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Original Article

Application of Geoelectric Resistivity Technique to a Selected Site for Agricultural Practices, at Kujama Farmland, Kaduna, Nigeria

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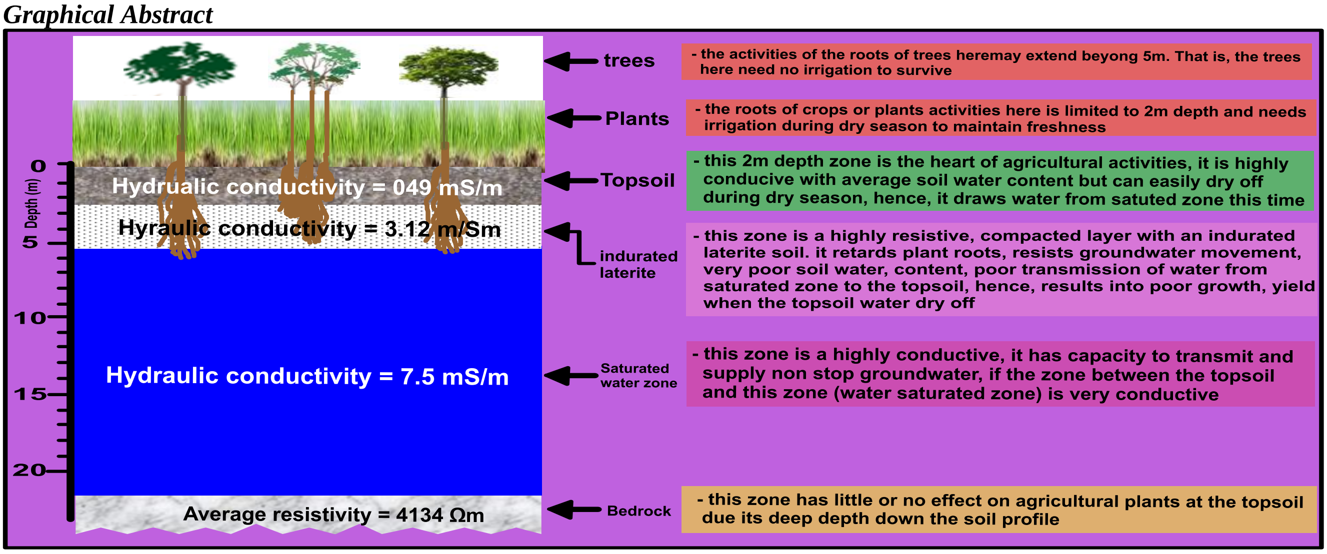
Abstract *- The data acquired and interpreted across the sixty (60) VES points of the study was used to evaluate the agricultural viability of the land. The terrain is underlain by four to five geologic layers comprised of topsoil (of average resistivity of 320Ωm), which is the heart of agricultural activities. The soil conductivity was evaluated from the first three layers with an average conductivity value of 3.13, 0.49 and 7.5 for the first, second and third layers respectively, all measured in milliSiemens per meter (mS/m). This implies high soil water content (SWC) which is the major factor that affects crop growth. However, the impermeable clay second layer between the topsoil and the saturated zone could resist the groundwater movement and the penetration of the roots down the soil, which suggest a poor environment for the growth of roots due to its poor SWC, the 2m depth topsoil is good enough for crops activities. However, the presence of impermeable clay implies poor soil water content and it has an advantage due to its ability to resist the infiltration of subsurface contaminants thereby increasing the protective capacity of the area aquifer.*

Keywords *- Agricultural viability, Soil conductivity, Soil water content, 2m depth topsoil.*

Highlights

- *Electrical properties of soil is a function of soil water content*
- *Soil water content provides an overview behavioural characteristics of roots and crops*
- *The degree of electrical conductivity defines the degree of roots penetration*
- *Soil porosity, moisture and density is a function of electrical conductivity*
- *Impermeable soil defines the limiting factors of groundwater transmission mechanism and roots penetration*
- *Saturated zones provides an addition support for groundwater transmission mechanism*

Graphical Abstract



- the activities of the roots of trees heremay extend beyong 5m. That is, the trees here need no irrigation to survive

- the roots of crops or plants activities here is limited to 2m depth and needs irrigation during dry season to maintain freshness

- this 2m depth zone is the heart of agricultural activities, it is highly conducive with average soil water content but can easily dry off during dry season, hence, it draws water from satuted zone this time

- this zone is a highly resistive, compacted layer with an indurated laterite soil. it retards plant roots, resists groundwater movement, very poor soil water, content, poor transmission of water from saturated zone to the topsoil, hence, results into poor growth, yield when the topsoil water dry off

- this zone is a highly conductive, it has capacity to transmit and supply non stop groundwater, if the zone between the topsoil and this zone (water saturated zone) is very conductive

- this zone has little or no effect on agricultural plants at the topsoil due its deep depth down the soil profile

I. INTRODUCTION

Human kinds often paid much attention majorly to non-life sustainable things but paid little or no attention to the main living pre-requisite. As one of the oldest occupations, agriculture remains the key to nation-building, poverty alleviation, and economic recovery across the world. Though, there are many factors according to UKEssays, (2018), that affect the fertility of agricultural land and produces. These factors include; the parent material, soil age, soil texture, soil erosion, soil nutrient, climate, water retention capacity, soil topography, soil profile depth, soil moisture and soil electrical conductivity. According to Reza, (2010), agricultural geophysics involves the determination of subsurface resistivity to identify and evaluate the subsurface flow pathways, soil compaction, soil water content, soil conductivity evaluation within the shallow depth of 0 to 2m of the topsoil, since the topsoil is the heart of agricultural activities. Based on this fact, this work employed electrical resistivity to exploit the electrical soil conductivity, soil moisture and the depth of soil profile as well as using a global position system (GPS) to determine the soil topography as applied to agricultural development. This is because Geoelectric resistivity depends on lithology, porosity, and pore ions concentration, water and air content in the soil (Telford, et al., 1990). Studies have shown that there is a strong relationship between the soil moisture, soil profile depth, soil conductivity and agricultural land fertility; because the process of water infiltration is an important factor to the agriculturist and hydrologist (Dorcas, and Michael, 2014; Yusof, et al., 2017; Aigbedion and Salufu, 2021). For instance, soils on the upper slope are less productive than the soils on a gentle slope or plain land because the soil on the upper slope is heavily affected by leaching and erosion UKEssays, (2018). Deeper soils (depth of soil profile) are more productive compared to the shallow soils because deeper soil allows the roots of plants to spread well enough to draw nutrients and water (Reza, 2010; UKEssays, (2018). Soil electrical conductivity is another important factor that affects crops because it measures the soil salinity (the presence of major dissolved inorganic solutes in the soil aqueous phase such as; Na^+, K^+, Mg^{+2} etc) and the amount of moisture in the soil (UKEssays, 2018; Mutair et al., 2018; Aigbedion and Salufu 2021; Christos, et al., 2022). Soil salinity is an important indicator of healthy soil because it affects crop viability, crop yields, and activity of soil micro-organisms which influence key soil processes (UKEssays, 2018); Yusof, et al., 2019). While (Aboh, et al., 2016; Alao and Dogara, 2018; Alao, et al., (2019), agreed that, the degree of hydraulic conductivity value is a measurement of its soil water content (SWC), the recent studies have shown that the SWC is a measurement of its agricultural viability and the crops yielding, since (Reza, 2010; Dorcas and Micheal, 2014; UKEssays, 2018; Aigbedion and Salufu 2021; Yusof, et al., 2019). This is because SWC is one of the prominent factors that affect agricultural production as it controls all other important physicals, biological and chemical processes like plant growth, solute transport, rainfall, runoff, and erosion. According to (Reza, 2010; 2014; UKEssays, 2018), geophysics is a vital tool used in solving the Earth’s subsurface challenges and the involvement of geophysics in agricultural development in the last decade has become a promising approach (Reza, 2010; Dorcas and Micheal, 2014). This work focuses on the application of geophysical resistivity to measure the soil water content with apparent soil electrical conductivity to predict the viability of the study area for agricultural purposes

A. Physical Factors Affecting Soil Fertility

The most limiting factor that affects agricultural productivity is soil fertility (UKEssay, 2018). Soil fertility is a function of soil conditions such as physical, chemical and biological properties. Agricultural geophysics (Agro-geophysics) investigations usually focus on the physical properties some of which influence soil fertility greatly (Bitella, 2015; UKEssay, 2018; Romero-Ruiz, 2019; Garré, 2021). To manage soil fertility and the selection of agricultural land, knowledge and understanding of these properties are required. According to Bitella, (2015); UKEssay, (2018); Romero-Ruiz, (2019). Soil electrical conductivity is one of the most powerful limiting factors that affect soil fertility because it controls the other factors such as soil porosity, soil density, soil topography, soil age, soil texture, soil nutrient, soil erosion, climate, soil profile depth as well as SWC. The SWC describes the soil moisture as well as the water-retentive capacity. The water retentive capacity, otherwise known as water holding capacity (WCH), defines the quantity of water that the soil can store for use by plants through their roots (Bitella, 2015); UKEssay, 2018; Garré, 2021).

B. Site Geology and Description

Kujama is located in Chikun LGA of Kaduna state with a vast grassland characterized by gentle slopes and peneplains which are often capped by layers of indurated laterites (Fig. 1). Kujama has a prominent agricultural land which has attracted the presence of Kujama prison farm, Kaduna hatchery and Kujama multi-purpose farms company, Kokau, founded on November 3, 2014, along Kachia Road, Kaduna. Kujama like other parts of Kaduna State; is drained by both surface water and groundwater with a dendritic drainage pattern (Alao, 2017; Alao and Dogara, 2018; Oyawoye, 1970; Danlami, et al., 2019; Kure, et al., 2019; Dogara, et al., 2017). Fig. 1 shows the topography map and the contour map of the study area showing its elevation as well. The study area lies on the geographical coordinates of latitude and longitude $10^0\ 26'\ 36''$N and $07^0\ 32'\ 36''$E and covers a total landmass of 550,000 square meters with an average height of 662 m above the sea level. According to [10-17], the study area is a crystalline basement complex with metamorphic rocks and the main aquifer components of the basement complex occur within the weathered, fractured basement. However, there exist some rock outcrops of hard resistant granite which usually result from the weathering activities of Precambrian rocks exposed by erosion (Aboh, 2016; Alao, 2017; 2018, 2022).

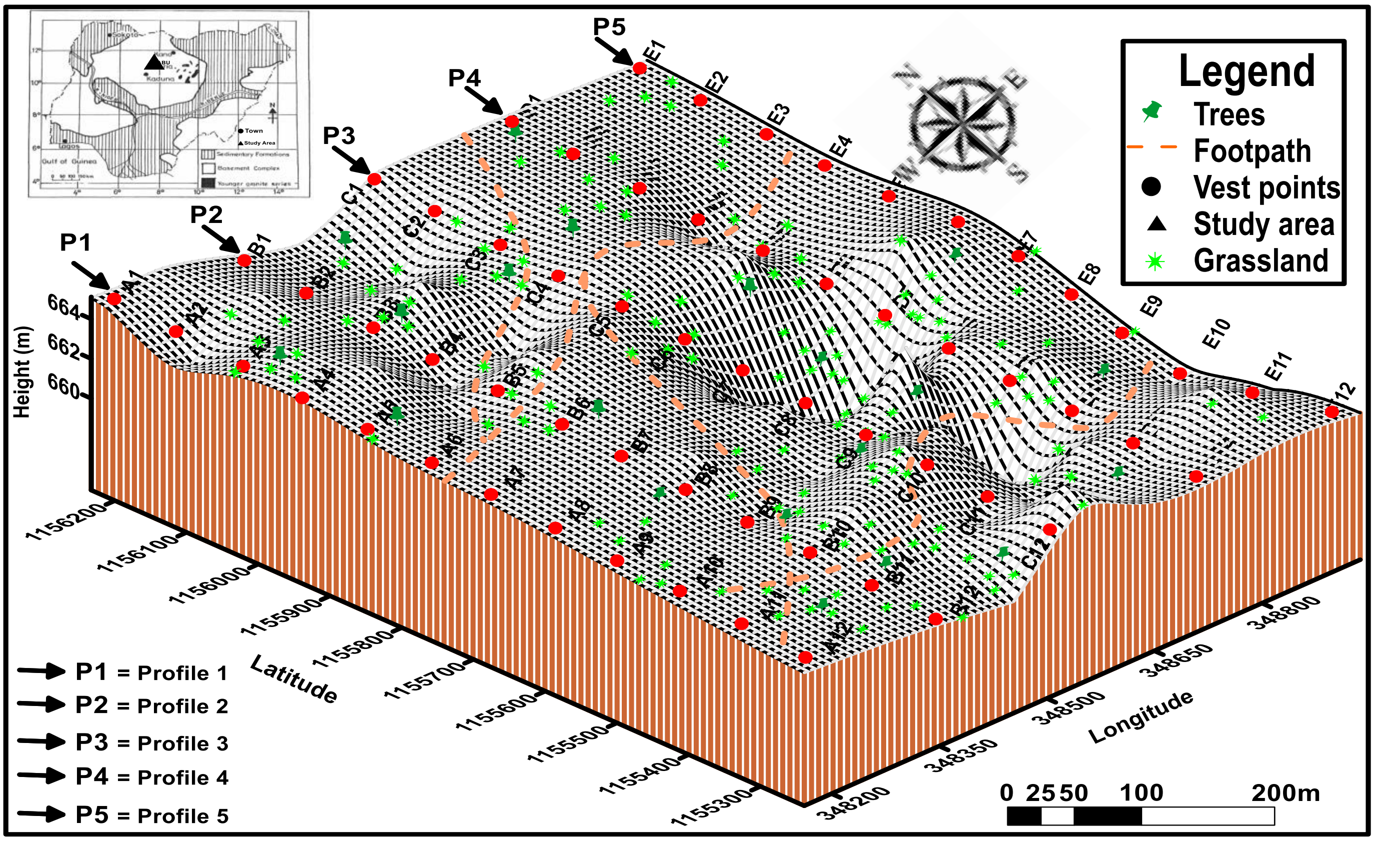


Fig. 1 Map of Study Area Showing the VES Points, the profiles and its Elevation

C. Materials and Method

Schlumberger array of maximum spread of 200m was adopted to acquire the subsurface resistivity distribution from sixty (60) vertical electrical sound (VES) points across the study area. It was done based on the principle of Ohm's law which is the fundamental law used in resistivity surveys that governs the flow of current in the ground (Alao, 2017; Alao and Dogara, 2018; Oyawoye, 1970; Danlami, et al., 2019; Kure, et al., 2019; Dogara, et al., 2017). According to Ohm's Law:

$$V = IR \qquad \Rightarrow R = \frac{\Delta V}{I} \tag{1}$$

The subsurface materials respond to the current flow through the ground (Telford, et at, 1990; Loke, 2000, Alao, 2017, 2019; Dogara and Alao, 2017). That is:

$$R = \frac{\rho_a L}{A} \quad \Rightarrow \rho_a = \frac{RA}{L} \tag{2}$$

From the Schlumberger array, geometry factor K which depends on the arrangement of the four electrodes is defined in Fig. 2 as:

$$K = \frac{A}{L} = 2\pi\left[\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{R_A} - \frac{1}{R_B}\right)\right]^{-1} \tag{3}$$

Substituting Equation (1) and (3) into (2), we say:

$$\rho_a = \frac{RA}{l} = \frac{2\pi\Delta V}{I\left[\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{R_A} - \frac{1}{R_B}\right)\right]} \tag{4}$$

Where R is resistivity and ρ_a is apparent resistivity. Therefore:

$$\Rightarrow \rho_a = RK \tag{5}$$

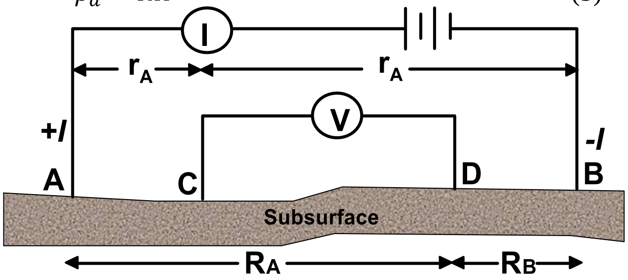


Fig. 2 Schlumberger Configuration for

D. Soil Conductivity

Apparent soil conductivity (σ_a) describes the ability of a soil to conduct (transmit) an electrical current (liquids) vertical or horizontally through the ground (Loke, 2000; Alao, 2017), and it is commonly expressed as:

$$\Rightarrow \sigma_a = \frac{1}{\rho_a} \tag{6}$$

E. Data Processing

To investigate the subsurface structural trends and soil profile sequence of the subsurface formation in the study area (Alao, 2017). The acquired data was qualitatively interpreted with the use of computer Iteration software (*Res ID version 1.00.07 Beta*). Res1D is automatic computer software that determines the resistivity model for the subsurface data obtained from the electrical survey, Alao, 2017; Kure, et al., 2019; Dogara, et al., 2017). Fig 3 is a typical example of a resistivity curve obtained from Res ID version 1.00.07 Beta for VES point A3 along profile A. consequently, the model resistivity parameters obtained from RED 1D were further used to generate the Geoelectric and geology section presented as Fig 4-8.

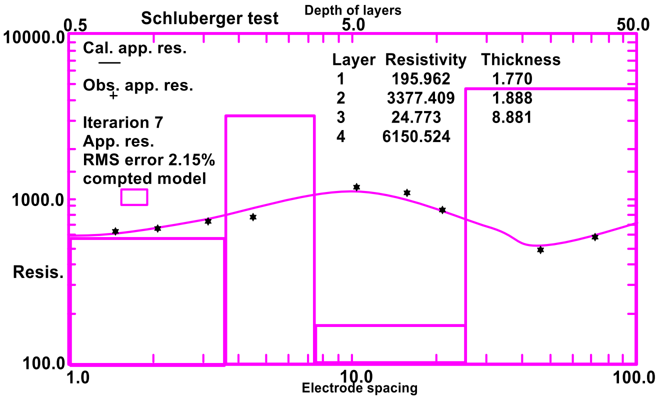


Fig. 3 Resistivity curve for Profile A: VES A3

III. RESULTS AND DISCUSSION

The result and discussions of this work were explained in three phases as follows:

A. Geoelectric/geology Section

The geoelectric and geologic section (Fig 4-8) is the soil profiles of the study, which according to (Alao, 2017, 2022; Dogara et al 2017), explains the earth's subsurface electrical properties with the sequence of layered rocks. This section provides us with geology resistivity layered values and its thickness, which were used to evaluate the agricultural viability of the study area. The result reveals that the study area is underlain by three to four layers with the composition of lateritic topsoil (first layer), indurated laterite/clay/silty/sand (second layer), weathered-fractured layer (third layer), identified as the saturated zone and the fresh basement (last layer). However, the fresh basement is excluded from Fig 4-8 because it is not needed for this research. This was done according to Reza, (2010), UKEssays, (2018), Mutar, et al., 2018; Aigbedion and Salufu 2021), which are of the view that the last layer does not contribute anything meaningful to the crop growth and viability of agricultural land. The average top layer resistivity and thickness have a resistivity value of 320 Ωm and 1.5 m respectively. This implies that the land is very good for agriculture except that the topsoil layer is preceded by a highly resistive indurated and compacted layer with an average resistivity of 3502 Ωm and an average thickness of 9.5 m. However, this resistive layer could provide a resistive cover to the groundwater against surface contamination (Alao, 2017, 2018, 2022; Ramaraju and Krishna, 2017; Fatima et al., 2022; Oyewumi et al., 2019), but this may not be suitable for agricultural land due to its poor conductivity and SWC. This implies that; the resistive layer between the topsoil and the saturated region would resist the groundwater transmission from the saturated region to the topsoil; since agricultural geophysics focused her interest and investigations on the 2m depth topsoil which is the heart of agricultural activities (Reza, 2010; UKEssays, 2018). The poor groundwater transmission could result in poor SWC during the dry season when the topsoil moisture must have dried off. According to (Reza, 2010; UKEssays, 2018; Ali et al., 2022; Christos, et al., 2022), the plants on the topsoil usually draw water from the saturated zone, but the presence of this highly compacted and resistive second layer would limit the process of groundwater transmission, since, studies have shown that, no matter how fertile an agricultural land is, it cannot yield well; if the soil water content and hydraulic conductivity is very poor (Christos, et al., 2022; Dorcas and Michael, 2014; Aigbedion and Salufu 2021).

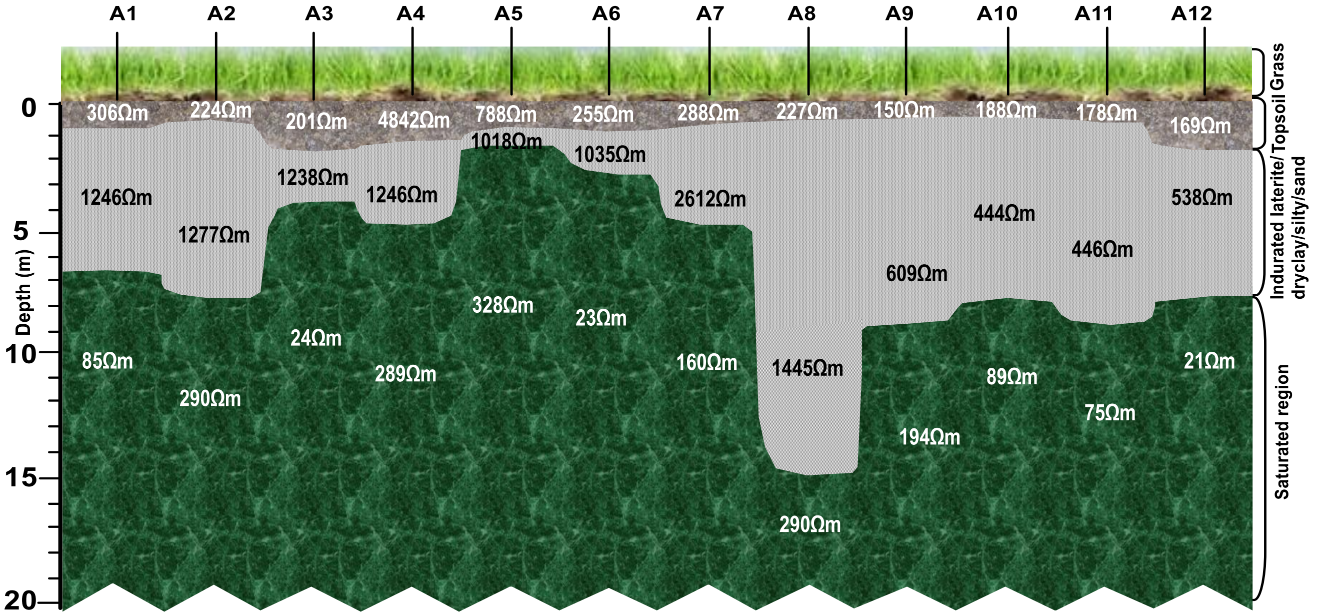


Fig. 4 Geoelectric / geologic section of profile A

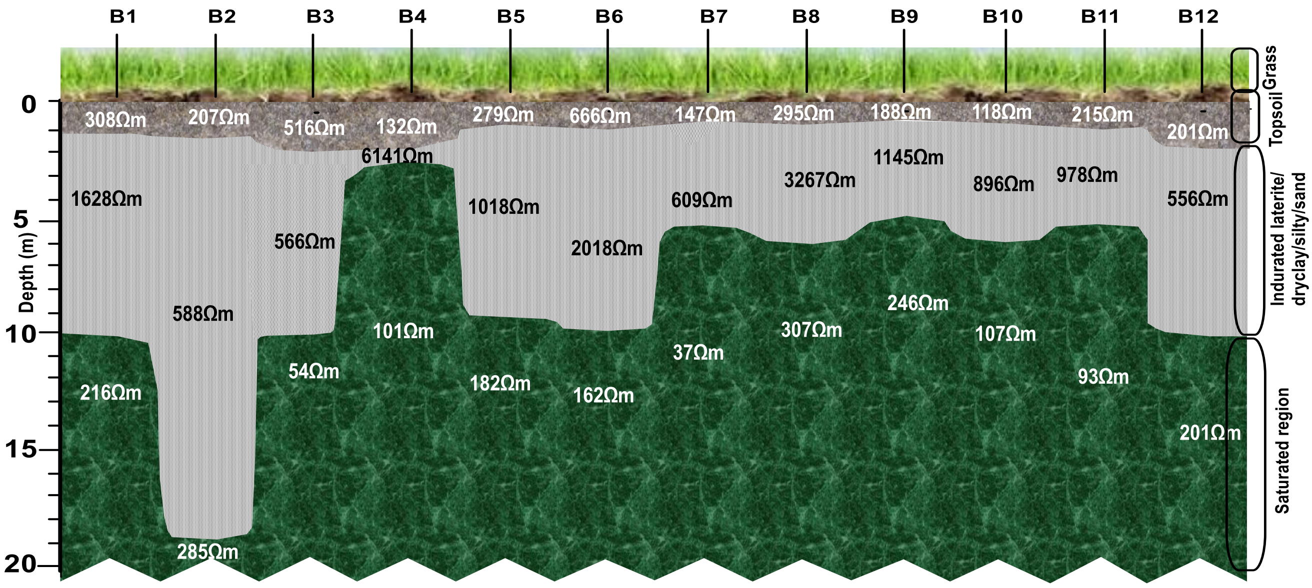


Fig 5. Geoelectric/geologic section of profile B

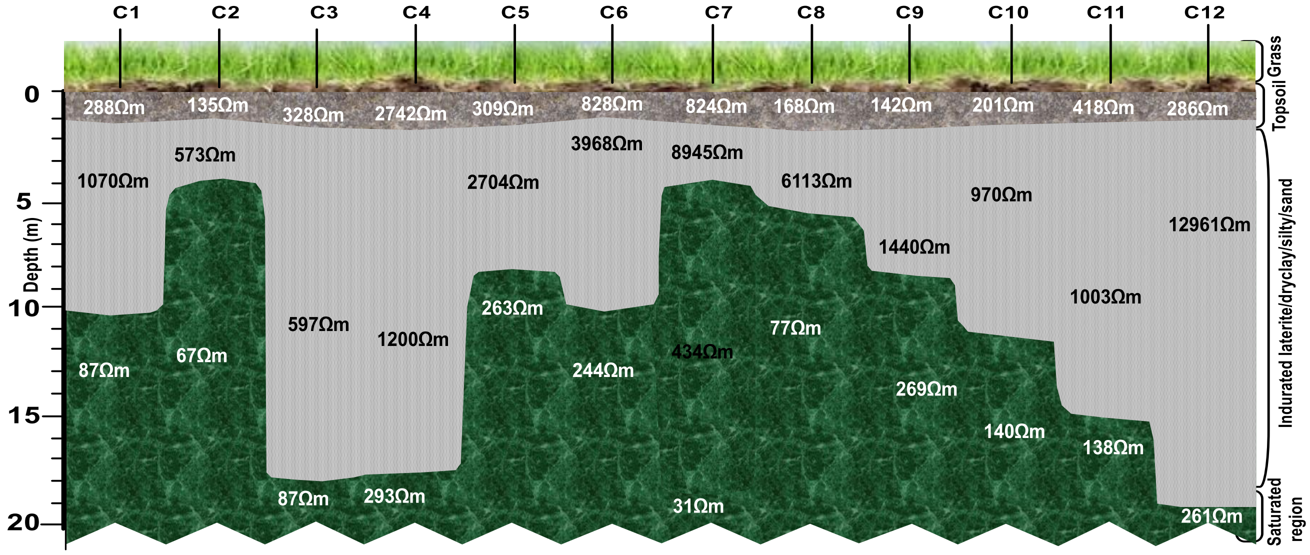


Fig 6. Geoelectric/geologic section of profile C

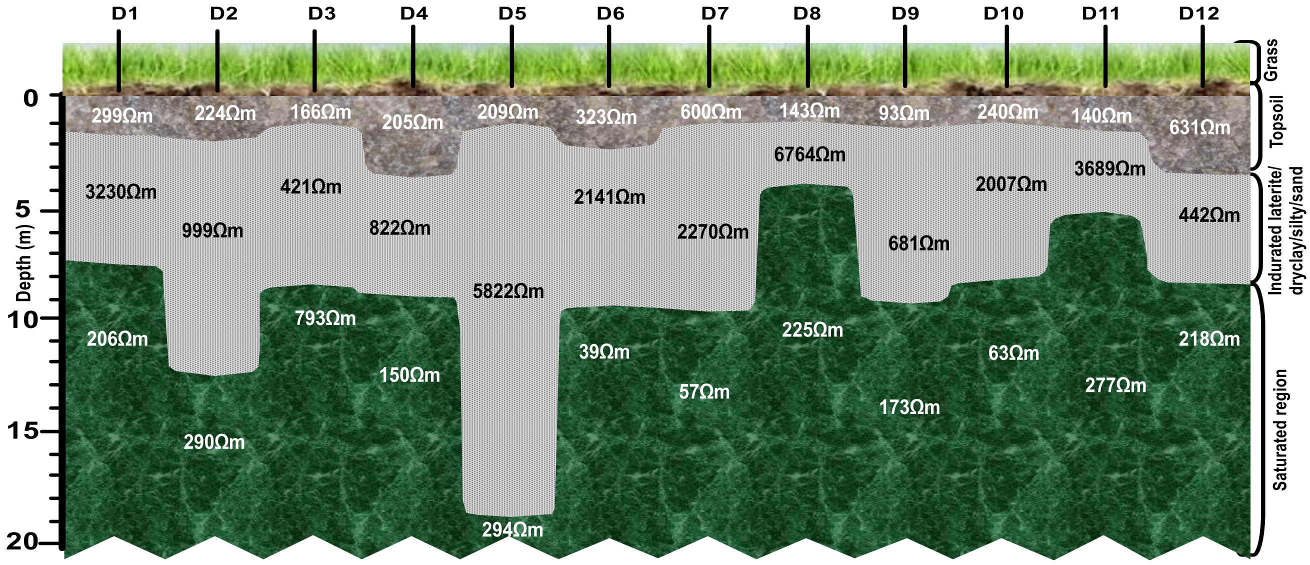


Fig 7. Geoelectric/geologic section of profile D

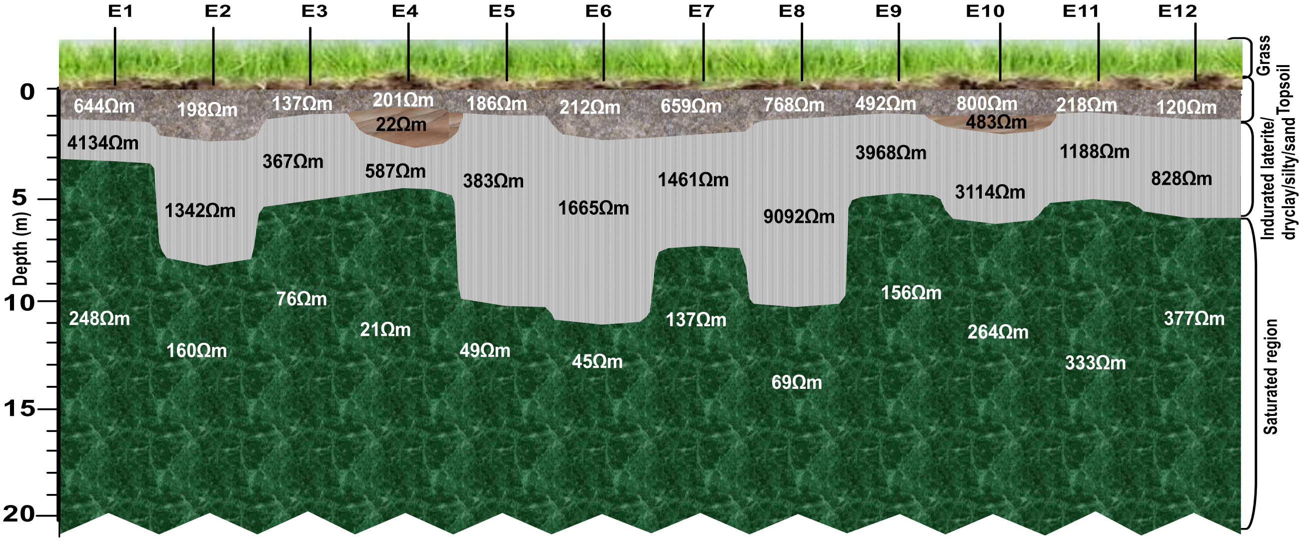


Fig 8. Geoelectric/geologic section of profile E

B. Evaluation of Soil conductivity, Soil water content and Agricultural Produces

The soil conductivity of the terrain was evaluated from the first three layers since most agricultural activities take place at the 2m depth topsoil (Dorcas and Michael, 2018; UKEssays, 2018). The study area has its topsoil layer, laterite/clayey layer and saturated layer with approximate conductivity values of 3.13, 0.49 and 7.5, all measured in milliSiemens per meter (mS/m) respectively. A highly compacted soil can impede the groundwater movement down to the roots and the penetration of the roots down in the soil (UKEssays, 2018; Christos, et al., 2022). The layer that preceded the topsoil of the terrain is highly resistive; and compact, and it implies a poorer environment for root growth. This layer of impermeable clay that formed between the topsoil layer and saturated zone not only hinders the growth of root and groundwater movement but also implies poor soil water content. However, this layer has an advantage due to its ability to resist the infiltration of subsurface contaminants, thereby offering to increase the protective capacity of the area aquifer according to Alao, (2018); Ramaraju and Krishna, (2017); Alao, (2022).

IV. CONCLUSION

The data acquired, interpreted and evaluated across the sixty (60) VES point of the study area is underlain by four to five layers with the first, second, and third layers having the resistivity of 320Ωm, 3502 Ωm and 134 Ωm on the average. The topsoil layer of the study area which is the bedrock and heart of the agricultural practice is very conductive and suitable for agricultural practices. However, the presence of a highly resistive and compacted indurated laterite/sand layer that formed between the topsoil and the saturated zone; may hinder the easy groundwater movement and the growing plant roots down to the deep soil profile could provide a poorer environment for agricultural practices. Also, the poor transmission of groundwater from the saturated zone to the topsoil could result in poor soil water content and consequently poor agricultural production. Therefore, the study area is recommended for irrigation farming to bridge the gap during the dry season. The dc resistivity as one of the Geophysics techniques has proved very successful in the identification and delineation of viable land for agricultural activities.

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The author wishes to acknowledge the support of Kujama prison farmworkers, Kujama multi-purpose farms company workers and the people of Kujama for providing enabling environment for this work.

DECLARATION OF CONFLICT INTEREST

In compliance, I hereby declare that there is no conflict of interest in this research work. All information provided in this work has been duly acknowledged in the text and the references provided. No part of the work has been previously published in any journal.

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