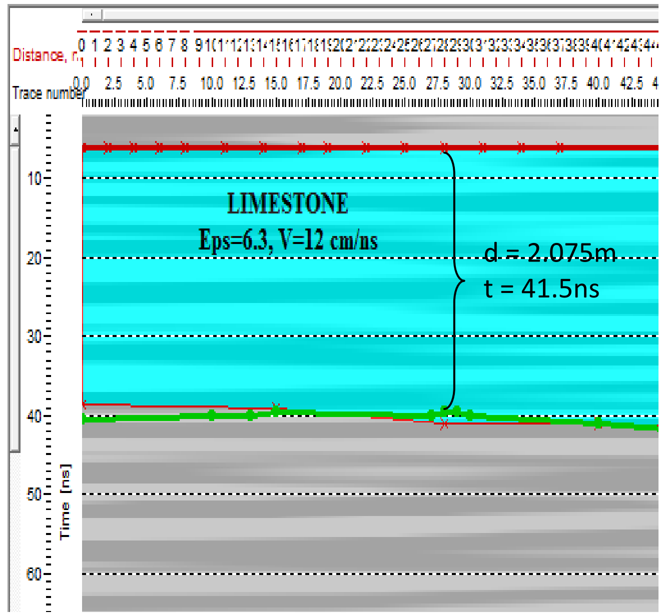

Fig. 6. GPR model of Awi community(Profile No: 0004)

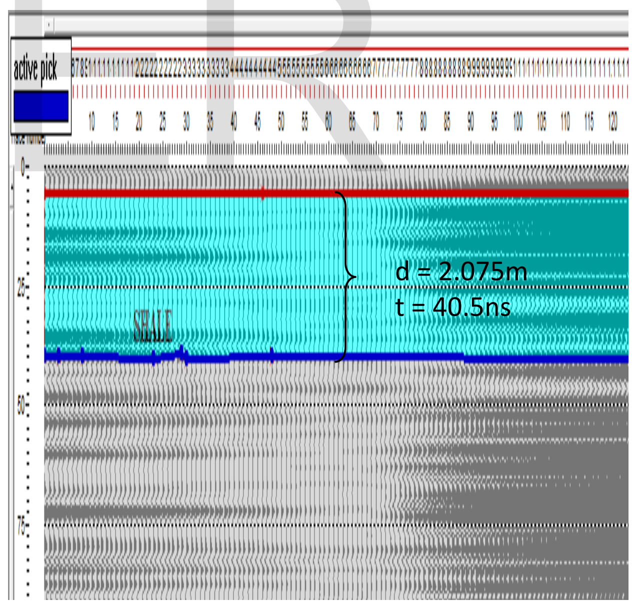

Fig. 7. GPR model of Odukpani community(Profile No: 0007A)

4.1 Ekenkpon study area result

The parameters presented in table 5 show that the average value of electrical conductivity of the area(Fig. 4) is 0.61895 mS/m. According to the analysis of the results and depending on tables 1a and 1b, the soil type is silt-loam. From table 2, the effect of salinity in this area is negligible.

4.2 Nsan study area result

The average electrical conductivity is 0.56945mS/m which indicates sandy soil from table 1a. The area (Fig. 5)is also free of salinity thereby promoting agricultural best practices.

4.3 Awi study area result

Electrical conductivity has its mean value as 0.56945mS/m.This value altogether suggests sandy soil for the area (Fig. 6) according to table 1a. This value is the same as that of Nsan areas. The similarity may arise from the fact that the two areas are very close to each other so the same velocity of the wave in the soil of the areas which amounted to similarity in dielectric permittivity.

4.4 Odukpani study area result

Odukpani is geologically known to contain some sedimentary rocks like limestone. This is confirmed from the mean value of electrical conductivity of 0.65205mS/m which is a typical value for limestone, according to table 1b. The area fig. 7 has a mean water content of 0.1393$m^3m^{-3}$and a mean porosity value of 0.4556m^3m^{-3}which also suggests loany soil and sedimentary rocks in the area [2]. From the analysis of this result and according to tables 1a the soil type of this area is loamy.
Also, the effect of salinity of the area is negligible and virtually all crops can grow well here. This is because the potential negative impacts on the soil and environment is at a reduced rate and the farmer can now maximize the crop yield through efficient application of nutrients.

4. CONCLUSIONS AND RECOMMENDATIONS

A constant offset method of GPR was used to characterize soil of the study areas for the purpose of determination of soil electrical conductivity for precision agriculture. The data obtained were analyzed using Rad-Explorer 1.4 software to obtain the velocity of the waves in the ground and dielectric permittivity. The mean value of electrical conductivity at Ekenkpon and Odukpani, were respectively 0.61895 mS/m, and 0.65205 mS/m while Awi and Nsan had similar results of value 0.56945 mS/m. From the analyses, it has been observed that the study areas composed mostly of loamy soil and sandy soils. Measurement of soil EC with GPR is an alternative to intensive soil sampling; it gives high resolution and reduces the cost of soil maps.

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