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(Research Article)

The use of ground penetrating radar (GPR) method in the evaluation of soil moisture content of parts of cross river central soil for precision agriculture in South-south Nigeria

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Abstract

Using a single offset of the GPR technique, the soil moisture content in the study areas has been satisfactorily characterized. The average water content of selected soils in the Central region of Cross-River State ranges from 0.24m3m-3 to 0.35m3m-3. The majority of the soil in the research area is loamy soil, which has little sand and silt particles, claims the study. The majority of loamy soil is made up of sand, silt, and a small amount of clay. When dry, loamy soil has the consistency of concrete and when wet, it turns into a sticky mess. The majority of plants and vegetables can be grown on loam soil rather than other types of soil. Since loam contains almost equal amounts of all three of these components, it is the best type of soil. In conclusion, some of the Central Cross River State's soils would be suitable for farming.

Keywords: Precision agriculture; Moisture content; Ground penetrating radar; Frequency; Subsurface

1. Introduction

The soil moisture is the volume of water in the soil that is present in the spaces between soil particles. The contact between the surface of the land and the atmosphere is altered by soil moisture, say [1] and [2], which has an impact on the climate and weather. It is critical for defining the important rainfall-runoff processes. The preservation of enhanced soil moisture is a crucial ecosystem service given by natural ecosystems; improper management could lead to desertification. The availability of soil moisture is essential for natural cycling, which is necessary for primary production. The terrestrial evapotranspiration process, which is regulated by soil moisture [3]; [4], [2], [5], is entangled with the cycles of energy, water, and carbon. Maintaining these related ecosystem services promotes biodiversity and raises the productivity of natural ecosystems, claim [6] and [7], acidity, field capacity, wilting point, and soil water are some examples of the chemical and physical properties of soil. The quality and production of the soil are influenced by potential and soil matric potential [8] Water availability in agroecosystems is also significantly influenced by soil moisture retention [9].

The soil's moisture serves as a binder, changing the stability and toughness of the structural integrity of the soil. Water availability primarily affects the yield of agricultural crops, and soil moisture plays a role in the processes of development and degradation in terms of both chemical and biological properties. The quality and productivity of a soil are determined by its chemical and physical properties, including alkalinity, acidity, field capacity, wilting point, soil water potential, and soil matric potential. Water availability in agroecosystems is also significantly influenced by soil moisture retention. Moisture in the soil acts as a binder, altering the stability and toughness of the soil's structural integrity. The production of agricultural crops is primarily influenced by water availability, and the development and degradation of chemical and biological qualities are both influenced by soil moisture. Therefore, the classification and

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monitoring of the soil qualities in the environment are required in order to develop site-specific management approaches that fit human activities with regional environmental requirements [10]. It is challenging to gather soil data with the required spatiotemporal resolution due to the subsurface's inaccessibility and inherent variability.

Determining the velocity and depth of the target dielectric constant is crucial in this study because the dielectric constant of the host material plays a significant role in GPR technology. A geophysical technology called ground penetrating radar (GPR) uses an electromagnetic (EM) method to scan the subsurface. Its goal is to describe how the (GPR) wave behaves when different hosting dielectric constants are present [11]. Electromagnetic waves and signals that are reflected off of subsurface objects are used in this non-destructive technique. GPR can evaluate a wide range of material, including rocks, mud, ice, snow, water, and structures. It can locate underground objects, different types of materials, fissures, and voids.

Geophysics has been employed in a number of fields in the past, including engineering, hydrology, and archaeology. There have been several improvements in the application of geophysics in agriculture, but little focus has been given to this field. With a focus on food, fiber, and raw materials as well as the need to manage a challenging environment while preserving and improving the quantity and quality of environmental resources, "sustainable agriculture" accurately describes the relationship between agriculture and the environment. The region where agriculture is conducted on this upper layer of the earth's crust, also referred to as the "skin" of the planet, is one of the complex systems in which the lithosphere, hydrosphere, and biosphere interact 0.2 meters or so.

The thickness of the zone below the earth's surface that is significant to agricultural research, according to [12] is about 0.2 meters. Ground Penetrating Radar (GPR) will be used in this study as a geophysical method to determine the kind of soils and their moisture content. Additionally, it seeks to validate the GPR technique as a substitute tool for figuring out the amount of soil moisture in certain areas in central Cross River State. The survey results will also be used to understand how soil properties behave for engineering and agricultural purposes.

Previously, a number of complex methods were needed for the geophysical analysis of the subsurface, but with the advent of GPR, a direct procedure was devised, cutting down on the amount of time necessary for geophysical interpretation of the subsurface. This is one problem that the GPR has been successful in resolving. Ground penetrating radar (GPR) has shown to be a helpful technology for applications including the identification of subsurface items. Along with metallic products, it is appropriate for wooden and plastic items as well. Despite its many advantages, detection is difficult due to the GPR's serious drawbacks. GPR-related problems are discussed, including low resolution, the antenna gain effect, clutter, and proposed solutions, such as the application of windowed average subtraction. The expensive expense of renting the equipment for Ground Penetrating Radar (GPR) is another issue.

2. Location and Geology of the Study Area

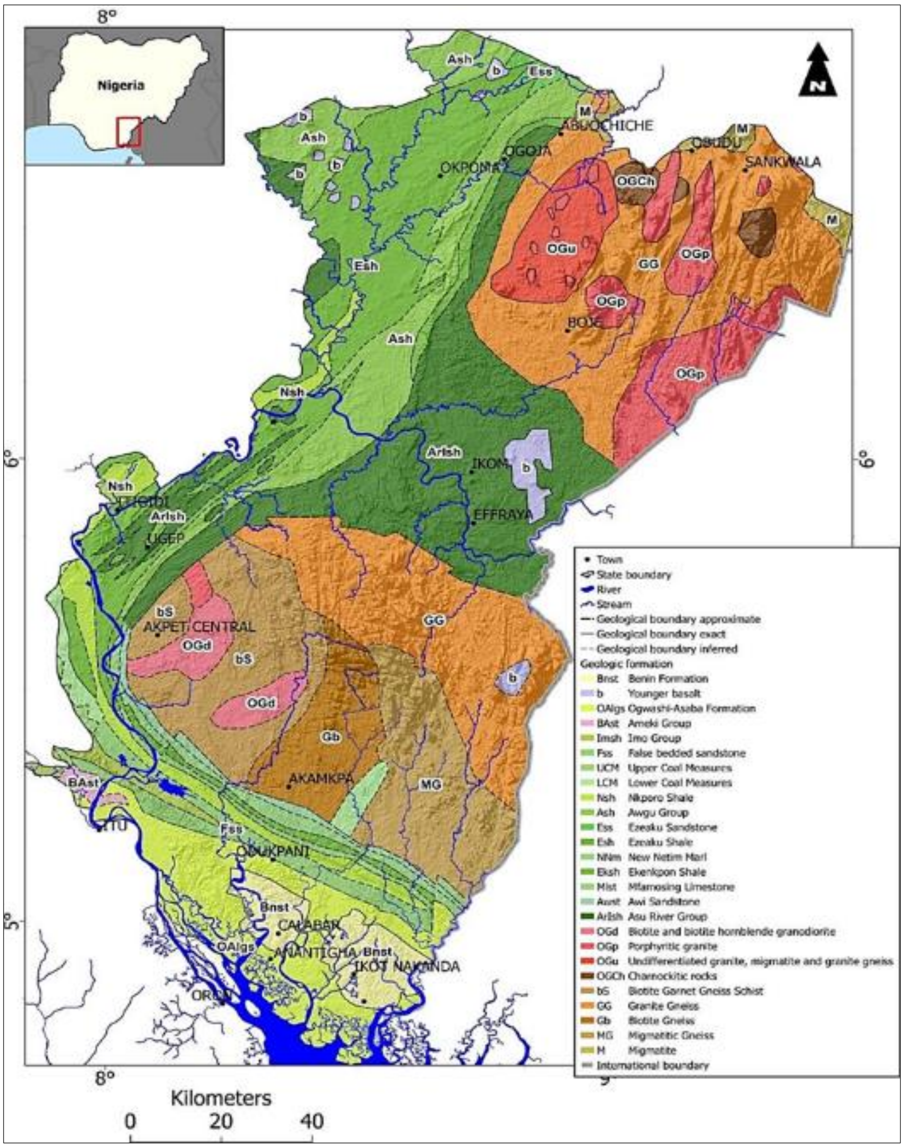


Figure 1 Geological Map of the Study Area

2.1. Geological Setting

The research area is located between longitudes 7.93 and 8.17E and latitudes 5.76 and 6.02N in Cross River State, Nigeria (Fig.1). The area is limited by Boki Local Government Area to the North; it is adjacent to Ebonyi State to the northeast and limited to the south Akpabuyo Local Government Area and the Atlantic Ocean. The area which comprises of semi urban communities in, Obubra, and Ikom Local Government Areas is located in the Ikom Manfe Embayment (IME)

The IME is bounded to the northeast by the Obudu Plateau and the Cameroun Volcanic Line and to the west by the Abakaliki Anticlinorium and Afikpo Syncline. In the southeastern part, it is bounded by the Oban Massif in Cross River State, Nigeria (Fig. 1a). The IME is characterized by low relief and gently undulating topography [13] and cuts across Abi, Obubra, Yakurr, Biase, and Ikom local government areas (LGAs) in Cross River State. Following the mid-Santonian tectonism and magmatism

Tectonically, the IME is believed to have its origin traceable to the regional tectonic episode that resulted to the splitting of the African and South American Continents. The Benue Trough was formed due to the failed rift (aulacogen) of the triple junction rift system and was, subsequently, filled with sediments [13]. Compressional folding during the mid-Santonian affected the entire Benue Trough producing several structures, such as the Abakaliki Anticlinorium and

Afikpo Syncline, which later became Afikpo Basin [14]. Sedimentation in the IME began with the deposition of marine Albian Asu River Group (ARG), which is the first lithostratigraphic unit resting unconformably on the Precambrian crystalline basement (PCB). The PCB consists basically of migmatitic gneiss, granitic gneiss, and schist with some pegmatitic intrusions in some locations (Fig. 1). The gneisses within the PCB are usually foliated with some pink feldspathic materials and vary from black to white hornblende, with porphyroclastic feldspars [15]; [16]. The regional strike direction of these rocks is N–S, although some occasional NE–SW swings have also been reported by [17] and [18]. Some pyroclastics of Aptian–Early Albian ages have been sparingly reported [19] . The ARG, nonmarine-to-marginal marine character sediments, consists of impermeable shales, sand lenses, sandstone intercalations, and ammonite-rich limestones [20]. The late Albian–Cenomanian thick flaggy impermeable calcareous and non-calcareous black shale; siltstone and sandstone of the Eze-Aku Group (EAG), which correlates with the marine Cenomanian–Turonian Nkalagu Formation (black shale, limestone and siltstone) and the interfingering regressive sandstones of the Agala Formation, overlays the ARG. The thickness of this formation do exceed 100 m locally [21]. The post-Cretaceous tectonic activities, which were believed to have originated from the adjoining Cameroun Volcanic Province and other low-grade metamorphism in the area, caused serious fracturing of the basement rocks and deformation of the adjoining Cretaceous lithostratigraphic units [22]. Thus, the overlying Cretaceous sequence is highly baked, domed, and seriously deformed in many locations [23]; [24]. In many locations, the sandstones in the EAG form ridges that averagely strike at N40^{0}E and dip between 20^0 and 68^0, e.g., Owutu–Afikpo–Adadama Ridge system (OAASRS). The shales within the EAG was reported by [2] as having secondary properties, such as interconnected porosities, joints, fractures, and folds, resulting from syn- and post-depositional deformations. These properties are very significant and necessary in the transmission and storage of fluid [26]. These striking characteristics of the IME introduce a slight geologic complexity in the lithostratigraphic architecture of the area at certain locations, especially those localities around the geologic contacts. The Nkporo Shale Formation (NSF) that [27] and other authors refer to as the Nkporo–Afikpo Shale Province unconformably overlay the Post-Santonian hiatus and represent a fossiliferous pro-deltaic facies of the late Campanian-early Maestrichtian brackish marsh deposits consisting of shale and sandstone lenses. Deposition of the sediments of the NSF reflects a funnelshaped shallow marine setting that graded into channel low-energy marshes which roughly runs across the Benue Trough [28]

Table 1 Conductivity, Velocity and Attenuation constants of various materials

Material	**K**	**Velocity v (m/ns)**	**Attenuation $\propto$ (dB/m)**	**Conductivity σ (mS/m)**
Air	1	0.30	0	0
Distilled water	80	0.033	0.002	0.01
Fresh Water	80	0.033	0.1	0.5
Sea water	80	0.01	1000	300000
Granite	4 – 6	0.13	0.01 – 1	0.01 – 1
Ice	3 – 4	0.16	0.01	0.01
Limestone	4 – 8	0.12	0.4 – 1	0.5 – 2
Shale	5 – 15	0.09	1 – 100	1 – 100
Dry Salt	5 – 6	0.13	0.01 – 1	0.01 – 1
Silt	5 – 30	0.07	1 – 100	1 – 100
Clays	5 – 40	0.06	1 – 300	2 – 1000
Dry Sand	3 – 5	0.15	0.01	0.01
Saturated(wet) Sand	20 – 30	0.06	0.03 – 0.3	0.1 – 1

Source: [29]

Table 2 Electrical conductivity of different soil type

Soils and Clays	Electrical Resistivity	Electrical Conductivity
Clay (general term)	1-100	10-1000
Loamy soil	4-40	25-250
Sandy soil	400-4000	0.25-2.5
Loose sands	1000-10^5	0.01-1
Clay-rich soil	100-400	2.5-10

3. Review of Related Literature

[30] employed ground penetrating radar (GPR) to measure the soil moisture, water content, and porosity in the farmlands of the communities of Ekenkpon and Odukpani. The mean depth of 2.075mm was chosen in order to calculate the wave velocity in the soil since the longest root of the crop can reach a depth of 1.8mm. The results of the investigation show that the soil at Ekenkpon and Odukpani measured 0.1393 mm3 and 0.4556 mm3 respectively, whereas the soil at Ekenkpon measured 0.12245 mm3 and 0.4606 mm3. These results showed that the predominant local soil types are sandy soil and loamy soil. GPR has thus shown to be the most efficient technology for hydro-geophysical soil characterization in the context of precision agriculture. The top 10 cm of a 3 acre California vineyard's soil was measured utilizing the Ground Penetrating Radar (GPR) ground wave technique to determine its soil water content. Over the course of a year, evenly spaced GPR travel time measurements using 900 and 450MHz antenna were carried out to determine the water content. The GPR water content estimate is compared to the gravimetric, time-domain reflectometry, and soil texture data. The results of this study imply that shallow water volume over large areas can be swiftly and non-invasively assessed using GPR ground wave. Volumetric water contents of 0.11 for the 900MHz data and 0.017 for the 450MHz data were found, with the highest errors occurring in exceptionally dry soils [31] used the GPR to quantify the spatial correlation of water content in a three-acre field as a function of sampling depth, season, vegetation, and soil moisture/texture. The GPR data was gathered using 450MHz and 900MHz antennas. The soil water content was calculated using measurements of the GPR groundwave at four specific intervals. Additional water content estimates were found using measurements of soil texture and time domain reflectometry. These findings demonstrated that while irrigation and precipitation increase the geographical variability of water content, shallow-rooted vegetation reduces regional variability. The study showed that the small-scale spatial correlations between water content and soil texture are often different, with deeper soil layers showing a closer correlation between water content fluctuation and soil texture than shallower soil layers. According to [32], it is difficult to consistently and spatially completely assess soil moisture. Non-destructive methods that can be used to directly estimate moisture content and give precise results with higher accuracy and resolution are required [33], The available techniques are divided into two groups: Direct methods and Indirect methods.

According to [34]and [35], measurements made with direct methods are calibrated against other measurable variables that change in relation to soil moisture content. By comparing the weights of a soil sample before and after it has been dried, the soil moisture may be calculated. The gravimetric method or the thermostat weight technique is the sole direct way; all others fall into the category of indirect procedures. With the exception of remote sensing, all methods for calculating soil moisture are dependent on the surface of the earth.

3.1. Theory of Ground Penetrating Radar (GPR)

A geophysical technique called GPR uses electromagnetic radiation to locate objects or interfaces buried below the earth's surface [36], A GPR system typically includes of three components, according to Conyers [37], transmitting and receiving antennas, a control unit with a computer and associated software, and a display device. The transmitting antenna generates and sends earth-bound radar pulses. The objects buried in the ground either absorb, reflect, or scatter the energy. In order to increase the signal-to-noise ratio and accurately record the subsurface conditions, a portion of the emitted radiations travel for a while before returning to the receiving antenna [38]. GPRs often operate in the VHS-UF region of the electromagnetic spectrum. In order to achieve the best earth penetration depths, one should choose the lowest frequency possible. But to make the radar wavelength short and enable the detection and resolution of small objects like pipes, a high enough frequency must be used. Radars mounted on carts typically operate at a central frequency of 250MHz. While 500MHz and 1000MHz are occasionally used for high resolution probing, frequencies as low as 20MHz are used to locate deep caves or mine shafts.

During a GPR examination, a source antenna (Tx) is utilized to send radio wave pulses (between 100 MHz and 2.6 GHz) into the ground. The radio wave signal gets distorted as it passes through the earth due to its electromagnetic properties. The radio wave signals are then measured at the limits where the subsurface electromagnetic characteristics abruptly change by the receiving antennas (Rx). Since they are sensitive to the electric fields transmitted by radio waves, receiver antennas act as transducers by converting the GPR signals they receive into electrical current. The induced current's resulting voltage is then digitally captured. Finally, GPR receivers measure the amplitude and polarization of incoming radio wave signals as a function of time. The amplitude and polarization of radio wave transmissions change as they are modified by earthly propagation because the raw data are eventually adjusted. GPR employs radio waves to convey data into the earth at speeds nearly equal to the speed of light (C=3.0 x 108 m/s) and across comparatively short distances. GPR signals have very short total travel times since they are transmitted from the transmitter antenna to the receiving antenna. The time series of a single GPR short can be captured up to a few hundred ns after the signal is generated.

For GPR surveys meant to scan very near to the surface, data is captured for a shorter period of time after the transmitter emits the GPR signals (resulting in a shorter trip time). Because shorts only persist for a split second, GPR measurements for a single short can be carried out repeatedly for the same transmitter-receiver pair at the same location (sounding). Different models have been built to represent the diverse geological conditions. The first model is a single profile that illustrates how electromagnetic waves move through different types of materials and how electromagnetic properties (such and) impact the wave. To better understand how electromagnetic waves (reflected waves from radar-grams) move through the geologic environment, the second model is used.

Velocity determination The wave's velocity is inversely proportional to the two-way travel time, reflector depth, and antenna separation (a, d).

$$V=\frac{2\sqrt{d^2+(0.5a)2}}{TWTT} \quad \ldots\ldots\ldots\ldots(1)$$

The dielectric permittivity**(k)** is related to electromagnetic wave c by;

$$K = \binom{c}{v} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:
K = dielectric permittivity,
C = Velocity of EM wave in m/n,
V = Velocity of the wave GPR analysis.

4. Material and methods

The following items were employed in this study project:

- MALA ProEx control unit
- Unshielded 200MHz antenna pair pairs (Transmitter and Receiver) Ethernet cable, third
- A 0.6-meter antenna separator
- Measurement tape Global Positioning System (GPS)
- Connecting cable
- Windows XP or 7 computer
- Battery

A quick device for acquisition, processing, and storage is the MALA ProEx control unit. Each data stream is handled by a different processor in the MALA ProEx controller, which contains parallel processors. Geographic Positioning System (GPS): GPS offers an unmatched breadth of services to commercial, military, and consumer applications regardless of time, place, or weather. Most of these services allow users who are in the air, on land, or in the sea to know their precise speed, location, and time whenever and wherever on Earth.

4.1. Field Data Collection Procedure

The traversal and data collecting were done in many places in the Central region of Cross River State. The ability of the 200MHz antennas for shallow depth penetration was the main factor in their selection. Using an unshielded antenna with a fixed spacing of 1.0m between the transmitter and receiver, the system is moved concurrently at a distance of 0.6m. The GPR system unit is connected to the antennas by three (3) cables: the Data cable (D), the Receiver cable (R), and the Transmitter cable (T). A different cable is now attached to the Universal Series Board (USB) port on a personal computer (PC). Two batteries are placed within the antenna's battery compartment, and one of them is placed inside the optical module system. The system unit is then turned on to allow specific instrument parameters. A ping sound and flashing light are released when the antenna switches are turned on, signaling that the apparatus is ready for operation. By moving both antennas across the ground surface at a fixed or constant interval of 1m and pressing the ENTER key on the PC at a location where the antenna was well-positioned, the GPR reflection data were obtained. A field crew member helped carry the antennas while another held the cables to prevent cuts in order to make the survey quicker and easier. Five (5) profiles were taken during the fieldwork,

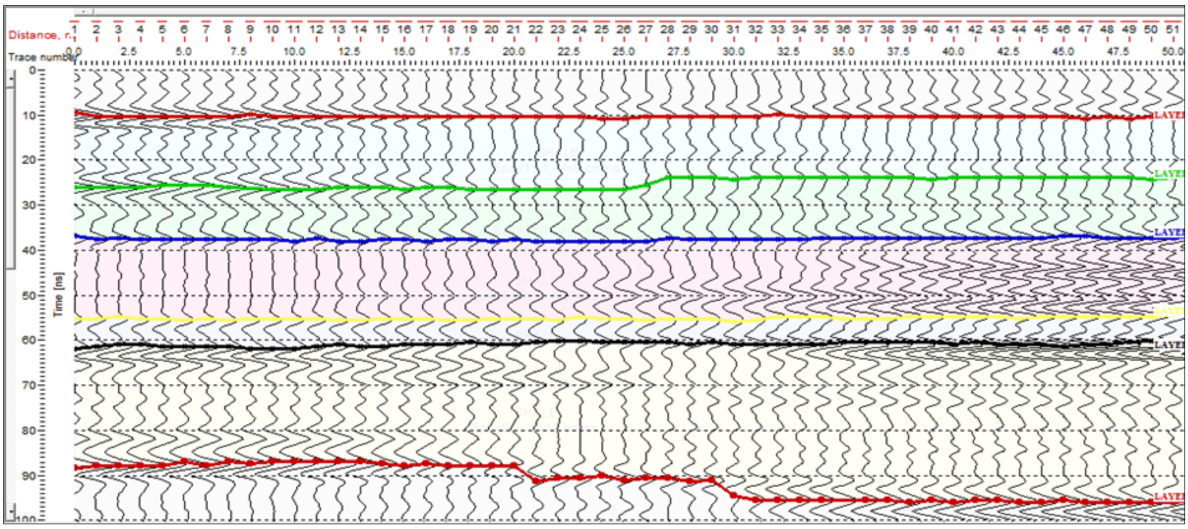
5. Results and discussion

The following procedures were used to process the raw GPR data using the RadExplorer 1.4 program

- 2. 1. DC removal: This method eliminates any constant signal components by changing the mean mode's start time to 0 ns and end time to 100 ns.
- The vertical time scale's zero point is determined by the time adjustment routine, which sets time zero as the moment the wave really left the antenna. This was done in case the instrument didn't pick up the field's zero time. This repacking made sure that the profile's depths were accurate (Awak et al., 2017). Use 2D spatial filtering to determine the sample and trace sizes. This type of 2-D mean filter was applied to average the data inside the filter application window. Based on how long the profile was, the number of traces was determined.

Table 3 Antenna properties for acquisition of GPR data

Antenna frequency	200MHz
Centre frequency	200MHz
Resolution	1.0m
Depth	7-12m
Number of samples	516
Trace number	According to profile length
Start time/end time	0/100ns
Antenna separation	0.6m
Background velocity	0.1m/ns
Air wave velocity	0.3m/ns



Location: Ochon; Profile length: 100; Av. depth: 2.075m, av. twtt: 44.011 ns, V = 11..4 cm/ns, K = 8.8

Figure 2a Raw data

In Fig. 2a above, a profile length of 50m was carried out at the on the soil, and from the Raw data above, it is observed that there are several wiggles in each layer which entails water content.

Wiggles are due to the changes in dielectric constant that has caused deflection in the electromagnetic wave. So, the wiggles in the Raw data above are as a result of a deflection caused by water content present in the layer of the ground.

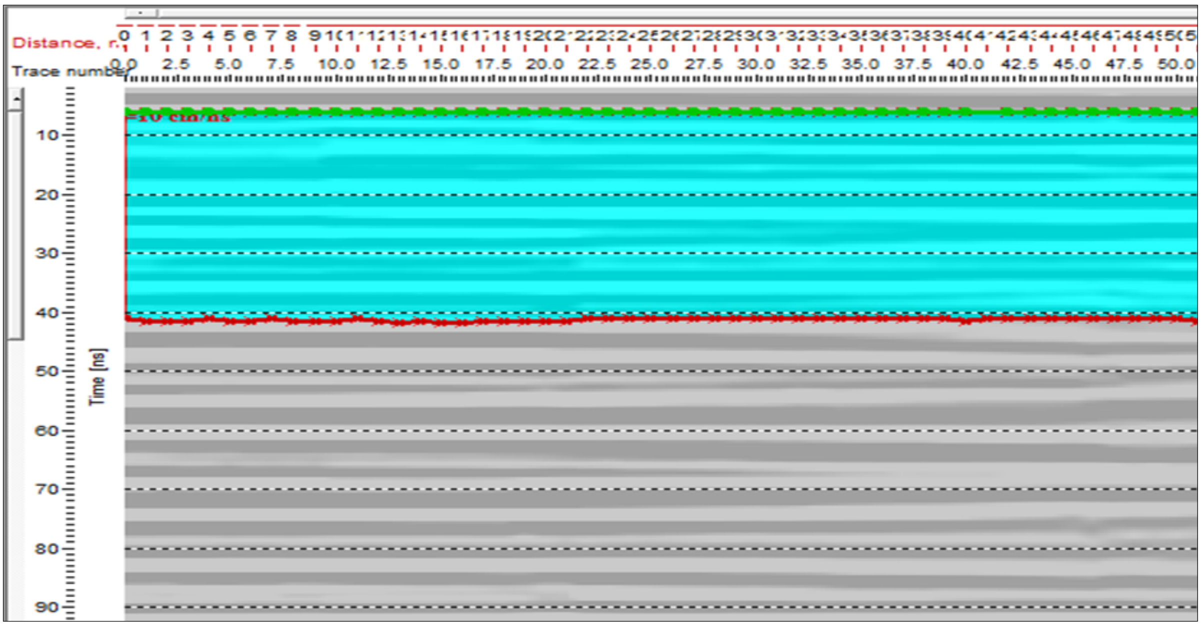
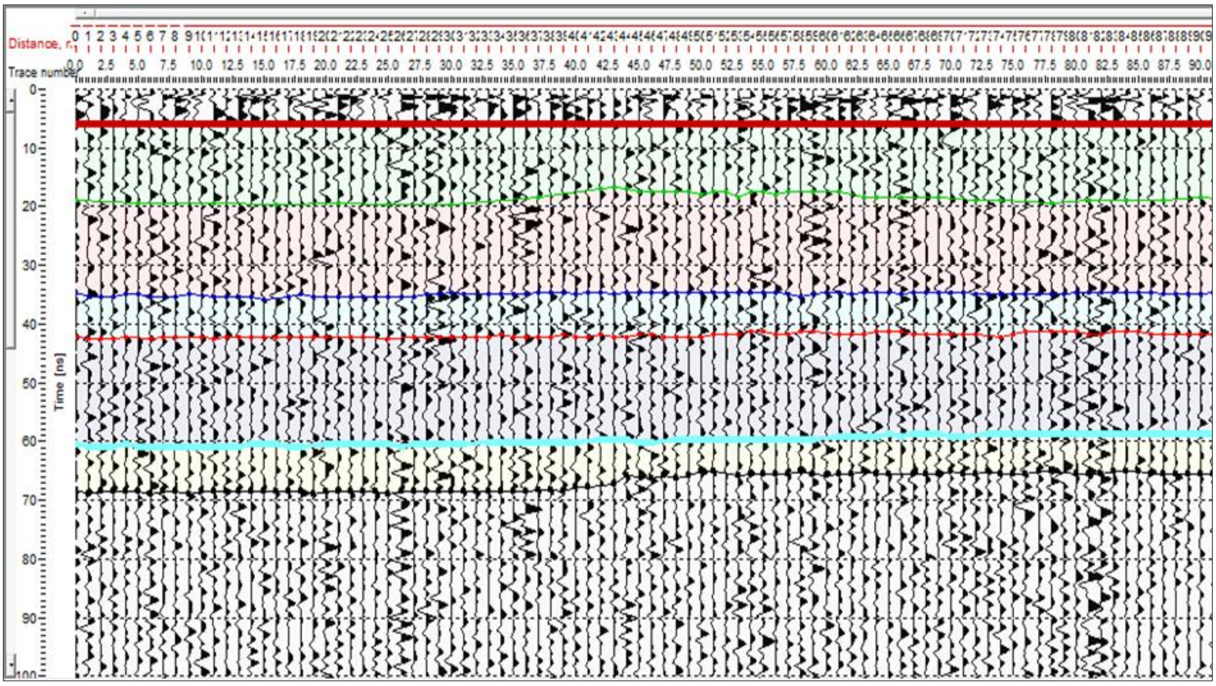
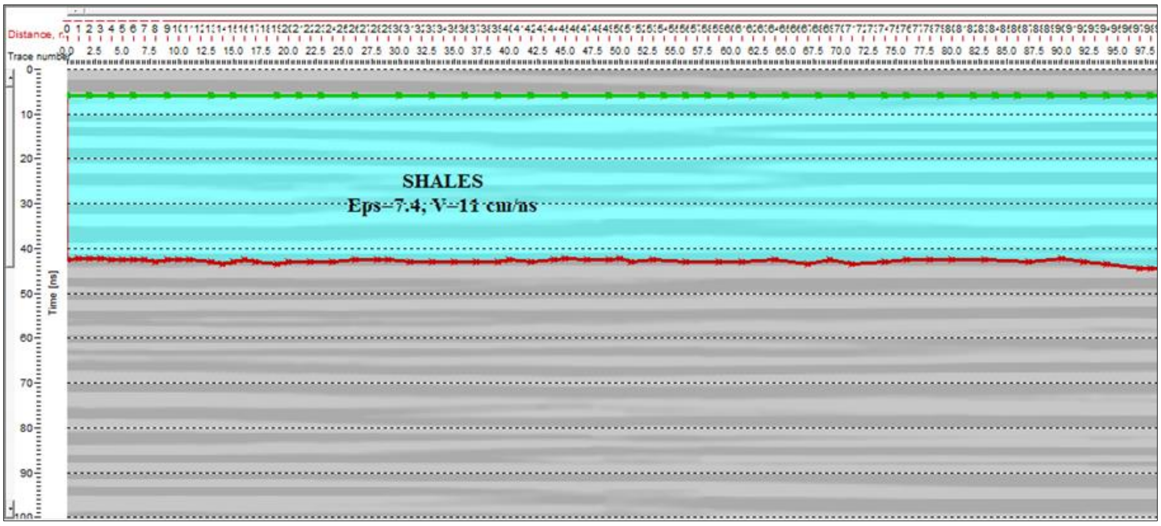


Figure 2b Model



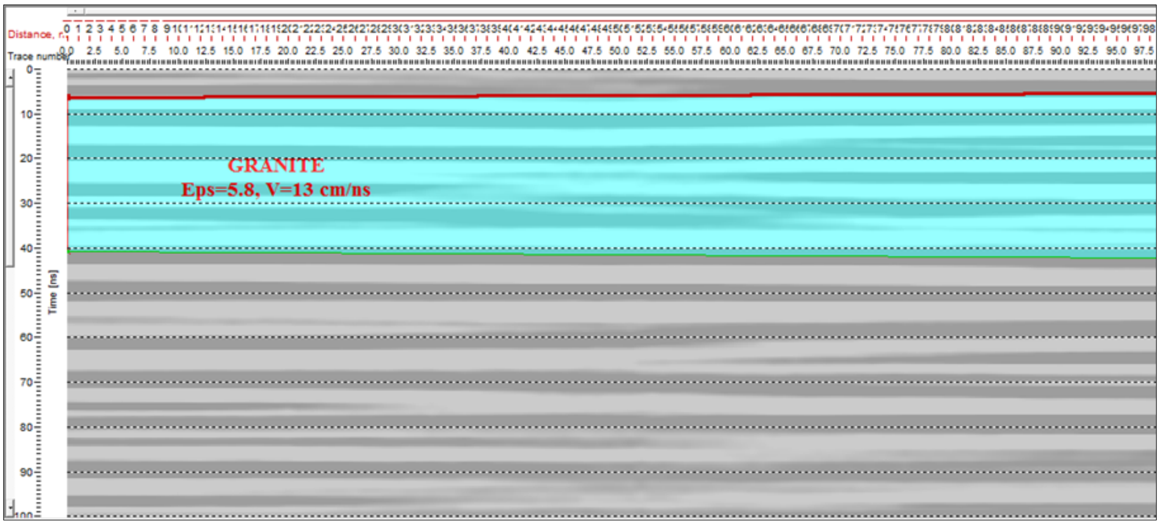
Location: Onyen; PROFILE DISTANCE: 100m; AVE. DEPTH: 2.075m AVE. TRAVEL TIME: 37.727 ns (43.687 – 5.960)

Figure 3a Raw data



DISTANCE 100m, MEAN. DEPTH: 2.075m MEAN. TRAVEL TIME: 33.417s

Figure 3b Model data



DISTANCE 100m DIRECTION: N-S: CRUTECH Farm

Figure 3c Model Data

Table 4 Average depth (m), Average Two-Way Travel Time (ns), Velocity V(cm/s), Dielectric constant (K), and Soil moisture content **θ**(m3m-3)

LOCATION	Profile Length	Av. Depth (m)	Av. TWTT (ns)	V (cm/ns)	K	θ (m^3m^{-3})
OCHON	50	2.075	44.011	11.4	8.8	0.1539
ONYEN	100	2.075	37.727	11.0	7.4	0.1347
OHANA	100	2.075	33.417	12.5	5.8	0.0987
OCHON	50	2.075	41.013	11.4	9.3	0.1630
ONYEN	100	2.075	38.625	13.0	8.4	0.1547
OHANA	100	2.075	34.317	13.5	6.8	0.0886

According to [30], Topp's equation relates soil water content to apparent permittivity K. The average depth of all the profiles, as seen in the table above, is 2.075m, however it's important to note that each root can grow to a maximum length of roughly 1.5m. We tend to increase the distance in order to sort for greater water content in that location because we are operating based on the soil moisture content. From the values of the soil moisture contents obtained from three (3) different locations, it can be seen that the farmland has a higher soil moisture content than the others, making it an ideal location for agricultural work and vegetation, whereas the other locations at the back of the physics department are mostly composed of shales. According to the range of values in my data, the study area is characterized by loamy soil, which was identified by the general dielectric constant and the amount of soil moisture content in each layer, which is influenced by the soil type. Loamy soil can hold a lot of water while still being able to drain away extra water. After rain or irrigation, the particles allow for unrestricted drainage, and any remaining water drains downward. When a soil becomes dry, loamy soil is not susceptible to cracking, which poses no threat to plant roots.

Table 5 Soil water contents expressed in different units for different soil

Soil type	Available water content (AWC)		
	(mm/m)	(m^2m^{-2})	(%)
Sand	25 – 100	0.025 – 0.1	2.5 – 10
Loamy	100 – 175	0.1 – 0.175	10 – 17.5
Clay	175 – 250	0.175 – 0.25	17.5 – 25

(Adapted from FAO Cooperate Document Repository, 1985)

Table 6 Ranges of water content that can support crop yield cultivated in the area

Crop	Available water content (□□/□)	
	Sandy soil	Loamy soil
Cassava (1st year)	40 – 64	70 – 112
Cassava (2nd year)	56 – 80	98 – 140
Pumpkin	80 – 120	140 – 210
Maize (field corn)	80 – 136	140 – 238
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

6. Conclusion

The soil moisture content in the research region can be characterized using a single offset GPR technique. At the University of Cross-River State in Calabar, the average soil water content ranges from 0.26m3m-3 to 0.39m3m-3. According to the study, the study region is largely made up of loamy soil, which contains tiny sand and silt particles. Sand, silt, and a little quantity of clay make up the majority of loamy soil, which when dry takes on the consistency of concrete and becomes a sticky mixture when wet. In comparison to other soils, loam soil can be preferred for growing the majority of plants and crops. The best type of soil is loam since it has almost equal levels of all three of these elements. The results of this study showed that planning precision agricultural programs and evaluating the effectiveness of water use depended on the monitoring of soil moisture content, and that doing so leads to crop yield maximization and damage minimization by making the best use of the water and land resources by adapting the soil moisture content (SMC). This is one of the major contributions of this work. The economy and the environment benefit from optimization since it boosts farm productivity and reduces irrigation expenses. In conclusion, some areas of the Central part of Cross River State, may be suitable for farming because loam soil, which best describes the soil composition for most farm crops, makes up the majority of the area. The soil is also regarded as excellent for civil engineering building and infrastructure due to the degree of soil moisture content that ensures the soil's bearing ability is not impaired.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest exists between the authors

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