Precision Agriculture using Ground Penetrating Radar (GPR): A case study of part of Odukpani Local Government Area, Cross River State, Nigeria

George, A. M[1],*Awak, E.A[1]and Abong, A.A[2]

Abstract: Ground penetrating radar(GPR) was carried out in farmlands ofEkenkpon and Odukpani communities to determine the soil water content and hydraulic property (Porosity) of the soil. The instrument used in data collection was MALA professional Explorer control unit (optical module) with antennae of frequency 200MHz. The data were collected at equal distance interval of 1m (distance based mode) using a single offset method. The data obtained were analyzed using Rad-Explorer software version 1.4 The mean depth of $2.075\ m$ was selected for the determination of the velocity of the wave in the soil since the depth of the longest root of the crop can penetrate the soil is $1.8\ m$. The findings of the study revealed that the mean value of soil water content and porosity of the soil at Ekenkpon were $0.12245 m^3 m^{-3}$and $0.4606\ m^3 m^{-3}$, and at Odukpani $0.1393 m^3 m^{-3}$and $0.4556\ m^3 m^{-3}$ respectively. These results showed that the soil types of the areas are mainly loamy and sandy. Hence GPR has proven to be one of the most effective methods for hydrogeophysicalsoil characterization for the precision agriculture.

Keywords: Available water content,Dielectric permittivity**,** Ground penetration radar**,**Precision agriculture, Single offset, Soilporosity, Soil water content.

──────────── ◆ ────────────

1.0 INTRODUCTION

PRECISION agriculture deals with acquiring real-time data on soil quality, soil water quality and quantity, air quality, and weather such that crop yield and maturity, availability of labor and equipment as well as their costs can analytically be predicted.

For precision agricultural to be successful, information on spatial distribution of soil water is very important [9]. Crop growth depends largely on the available quantity of soil water content profile. For crop yield forecasting and irrigation scheduling, soil water content or moisture profile information is necessary. This is because too much water may cause reduction in crop yield due to water logging at the plant roots but with too little water, crop can be damaged permanently because of drought stress [9]. Crop yield will decrease if the soil water content is below a crop-specific range [10]. Apart from soil water content, porosity which is the ratio of the total pore volume to the total volume of the sample of the medium is also very important. Porosity varies considerably across a given field and plays an important role in precision agriculture.

1.   *Physics Department, University of Calabar, P.M.B 1115, Calabar, Cross River State-Nigeria.*
Email: ufan14@yahoo.com
*Email: emma4xst@gmail.com
2.   *Physics Department, Cross River University of TechnologyP.M.B   1123,Calabar-Nigeria.*
Email: austine9u2008@yahoo.com

Proper estimate of soil water content and porosity in a crop field is important for maximizing crop yield, efficient application of irrigation, and minimizing the potential environmental impacts of farming [6].

Some of communities inOdukpaniLocal Government Area where this study was carried out had experienced severe flooding in the last few years. Farming, being the main occupation of the inhabitants of this area, it is therefore necessary to investigate soil content and porosity using ground penetrating radar (GPR).

1.2   Location and Geology of the study areas

The study areas are located in parts ofCalabar flank and Oban massif Basement Complex which lie between latitudes 5° 00'N - 5° 50'N and longitudes 8° 00'E - 8° 50'E in the southern part of Nigeria, [8].

The study areas are Odukpani, and Ekenkpon.Odukpani is located between longitudes 8.20°E and 8.21°E and latitudes 5.09°N and 5.10°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 are all in Odukpani Local Government Areas, Cross River State. Geologically, 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 (Fig. 1).
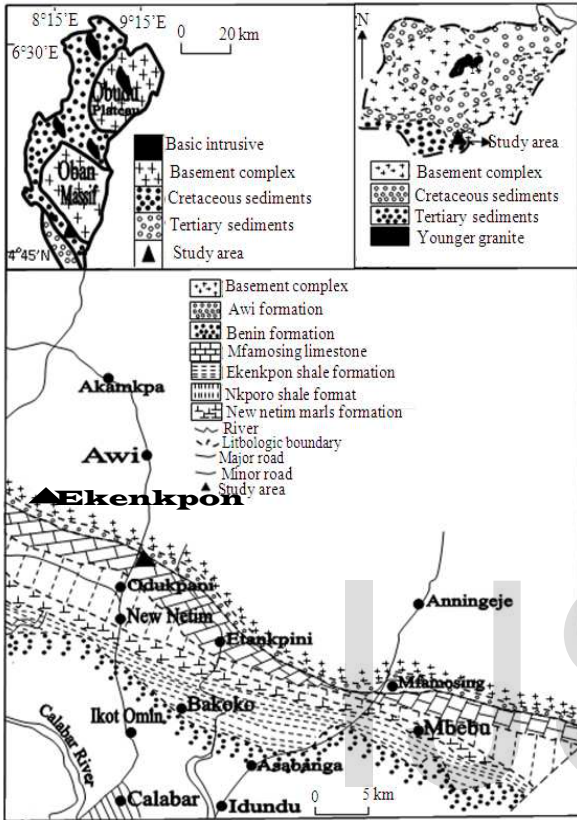

Fig. 1. Geologic map of the study areas, [1]

1.3 Theoretical Background

1.3.1 Velocity determination

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

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

1.3.2 Dielectric permittivity

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

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

1.3.3 Available water content (AWC)

Available water content is determined in any farmland using the expression given by [7]

$$AWC = 1000(\theta_{FC} - \theta_{WP})Z_r \qquad (3)$$

θ_{FC} is water content at field capacity, θ_{WP} is water content at wilting point

Z_r − rooting depth in mm, AWC − available water content in m

Table 1a gives difference between the water content at field capacity and wilting point, which is the available water content for the uptake of the crop.

1.3.4 Determination of soil water content

The water content of the soil was computed using Topp's equation as given by [5]

$$\theta = -0.053 + 0.0292k - 0.00055k^2 + 0.0000043k^3 \qquad (4)$$

Where k is the dielectric permittivity of the soil and θ- the soil water content.

Table 1b shows the water content values for different soil types expressed in different units,

1.3.5 Determination of soil porosity

The porosity of the soil is given by [12]

$$\psi = \frac{\sqrt{K_t} - \sqrt{K_g} + \theta(\sqrt{K_a} - \sqrt{K_w})}{\sqrt{K_a} - \sqrt{K_g}} \qquad (5)$$

For most grain medium $\sqrt{K_g} \cong 4.8$

Where K_t – the bulk (total) dielectric constant, K_a- dielectric constant of air, K_g- dielectric constant of the soil grain, K_w- dielectric constant of water, θ- the soil water content and ψ is the soil porosity.

Table 2 summarizes the hydraulic property (porosity) of the soil from different authors.

TABLE 1A:
Water content values for different USA soil type [4]

Soil type (USA soil texture classification)	Soil water characteristics (m^{3}m^{-3})		
	θ_{FC}	θ_{WP}	$\theta_{FC} - \theta_{WP}$
Sand	0.120	0.040	0.080
Loamy sand	0.140	0.060	0.080
Sandy loam	0.230	0.100	0.130
Loam	0.260	0.120	0.140
Silt loam	0.300	0.150	0.150
Silt	0.320	0.165	0.155
Sandy clay loam	0.330	0.175	0.156
Silt clay loamy	0.340	0.190	0.150
Silty clay	0.360	0.210	0.339
Clay	0.360	0.210	0.339

TABLE 1B:

Water content values for different soil type [7].

Soil type	Available water content (AWC)		
	(mm/m)	($m^3 m^{-3}$)	(%)
Sand	25 – 100	0.025 – 0.1	2.5 – 10
Loam	100 – 175	0.1 – 0.175	10 – 17.5
Clay	175 – 250	0.175 – 0.25	17.5 – 25

TABLE 2:

Ranges of porosity for USA soil textural classes [2]

Soil type (USA Soil texture classification)	Porosity ($m^3 m^{-3}$)		
	(Saxton and Rawls, 2005)	(Rawls et al.,1998)	(Clapp and Hornberger, 1978)
Sand	0.48 – 0.46	0.44 – 0.39	0.40
Loamy sand	0.47 – 0.44	0.45 – 0.39	0.44
Sandy loam	0.47 – 0.42	0.47 – 0.37	0.44
Loam	0.48 – 0.46	0.47 – 0.39	0.45
Silt loam	0.48 – 0.46	0.49 – 0.39	0.49
Silt	0.49 – 0.47	-	-
Sandy clay loam	0.45 – 0.42	0.44 – 0.37	0.42
Silt clay loamy	0.53 – 0.49	0.50 – 0.43	0.48
Silty clay	0.55 – 0.50	0.53	0.49
Clay	0.56 – 0.46	0.48 – 0.40	0.48

2.0   MATERIALS AND METHODS

The equipment used for this study is MALA Professional Explorer GPR system (optical module) with 200 MHz antennae, 3 GPR batteries, 0.6m handle, backpack kits (Fig. 2b), 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, the receiver cable, and the transmitter cable. From it again, another cable is connected to a personal computer (PC) through universal serial board (USB) port.

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. 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. The data were collected in early October, 2014 and there were four profiles taken across the two locations at equal interval of 1m.

2.1   GPR 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 [11]. 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.

2.1.1   Velocity of the wave in the soil

Since the two-way travel time ($TWTT$) and the depth models, d were obtained from the radagrams, the velocity analysis was done by using (1).

The velocities, v of the models were fed into the active polygon parameter section of the software and it automatically computed the dielectric permittivity of the soil k in accordance with (2).

2.1.2   Soil water content

After obtaining dielectric permittivity of the soil, the water content was then computed using (4). This computed soil water content, θ is the difference between the water content at field capacity and water content wilting point($\theta_{FC} - \theta_{WP}$) as part of (3)

2.1.3   Soil porosity

Analysis of the porosity of the soil was done using (5). The square root of the dielectric permittivity of the grains of the medium was taken to be 4.8 [12]

3.0   RESULTS AND INTERPRETATION

3.1 Ekenkpon study area result

From the parameters presented in table 3, the soil water content of Ekenkpon study area has a mean value of $0.12245 m^3 m^{-3}$

which shows that the soil type is loamy according to tables 1a and 1b. The porosity of soil of this area has a mean value of $0.4606 \text{m}^3\text{m}^{-3}$, according to table 2, the soil type is loamy.

3.2 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 $0.65205 mS/m$ which is a typical value for limestone [3]. The area has a mean water content of $0.1393 m^3 m^{-3}$ and a mean porosity value of $0.4556 m^3 m^{-3}$.

From the analysis of these results and according to tables 1a, and 2, the soil type of this area is loamy.

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 [3].

Some selected crops cultivated in the study areas are presented in table 5, the maximum rooting depth of these crops are supplied by [7]. Using equation 3 and water content values for the two important types of soil that can support crop yield in the areas are calculated and presented (table 5).

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

TABLE 3:

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
Odukpani	0006A	0.12	6.3
	0007A	0.10	9.0

TABLE 4:

The results of soil water content and porosity of the areas.

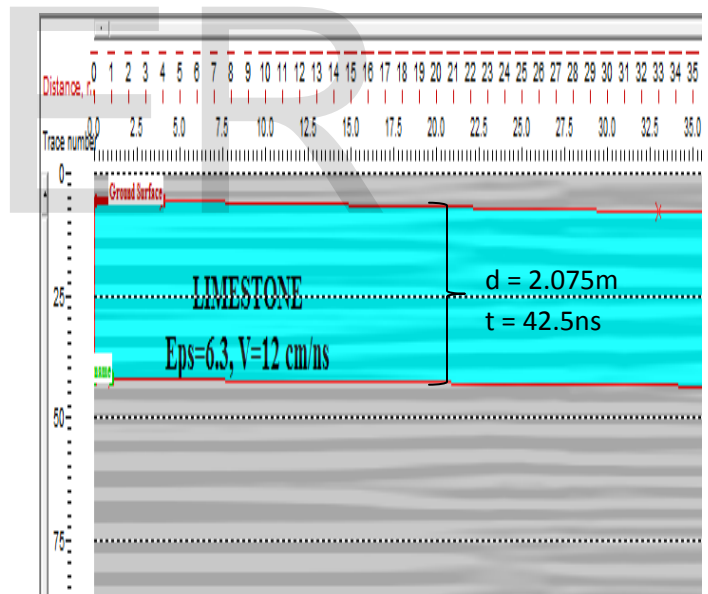| Study Area	Profile Number	Water content (m^3m^{-3})	Porosity (m^3m^{-3})
Ekenkpon	0001	0.1347	0.4540
	0002	0.1102	0.4672
Odukpani	0006A	0.1102	0.4672
	0007A	0.1684	0.4440
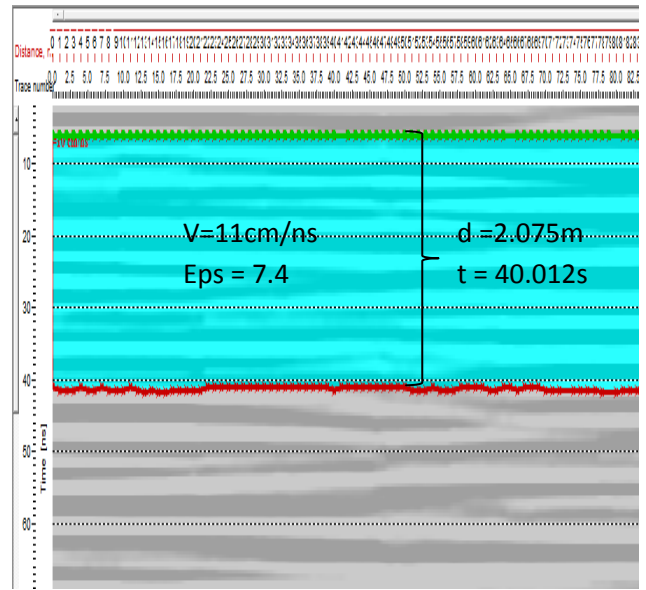
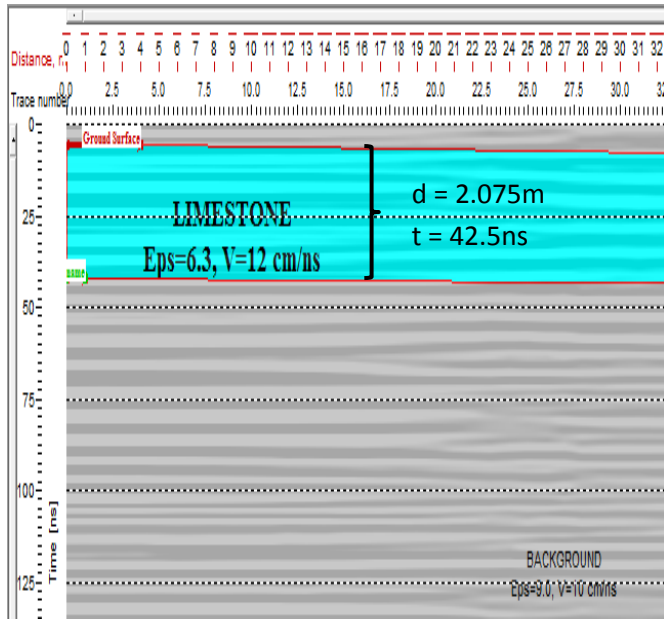Fig. 5. GPR model of Ekenkpon study area (Profile No: 0002)

Fig. 6. GPR model of Odukpani study area (Profile No: 0006A)

TABLE 5
The ranges of water content that can support crop yield
cultivated in the areas

Crop	Available water content (mm/m)	
	Sandy soil	Loamy soil
Cassava (1st year)	40 – 64	70 – 112
Cassava (2nd year)	56 – 80	98 – 140
Pumpkin	80 – 120	140 – 210
Maize (sweet corn)	64 – 96	112 – 168
Cucumber	56 – 96	98 – 168
Sweet melon	64 – 120	112 – 210
Water melon	64 – 120	112 – 210
Tomato	56 – 120	98 – 210
Sweet pepper	40 – 80	70 – 140
Groundnut	40 – 80	70 – 140
Banana	40 – 72	70 – 126
Palm tree	56 – 88	98 – 154
Pineapple	24 – 48	42 – 84
Rubber tree	80 – 120	140 – 210
Beans (large vines)	64 – 96	112 – 168

4.0   CONCLUSIONS AND RECOMMENDATIONS

A single offset method of GPR has proven to be suitable to characterize the soil in the study areas. The mean values of water content and porosity of the soil at Ekenkpon were $0.12245 m^3 m^{-3}$ and $0.4606\ m^3 m^{-3}$, Odukpani $0.1393 m^3 m^{-3}$ and $0.4556\ m^3 m^{-3}$ respectively.

The study revealed that the study areas are composed mostly of loamy and sandy soils which are suitable crops in table 5. It is therefore recommended these crops should be cultivated in the area for positive yields since the water contents and porosity of the soil fall within the specified range.

Acknowledgement

References

[1] E.A. Akpan, T.E. Chidomerem, and I.O Akpan,"Geophysical and laboratory studies of thespread andquality of the Odukpani Limestonedeposit,"*AmericanJournal of Environmental Sciences* 10 (4): 347-356, 2014

[2] J.L Anderson and J.S Gulliver. "Assessment ofstorm waterbest management practices" *Regentof the University of Minnesot,* 2007.

[3] E.A. Awak, "Hydrogeophysical soilcharacterization using Ground Penetrating Radar(GPR): A case study of partsof Odukpani andAkamkpa Local Government Areas, Cross RiverState".(Unpublished M.Sc.Thesis),

[4] B.K. Bellinham,"Method for IrrigationSchedulingBased on soil moisture DataAcquisition"*USA,United StatesCommittee onIrrigation and Drain*2009

[5] J. Davis and A. Annan, "Ground penetratingradar forhigh resolution mapping of soil androck stratigraphy."*Geophysical Prospecting,*37,531–551,1989.

[6] N.K. Fageria, "Maximizing Crop Yields" *Mercel Dekker, New York, 133–168,* 1992.

[7] F.A. Organization. Corporate DocumentRepository,"Irrigation WaterManagement:Introduction toirrigation". Produced byNational Resource Management andEnvironmentalDepartment, 1985

[8] N.J. George, A.E. Akpan, A.M. George, and I.B.Obot,"Determination of elastic properties of the overburdenmaterials in parts ofAkamkpa, southeastern Nigeria using seismicrefractionstudies". *Archives of PhysicsResearch*, 1 (2):58-71, 2010.

[9] J.A. Huisman, S. Hubbard, J.D. Redman, and A.P.Annan,"Monitoring soil water contentwithgroundpenetrating radar" A review:*Vadose Zone Journal*, 2,476–491, 2003.

[10] S. Lambot,"Hydrogeophysical characterizationof soilusing ground penetrating radar". (Ph.D.Thesis),Catholic University of Louvain.Belgium,2003

[11] M.A. Seger and A.F. Nashait,"Detection ofwater table by using GPR". *Eng. & Tech.Journal*, 29 (3):554-566,2011.

[12]Z. Ziaqiang, X. He, G. Lu, Q. Liu, and J. Li,"Ground PenetrationRadar Exploration forGround Water andContamination": *PIERSProceedings* (pp 1316-1320). Moscow,1999.