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RESEARCH PAPER

# Assessing the Spatial Patterns in Soil Properties Which Strongly Influences High Crop Yields, Through Electrical Resistivity Method, in Mokwa, Niger State, Nigeria.

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## ABSTRACT

The escalated population, booming agricultural productions and marketing activities in Mokwa area brought about unending agricultural land-use, soil and water quality challenges among others. The Mokwa sedimentary exploration for clean soils and groundwater for plants with maximized economic convenience thus became paramount using efficient Geophysical methods. Electrical Resistivity survey adopting Wenner Profiling array and 2-D imaging was used to investigate the spatial-variability in physical properties of subsurface-soil and groundwater at College of Agriculture Mokwa Farm (latitude 9o18' N and longitude 5o04' E), southern guinea savanna zone, Nigeria. Delineated were; geologic features (claystones, sandstones and conglomerates), weathered basement, fresh basement, fractures, horizontal spatial patterns indicated low resistivity zones <26 Ωm in soil properties near the top horizon identified as viable and potentially high-quality and maximum crop-yielding zones. Shallow aquifer and water-table zones at the depth of 6.75 m at points GW (profiles 3 and 4), water-flow patterns and viable areas for locating agricultural infrastructural facilities with highest resistive zones >924 Ωm (Profiles 2 and 5) at farm were among the discoveries with practical economic compromise between the obtained results quality and low survey costs, thereby proving the geophysical method's convenience. Geophysical methods adoption in agricultural soil/plant researches were among the recommendations based on their conveniences in quick-extensive data measurement without soil disturbance, modeling/interpretations and possibility of assessing growing plants in its natural conditions.

**Keywords**: Agricultural land-use, profiling mode, spatial-variability, viable locations, aquifer zones.

## INTRODUCTION

The unprecedented increase in population and commercial activities within Mokwa area and its environs have persistently caused unending agricultural land-use problems and great demand for groundwater. This constitutes a challenge to the quality of humans' and plants' health as well as the entire environment. The high potential of Mokwa sedimentary environments for agricultural activities and viable farm infrastructural facilities emplacements, which are very vital for a buoyant national economy, has not been explored. Studies on such permeable clean soils that are capable of yielding useful qualitative and quantitative groundwater to domestic wells, streams/rivers and agricultural crops which are very important, most especially, considering its very crucial life dependence role in relation to both human and plants' health had also been scarce so far.

Geophysical Surveys today, thus encounter challenges ranging from the most immediate needs of the society with a vast growing population, to the reduced and availability of important resources. Pursuing sustainability plays a key role and requires knowledge of environmental mechanisms and the ability to monitor the impact of strategy implementation.

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The issue of sustainable agriculture best identifies the relationship between agriculture and environment, with the specific mandate of producing sufficient qualitative food and raw materials among others. These are to be achieved within acceptable environmental costs, management of difficult environments, preserving and enhancing the amount and quality of the environmental resources. The integration of these environmental interests and challenges into agricultural policy was the key strategy for enhancing the sustainability of agro-ecosystems (EEC report, 2013). This relationship is more evident if we consider the increasing frequency of the climate-related hazards and the role of agriculture in the climate adaptation strategies as contained in IPCC Report (Fifth Assessment Report, 2014).

The scene where agricultural lands use and environmental processes meet is the soil which is the thin upper part of the Earth (the Crust). It also represents one of the more complex systems in which lithosphere, hydrosphere, and biosphere interact and are strongly linked. The thickness of the zone beneath the Earth surface that is of interest for agriculture falls within the range of 0–2 m. This brings about a growing demand for near-surface observing technologies for studying a wide spectrum of phenomena in the soil having implications on both agriculture and environment.

Geophysical methods such as electrical resistivity, induced polarization, self-potential, ground penetrating radar, e.t.c., address all these challenging themes with latest observing technologies based on completely innovative sensors, advanced algorithms for 1-D, 2-D and 3-D tomography imaging using computer software, and new technologies for field surveying. Today, conveniently and efficiently, geophysical methods provide a set of robust, cost-effective, and completely noninvasive or minimally invasive technologies for near-surface investigations able to estimate the physical properties of the shallow layers of soil and subsoil required by both agricultural and environmental quality assessments. Such technologies had also been used for the acquisition of information that can be directly used for the description and monitoring of relevant subsurface features or can guide strategies for sampling (Rossi, *et al.* 2011).

One of the most challenging issues in Agro-ecosystem, particularly interest of the College of Agriculture Mokwa in practicing precision agriculture, is the development of site specific principles for the crop management based on the variability of soil and hydrological properties. Accessing this spatial variability of soil properties through the usual classical methods of destructive, single-point measurements for inspecting soils normally require high-density and repetitious sampling techniques which are too costly, time-consuming, and labor-intensive. Another very crucial challenge on the adoption of precision agriculture technology generally is the identification of productivity-related variability of soil properties in addition to positioning the agricultural infrastructural facilities in their viable locations accurately and cost-effectively.

This Study was therefore, planned to:

i. Create a reference database on the subsurface environment, at the College farm site which will greatly influence the crop yields with economical convenience.
ii. Promote agricultural practices within and outside the study area.
iii. Protect the agricultural soil and groundwater resources, public health and environment.
iv. Complement the future surveys at the study area.

These would be achieved using Geophysical Method of Electrical Profiling to determine the soil and water Quality in addition to mapping out the viable locations for farm infrastructural facilities at the College of Agriculture New Farm site Mokwa, Nigeria. The specific objectives are:

i. Delineation of the horizontal spatial patterns in soil and hydrologic properties that strongly influence maximum crop yields.
ii. Provision of detailed Farm Site Map indicated different partitions within the farm based on the spatial variability in the soil and hydrological properties.
iii. Determination of the geo-electric formations and possible subsurface structures around the farm sites.
iv. Determination and mapped out viable locations for emplacing farm buildings and hydrological infrastructures.

Several authors have used electrical resistivity and other geophysical methods to map out agricultural lands in Nigeria which affirms the efficacy of the applications of geophysical methods within a number of different Agro ecosystems. Results from some of such studies by Barry and Hamid (2012) from the Correlation of Soil Electrical Conductivity (EC) and Crop Yield were a clear testimony of the efficacy of EC method in use for agricultural application. The EC Maps were correlated with Yield Maps obtaining the result which indicated a very strong Correlation between Soil EC and Crop Yield. It was noted that, soil EC maps usually indicate areas where further exploration was needed and most importantly, the soil EC maps gave valuable information on soil differences and similarities that thus made it possible to partition the field into smaller management zones. The influence of soil moisture content on electrical conductivity and its relationship to the growth rate of maize crop was also investigated by Ezeoke(2014)using Miller 400D digital resistance meters in Wenner electrode array configuration. The result indicated that areas with high electrical conductivity or low electrical resistivity in the area coincided with areas where there were abundant moisture content. Also, maize plants located at these points had better growth rate than those located in the area of depleted moisture content which coincided with area of lower electrical conductivity or higher electrical resistivity. 2-D imaging involving geo-electrical resistivity and time domain Induced Polarization (IP) supported by physicochemical method had been used by Ahzegbobor (2014) to assess the spatial variability of the physical properties of subsurface soil. The results showed that soil salinity level was within the range 2 - 4 dS/m for normal soil and therefore healthy for plant growth. The inverse model sections were integrated with the laboratory test to qualitatively assess soil salinity, degree of compaction (bulk density), and depth. Other soil properties such as clay volume, moisture content and organic matter which are related to soil conductivity were also inferred to be normal.

## METHODOLOGY

### Site description

The entire study area is the College of Agriculture New Farm Site Mokwa. It is located between latitudes 9°20.215′ N and 9°20.276′ N and longitudes 5°02.171 ′E and 5°02.137′ E. The farm site covers an area of about 200 $m^2$. The topography of the area is relatively flat.

Mokwa area is situated within the Mid-Niger Basin otherwise known as the Bida Basin or the Nupe Basin which is a NW–SE trending intracratonic sedimentary basin extending from Kontagora in Niger State to areas slightly beyond Lokoja in Kogi State. It is delimited in the northeast and southwest by the basement complex while it merges with Anambra and Sokoto basins in sedimentary fill comprising post orogenic molasse faces and a few thin unfolded marine sediments (Obaje *et al.*, 2011). The basin is a NW–SE trending embayment, perpendicular to the main axis of the Benue Trough and the Niger Delta Basin. Interpretations of Land-sat images, borehole logs, as well as geophysical data across the entire Mid-Niger Basin suggest that the basin is bounded by a system of linear faults trending NW–SE (Ajibade *et al*., 1989). Gravity studies also confirmed central positive anomalies flanked by negative anomalies as shown for the adjacent Benue Trough and typical of rift structures (Udensi and Osazuwa, 2004).

Mokwa is underlain by sedimentary terrain consisting of essentially claystones, sandstones and conglomerates of Campanian to Maastrichtian age and basement complex rocks comprising of migmatites gneiss, quartzite complex, granitoids and minor acid dykes which had different water retaining capacities all year round (Obaje *et al*., 2011) and (Amadi *et al.*, 2010). The sedimentary rocks to the southern Niger State are characterized by sandstones and alluvial deposits, particularly along the Niger valley and in most parts of Borgu, Bida, Agaie, Lapai, Mokwa, Lavun, Gbako and Wushishi Local Government Areas where the study area is geographically located (Figure 1.0). To the north is the basement complex, characterized by granitic outcrops or inselbergs which can be found in the vast topography of rolling landscape. Such inselbergs dominate the landscape in Rafi, Shiroro, Minna, Mariga and Gurara in Niger State.

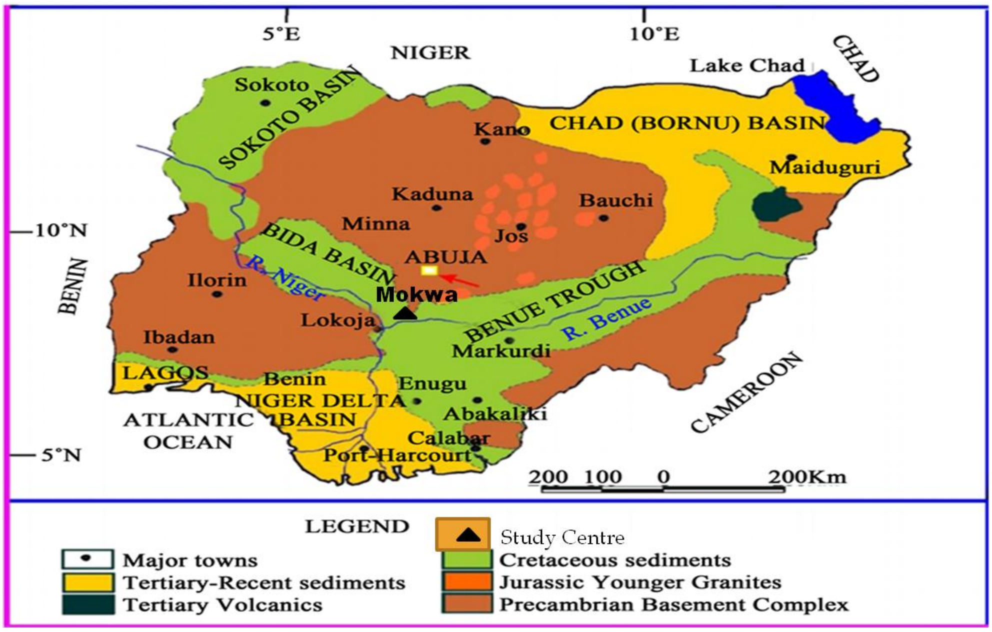


Figure 1.0: Study Location and Geology of Niger State (Geology Department, Federal University of Technology, Minna).

## Field Procedure

Electrical Profiling (EP) method with Wenner array was used to determine the horizontal or lateral variations of resistivity at the farm site. In the Wenner array configuration (Figure 2), the spacing between successive electrodes (**a**) remained constant and all electrodes were moved for each reading, this method was more susceptible to near surface and lateral variations in resistivity and it is sometimes called horizontal electrical profiling. The four electrodes were collinear and the separations between adjacent electrodes were equal (**a**) with MN in between AB as shown in Figure 2. The choice of this electrode spacing was primarily based on the depth of the anomalous resistivity features (high crop yielding and farm infrastructural viable locations) to be mapped (Sharma, 1997). The apparent resistivity with Wenner array configuration is written in the form of equation (1):

$$\rho = 2\pi \mathbf{a}\Delta V / I \qquad (1)$$

Where: **ρ** is the apparent resistivity, **2πa** is the geometric factor (K) and **a** is the electrode spacing, **ΔV i**s the potential difference and **I** is the electric current.

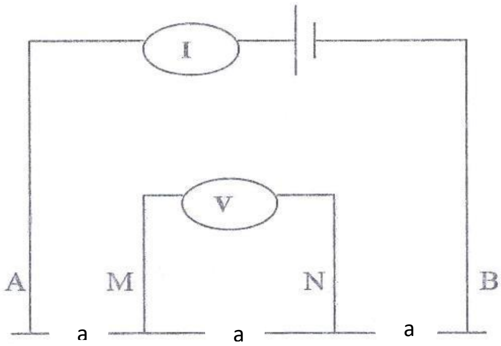


Figure 2: Geometry of current and potential electrodes for Wenner configuration..

## Data Collection

The field procedure was 2-D imaging involving Electrical Resistivity survey using Profiling mode with Wenner array where 5 profiles of 50 m inter profile spacing were occupied covering the total farm area of 200 $m^2$ to investigate the spatial variability of the physical properties of subsurface soil and groundwater using ABEM SAS Terrameter 4000 model (with appropriate electrodes, cables on reels, and other accessories) for the geophysical data acquisition. This portable instrument equipped with high signal to noise ratio and an in-built booster for greater depth of penetration was used to probe the maximum 200 m length for each of the profiles 1 to 5 and were traversed along North-South direction. The minimum electrode spacing of 5 m was used for the data measurements of up to 11 data levels generated and the maximum potential electrode spacing achieved for each of the profiles was 55.0 m. This minimum electrode spacing and data level reached was to ensure that the effective depth of investigation was confined to the root zone which is about 2 m in depth (al Hagrey, 2007), aquifer level and bed rock. The Apparent resistivity was then measured and recorded along the five traverses. The recorded data were thereafter further processed using RES2DINV computer package which yielded the 2-D inverse models of the subsoil resistivity.

## RESULTS AND DISCUSSION

The 2-D electrical images along the five profiles and their geologic interpretations are presented graphically in form of inversion results for each profile. Figures 3 to 7 shows the images of the pseudo-sections (geo-electric sections) obtained from the processed measured and calculated data. The results show three distinct images for each profile. The upper image is a plot of the measured (observed) apparent resistivity pseudo-section. The middle image is the calculated apparent resistivity pseudo-section and the lower image is the true resistivity model obtained after mostly three to six iterations of the inversion programme.

### Profile 1

Figure 3.0 shows the resistivity inversion results after 6 iterations with 8.2% total average RMS error for profile 1 at which the best fit between the measured and calculated apparent resistivity data were achieved. The dominantly low resistivity with high contrast ranged (41 – 127) Ωm were isolated near the surface at top horizon in points **A, B, C** and **D** along the profile at a depth ranged (0 – 3) m implied a saturated permeable claystones and sandstones with relatively high humus content and cat-ion exchange capacity and hence, a high density of mobile electrical charges (Obaje *et al.*, 2011) and (Amadi *et al.*, 2010). Conversely, this lowest resistivity values (< 41.9 Ωm) observed at points **A** and **D** with high moisture content is favorable to some agricultural crops and so could be earmarked for those higher moisture demanding crop types to guarantee maximum yields(Ezeoke, 2014). The delineated large contrast in electrical resistivity that resulted from high humus content and the ionic concentrations being much higher than that of the natural soil and groundwater, proved the suitability and the convenience of this geophysical method to soil and groundwater quality investigation. This facilitates the Precision Agricultural practices and those areas were identified as the viable and highest qualitative and higher crop yielding zones within the farm. This was a great contribution to the improvement of the management strategies aimed to improve and enhance the quality of the crop production (Rossi, *et al.*, 2013).

The underlying horizon with resistivity values ranged (130 – 1000) Ωm mostly consists of sandstones with very high groundwater potential which was supported by (Obaje *et al.*, 2011) and (Amadi *et al.*, 2010). The density of mobile electric charges was much lower in this horizon than that in top horizon and therefore, the resistivity at this horizon was higher. Color variations in the basement rock were indication of contacts between different rocks which was interpreted as fractured zones. The red color indicated the weathered sandstone and conglomerate basement having resistivity values from 1174 to 2046 Ωm with its depth ranging from 13.4 – 26.2 m. The purple color delineated at the bottom with resistivity value (>2050 Ωm) was interpreted as a fresh basement.

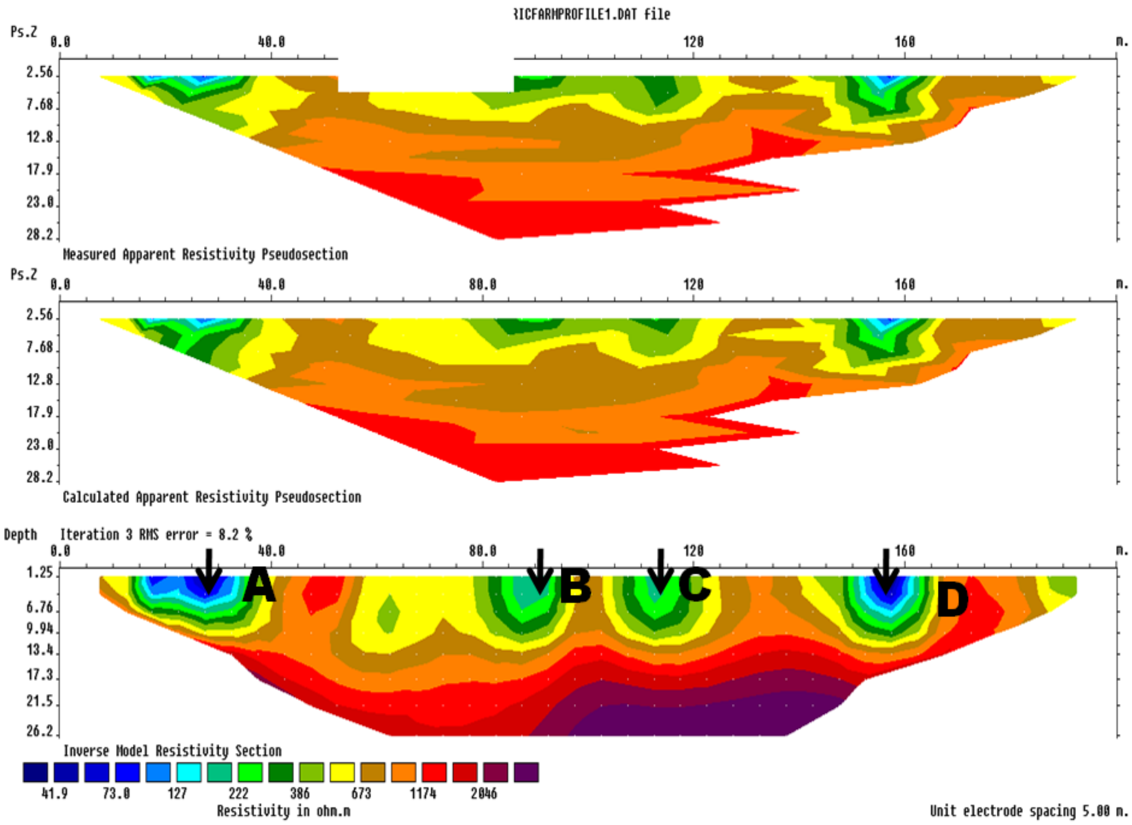


Figure 3: Result of 2-D inversion of the Wenner-array data along profile 1

**Profile 2**

In figure 4 the only very low resistivity zone was delineated at point **A** where the resistivity ranged (26 – 87.1) at a depth ranged (0 – 6.76) m which implied saturated and permeable claystones and could also be earmarked for the high water demanding crops. The dominant materials in the second geologic zones along this profile were moderately low resistive, implying sandstones with relatively low humus content and so favorable to some agricultural crops. The red color zone delineated at very shallow depth towards the beginning of the profile indicated a weathered sandstone basement having resistivity values ranged (924 – 1668) Ωm with its depth ranged (1.25 – 26.2) m. These horizontal zones ranged (70 – 200) m along the profile at points **F, G** and **H**, imply well sorted sandstones and conglomerates which can withstand heavy agricultural infrastructures and thus the zone is recommended for locating building structures. This is represented by red color with resistivity value (>1670 Ωm) which is an extension of the weathered basement delineated from profile 1.

**Profile 3**

Figure 5 shows the resistivity inversion results for profile 3 where dominantly very low resistivity doted the top horizon and it ranged (31.4 – 126) Ωm. These low horizons were isolated near the surface at top horizon in points **A, B, C, D** and **E** along the profile at a depth ranged (0 – 3) m imply a saturated permeable claystones and sandstones with relatively higher humus content and cat-ion exchange capacity and hence, a high density of mobile electrical charges. Conversely, the lowest resistivity values (<31.4 Ωm) imply higher electrical conductivity due to water / humus content which favors some agricultural crops, this agreed with observations by (Barry and Hamid, 2012). The underlying horizon with higher resistivity values ranged (504 – 1009) Ωm mostly consist of poorly sorted or very coarse and pebbly sandstones and conglomerates as observed by (Obaje *et al.*, 2011) and (Amadi *et al.*, 2010), with higher resistive horizon and lower density of mobile electric charges than that observed in the top horizon (indicated by color variations -

yellow, brown and red colorations) interpreted as fractured and aquifer zone with high groundwater potential which was free from any contaminant plume with very shallow water table at the depth of 8 m which fall within the range of (0.9 to 18.2) m observed by Olusola *et al.*,(2012) for the same study area. The delineated red color at the basement rocks was interpreted as weathered basement of sandstones and conglomerates with resistivity value ranged (2020 – 4045) Ωm and depth ranged (12.0 – 26.2) m while the purple color at the bottom (>4050 Ωm) is a fresh basement (Asuerimen, 2008).

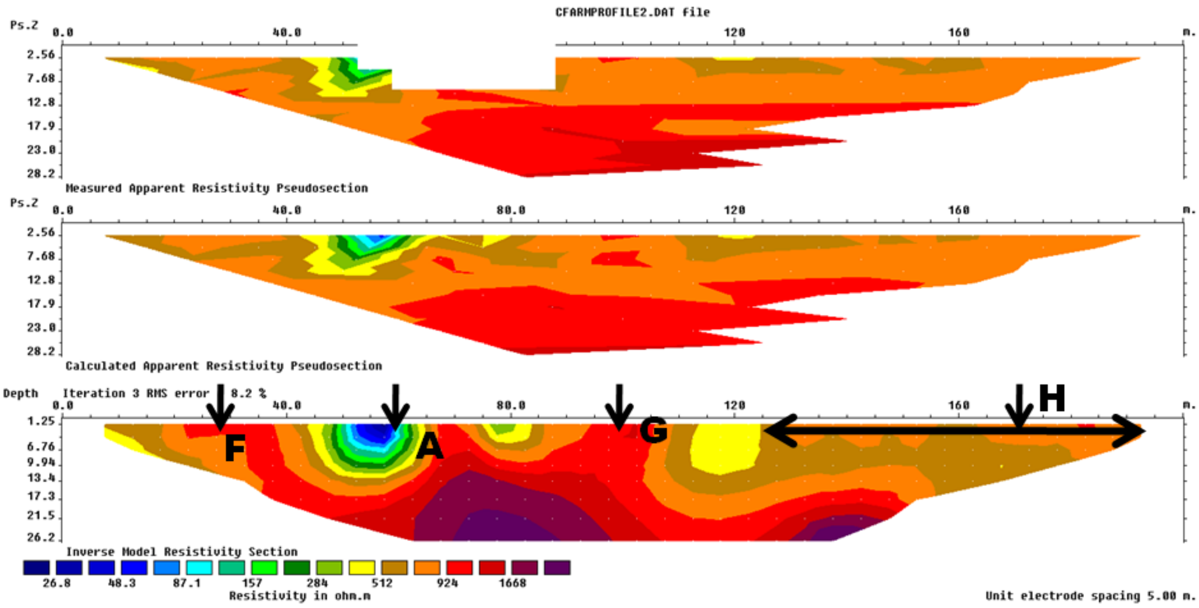


Figure 4: Result of 2-D inversion of the Wenner-array data along profile 2

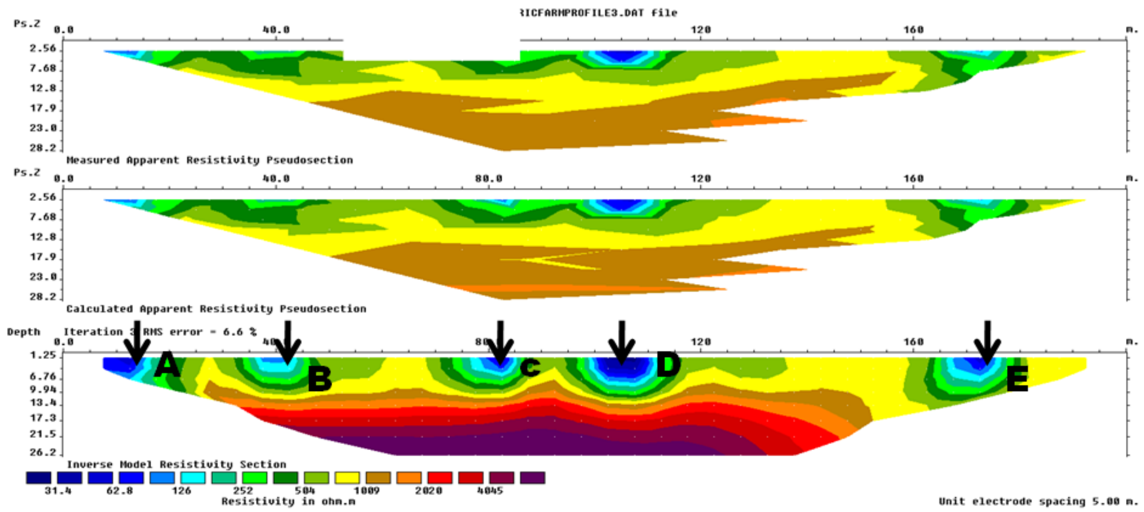


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Figure 5: Result of 2-D inversion of the Wenner-array data along profile 3.

**Profile 4**

The resistivity model for profile 4 (figure 6.0) showed evidence of moderately high electrical conductivity observed laterally up to about 164 m wide along the profile from the topsoil down to a depth of 26.2 m as indicated by the resistivity zone of (241 – 477) Ωm which was inferred as bleached saturated sandstone grains with high humus content strategically at points **A, B, C** and **D** with depth ranged (1.25 - 17.3) m. This horizontally and vertically delineated spatial conductivity patterns in this agricultural soil along this profile were among the very influential soil properties that could strongly influences the crop yields in this farm as indicated by its high potential for quality soil and groundwater (at point **GW)** in addition to the more economically very shallow water table depth (6.75) m. The south – north direction trends in this model imply that groundwater flows in S – N direction. This understanding of the subsurface water flow patterns will definitely facilitate the adequate and sustainable agro-ecosystem planning, monitoring and management at the college farm for maximum output and soil quality standard. The delineated dominantly moderate high apparent resistivity zone (478 – 1322) Ωm from the top soil down to depth of 26.2 m across the profile was indicative of a soil texture mostly believed to consist of saturated sandstone with the density of mobile electric charges much lower than that in top horizon and therefore indicate aquifer zone with a very high groundwater potential due to the traces of fractured zones around the varying green colorations which is free from any contaminant plume. The delineated red color variations in the basement rocks was also interpreted as the partially weathered sandstones and conglomerates basement which is highly resistive (1857 – 2689) Ωm with depth ranged (13.4 – 26.2) m, while the purple color at the bottom was interpreted as fresh basement and is the most resistive zone with values (>2689 Ωm).

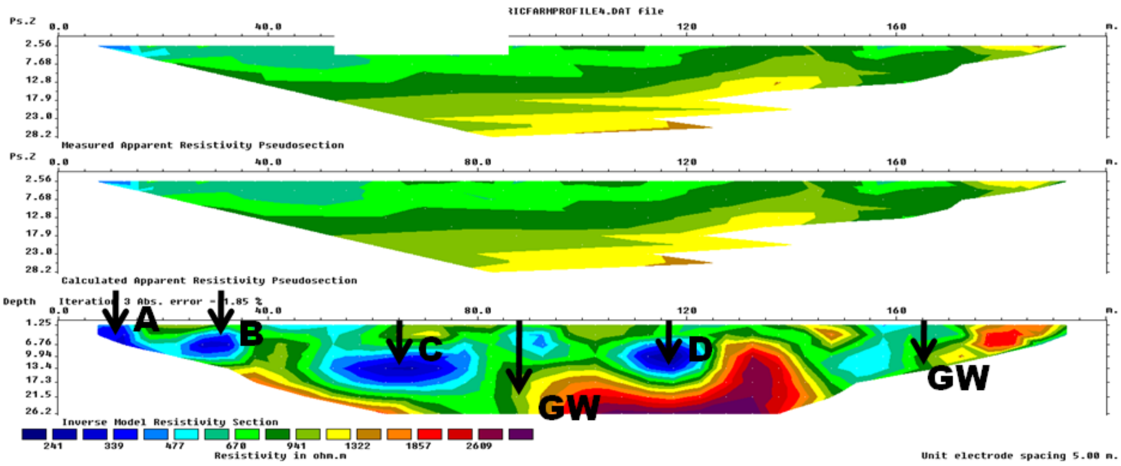


Figure 6: Result of 2-D inversion of the Wenner-array data along profile 4.

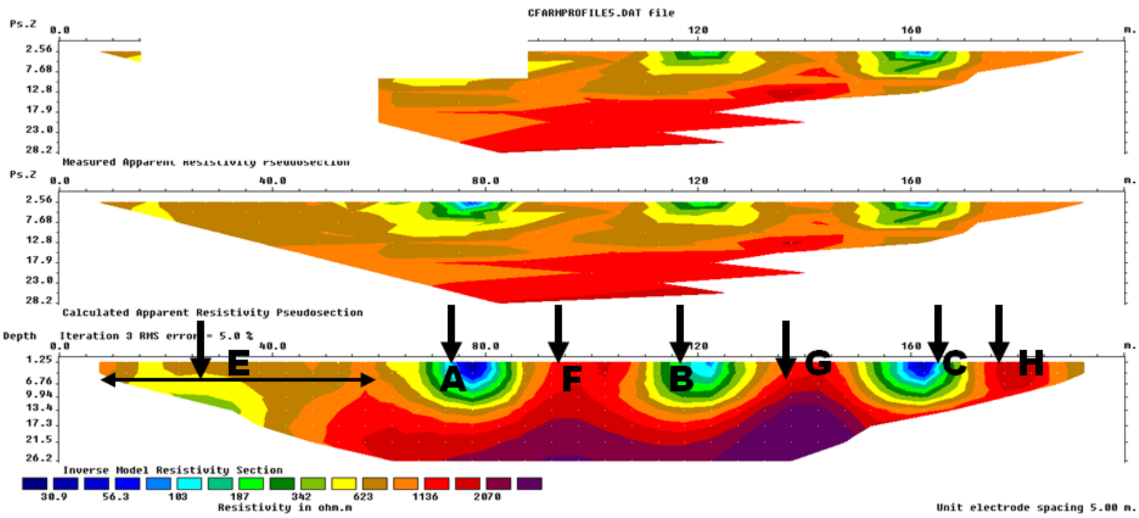


Figure 7: Result of 2-D inversion of the Wenner-array data along profile 5.

**Profile 5**

Figure 7.0 shows the resistivity model for profile 5 where dominantly very low resistivity values doted the top horizon (38.9 – 183) Ωm along the profile around 80 m, 120 m and 160 m (A, B and C) points at a depth ranged (0 – 6.75) m implying a bleached claystones and sandstone grains with relatively higher humus content and cat-ion exchange capacity and hence, a high density of mobile electrical charges. The lowest resistivity values (< 38.9 Ωm) were also attributed to higher water and/or humus content which favors agricultural crops and there was no observed evidence of contamination of the topsoil or the groundwater from the inversion model. The underlying horizon which is highly resistive (197 – 623) Ωm mostly consists of sandstones and well sorted conglomerates. The decrease in density of mobile electric charges here is much lower than that in the top horizon and the higher resistivity observed at this horizon shows an aquifer which is free from contamination with water table delineated at a very shallow depth of 6.75 m. This horizon had positive inference in terms of thick overburden and a well-defined fractured basement. As such, it possesses requisite hydro-geological characteristics that could supply underground water in fair quantity that will be adequate for farm water requirement when drilled. Points A, B and C are therefore, viable drill points and are recommended for spotting borehole. The shallow water table is convenient and economical in terms of the provision of quality groundwater for irrigation or for watering requirements of the crops thereby facilitating and encouraging both the wet and dry season farming to guarantee food security. This identified nature and quality status of both the soil and the groundwater viability in relation to a sustainable agricultural practices is a testimony that Agricultural geophysical researches remain the most simplest, convenience, economical and rapid methods in as much as the soil water/humus content remains the key control on plant growth and health. A continued and precise spatially and temporal follow-up of these soil physical and chemical properties became mandatory in order to obtain maximum yields with a guaranteed quality.

The highly resistive weathered basement (1136 – 2070) Ωm with its depth ranged (0.0 – 26.2) m was delineated and indicated by the varying red colorations. The model revealed an outcropping bedrocks even at the top subsurface horizon at points (E, F, G and H) with resistivity value (>1136 Ωm). These delineated zones were consolidated basement rocks which can withstand architectural constructions and thus can be demarcated for building infrastructures for farm purposes. A fresh basement (purple color) was delineated at the bottom with resistivity value (>2070 Ωm).

## Conclusion

Electrical Resistivity Profiling with Wenner array and 2-D imaging were carried out along five profiles to investigate the spatial variability of the physical properties of subsurface soil and groundwater at College of Agriculture Mokwa Farm, north-central, Nigeria using ABEM SAS Terrameter 4000 model. Three dominant geologic features (claystones, sandstones and conglomerates) were delineated at various locations among others like; weathered basement, fresh basement, fractured and aquifer zones. The delineated horizontal spatial patterns (low resistivity) in soil properties near the surface at top horizon in points (**A, B, C** and **D**) along profile 1 were interpreted as a bleached claystones grains and sandstones with relatively high humus content and cat-ion exchange capacity with their picks at points **(**A and D**).** This was attributed to higher water content which strongly influences the crop yields recommended for cultivation of those higher water demanding crop types to guarantee maximum yields. Furthermore, the delineated low electrical resistivity zones exhibited the horizontal spatial variations in the natural soil and groundwater properties such as humus content, the ionic concentrations and others. It also unveiled the viable and potentially high quality and maximum crop yielding zones (points **A, B, C, D** and **E** along all profiles) within the farm. All these were achieved with a most practical economic compromise between the accurate results obtained and at the very low survey costs. Also exhibited are the suitability and the convenience of this geophysical method to soil and groundwater quality investigations. The discovery of the subsurface water flow patterns along South – North direction will definitely facilitate the adequate and sustainable agro-ecosystem planning, irrigation construction, monitoring and management of the college farm for maximum output as well as sustaining the soil quality standard and this was a great contribution to the improvement of the management strategies aimed at improving and enhancing the quality of the crop production. With this developed detailed farm site map revealing among others - the different partitions such as shallow aquifer zones with water table ranged (6.75 – 8.00) m, delineated potentially stable and viable areas for locating the farm infrastructural facilities (like buildings)at points (F, G and H) and others, the inferences on facilitation of different management zones (such as precision farming techniques and other vital farming decisions)can easily and effectively be implemented to maximize economic benefits, food security, human health and environmental quality enhancement with very high crop output and very minimal production/input cost.

Therefore, these most convenient -field measured variations in soil properties capable of influencing the variation in crop yields revealed the possible stable patterns in crop yield/loss, especially on perennial horticultural crops and also, as an indicator of the complex of soil properties influencing crop yields, electrical resistivity could also be correlated with crop yields since the electrical potentials between topsoil and growing plants can be used to monitor plant growth, yields and health continuously and non-destructively. Based on the conveniences of quick extensive data measurement and modeling on the vertical and lateral distributions of electrical properties in soil profiles without the soil disturbance and also the possibility of measuring parameters of the growing plants in its natural conditions, the electrical geophysical methods are recommended for utilization in variety of agricultural practices and other soil/plant research.

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