Journal of Basics and Applied Sciences Research (JOBASR)
ISSN (print): 3026-9091, ISSN (online): 1597-9962
Volume 3(4) July 2025
DOI: https://dx.doi.org/10.4314/jobasr.v3i4.3

Assessment of Subsurface Salinity on Annual Agricultural Activities Using Geophysical Method at Gada-Mashegu Area North – Central Nigeria

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ABSTRACT
The Gada area, located in the Mashegu area of North-Central Nigeria is known to have significant agricultural practices with the aid of chemical fertilizers and herbicides which contribute to soil salinity. However, there is lack of detailed understanding of subsurface salinization and its distribution in the region. This study aims to assess the level of subsurface salinity and its implications for agricultural activities in the area. A 2D electrical resistivity survey was conducted to probe subsurface salinization. Five profiles were acquired using Werner Schlumberger array, two profiles were acquired in agricultural farm where chemical fertilizer, insecticides and herbicides are applied, one profile in an uncultivated native vegetative land and two profiles in an uncultivated abandoned (Deserted) land. The subsurface salinity levels in the study area base on the apparent resistivity levels profile has ρa (184 – 542 Ω-m) topsoil slightly saline, profile two ρa (0.590 – 106 Ω-m) severely saline, profile three ρa (2.549 – 449 Ω-m) partly saline, profile four ρa (0.247 – 401 Ω-m) slightly saline probably leachate salinity and profile five ρa (114 – 955 Ω-m) not saline mostly sandy. Based on the results profiles one and two conducted at the cultivate land are more saline followed by vegetative uncultivated land and deserted uncultivated land is not saline except in a small portion of profile four which could be a leachate salinity. The high levels of salinity in the cultivated area are possibly the effect of fertilizer, herbicides and pesticides application in the area. This salinity may adversely affect crop yield if not managed properly

Keywords:
2D,
Electrical Resistivity,
Annual agriculture
and salinity

INTRODUCTION

One of the most significant abiotic stresses is salinity, which restricts crop yields in dry and semi-arid areas where precipitation may not be enough to allow for leaching and where soil salt concentration is naturally high. (Yadav *et al*., 2011). More than 800 million hectares of land, or more than 6% of the world's land, are impacted by salinity or sodicity, according to the Food and Agriculture Organization's Land and Nutrition Management Service (2008). The characteristics of saline soils are defined by (Yadav *et al*. 2011) as those that contain sufficient salt in the root zone to impose the growth of crop plants. Since salt injury varies depending on species, variety, growth stage, environmental conditions, and the nature of the salts, precisely defining saline soils can be challenging.

The most widely accepted definition, based on FAO (1996), describes saline soils as those with an electrical conductivity (EC) of 4 dS/m or higher, with soils exceeding 15 dS/m classified as strongly saline. Agriculture serves as a crucial livelihood and economic activity in the Gada-Mashegu area of North-Central Nigeria. The rising occurrence of subsurface salinity threatens the region's agricultural productivity, prompting this study to utilize 2D electrical resistivity surveys to investigate subsurface salinization.

Several authors have studied salinity and its effects on crops. For example, Bawa *et al*, (2020) suggested that regions with high salinity tend to affect crop yield in agricultural farms, Muhammed *et al*, (2019) also revealed that crop production is adversely affected by soil salts and significantly affects legume yield. Similarly, Zahra *et al*, (2012) concluded that salt stress can adversely affect the germination percentage, germination rate, mean germination time, length of radicle plumule and seedling and seed vigour of some hybrid varieties of some maize. Most of the researchers stated above conducted their researches mainly on irrigation farms, neglecting areas where both grains and legumes are cultivated annually with the aid of chemical fertilizers and herbicides.

The study area has no published geophysical record of subsurface salinization. Hence the use of 2D electrical resistivity survey is proposed to assess the subsurface salinization levels in the Gada- Mashegu area of Niger state northcentral Nigeria. The research aims to utilize 2D electrical resistivity imaging technique to delineate salinity affected zones, quantify salinity levels at various depths and evaluate how these factors influence crop productivity over different planting seasons

The method is based on the flow of d.c current underground. The flow injected current is governed by equation (1) as shown in Fig. 1.

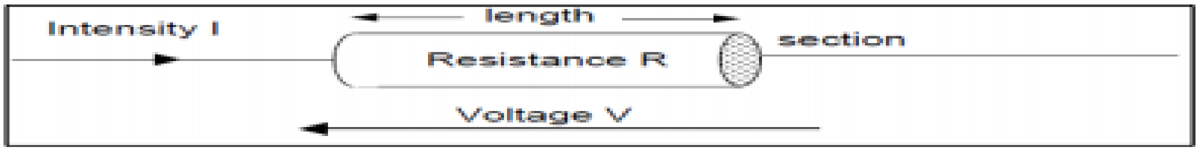

Figure 1: Distribution of the Current Flow in a Homogeneous Soil

$$R = \frac{V}{I} \quad (1)$$

Reynolds (1997), in the commonly used four electrodes system for subsurface direct current resistivity, the relationship between the injected current (I), the measured potential difference (ΔV) and the generalized surface electrode distribution is given by

$$\rho = \frac{\Delta V}{I} 2\pi \left[\!\left[\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right]\!\right]^{-1} \quad (2)$$

In short form

$$\rho = KR \quad (3)$$

$$K = 2\pi \left[\!\left[\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right]\!\right]^{-1} \quad (4)$$

Where K is the geometric factor, r with subscripts stand for electrodes spacing (Fig. 2) and R stands for resistance of the medium that is given by the ratio of ΔV to I and a is the spacing between the potential electrodes (Augie *et al*.. 2019)

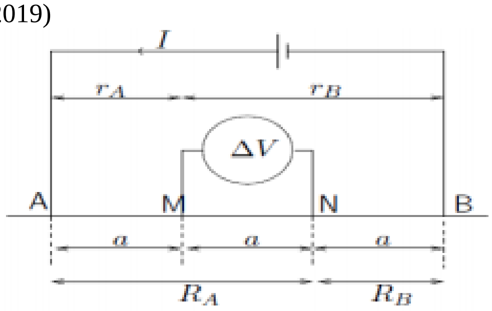

Figure 2: Generalized Four Electrode System. S

According to Telford *et al*. (1990), the geometric factor (K) for Wenner array is given as

$$K = 2\pi a \quad (5)$$

Thus, apparent resistivity for Wenner array is given by

$$\rho a = 2\pi a R \quad (6)$$

Where R is the resistance measure

Location and geology of the study area

Mashegu is located between latitudes 9°40’ and 9°70’ N and longitudes 4°35’ and 4°50’ E, covering an area of approximately 9,182 square kilometers. The climate resembles that of much of West Africa, featuring distinct rainy and dry seasons. The seasonal rainfall pattern results in a wet season lasting about seven months with an average rainfall of 250 mm, and a dry season of roughly five months with minimal or no rainfall. The basement geology comprises a suite of Precambrian gneisses, migmatites, and metasedimentary schists, which are crosscut by granitoids (Oyewale, 1972). The sedimentary formations are part of the Bida Basin, also known as the mid-Niger or Nupe Basin, a NW–SE trending intra-tectonic sedimentary basin extending from Kontagora in Niger State to areas just beyond Lokoja in the south. The basin stretches approximately 400 km in length, with a maximum width of around 160 km that narrows to less than 60 km at Dekina. The largest portion of the basin—the northern part—is located in the southern half of Niger State, as illustrated in Figures 3 and 4.

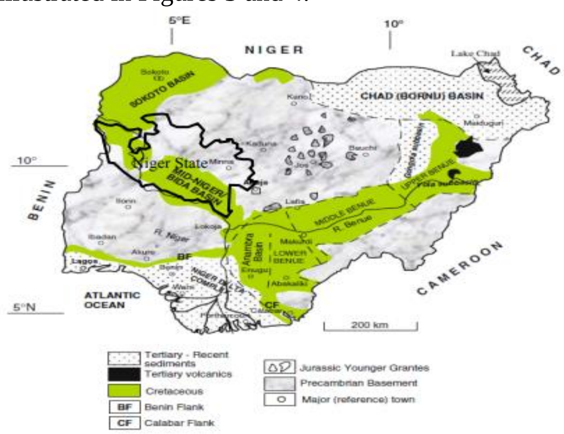

Figure 3: Geological map of Nigeria showing Niger State (Adopted from Obaje, 2009)

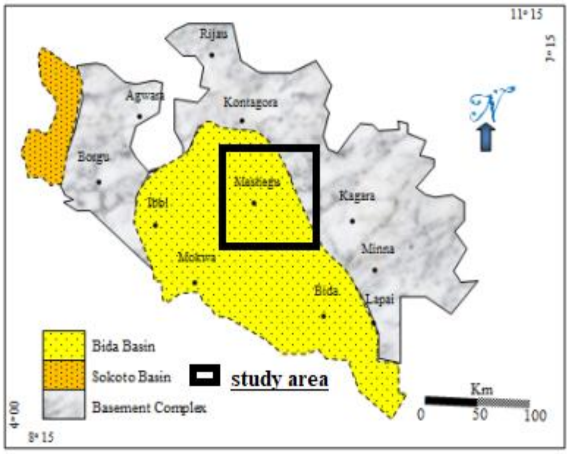

Figure 4: Geological map of Niger State showing Mashegu area. (Obaje, 2009)

Figure 5: Profiles layout Map of the Study Area

MATERIALS AND METHODS

The aim of the geoelectrical survey was to assess the subsurface resistivity distribution through measurements conducted on the ground surface (Magnus *et al*., 2019). These measurements enable the estimation of the true resistivity of the subsurface. Ground resistivity is influenced by several geological parameters, including mineral and fluid content, porosity, and the level of water saturation within the rocks (Islami, 2011).

The following equipment were used for data collection

a. Batteries,
b. Global Positioning System (GPS) device,
c. Terameter and its accessories
d. Hammer
e. Measuring tape
f. Copper electrodes
g. Four reels of wire and connecting wires

Procedure for data collection

Three (3) sites were selected for resistivity imaging surveys, these sites include cultivated land, uncultivated (native vegetative) land and uncultivated (deserted) land, all in the Gada- Mashegu area of Niger state, North central Nigeria. 2D electrical resistivity points were coded 1 to 5 showing locations and GPS co-ordinates of the study area taken by global positioning system (GARMIN GPS) device. 2D electrical resistivity explorative survey was carried out around Gada – Mashegu area in Niger State Nigeria in December, 2024 with the aid of SAS 4000 Terameter instrument and its accessories during which the resistivity data were acquired. Five profiles (Fig. 6a – 6e) were covered and the imaging technique was executed about these profiles using Wenner array with the profile length ranging from 0 to 200m. To ensure accuracy in data collection the equipment was properly calibrated, and measurements were taken two times for each profile to minimize error

Initially the four electrodes were placed at 5 meter spacing along transect symmetrically about point 0 (x - position). The outer electrodes are the current electrodes whereas the inner electrodes are the potential electrodes. The measured resistance in ohms were recorded and at each measurement the product of resistance measured (ohms) and its corresponding values of geometrical factor (K) gives the apparent resistivity in ohms-meter. The electrodes were shifted by 5m; thus x-position (distance along the profile) was also shifted by 5 meter and the reading repeated (Fig. 6). The same procedure was repeated until the x-position reached a maximum of 200m. RES2DINV64 was used to analyze the acquired data across the five profiles. All the areas surveyed were granted permission by the owners, the cultivated and uncultivated(deserted) lands owned by officer in charge Nigeria police out post Gada, uncultivated (native vegetative) land owned by former councilor Gada/Kasanga ward of Mashegu local government area, Niger state. The three areas surveyed were selected to provide a comprehensive perspective on how land use influences soil salinity, it also allows for spatial comparison and aid in identifying sources and patterns of salinity, and suggests the development of effective land management and reclamation strategies based on resistivity data. Cultivated land typically subjected to fertilization and other agricultural practices which can influence the salinity levels through salt accumulation from water and fertilizer runoff. Vegetative (native) land can influence the soil moisture and salt dynamics, often acting as indicators of salinity stress. Uncultivated deserted land represents areas with minimal human intervention, serving a baseline or reference zones that might naturally have higher or lower salinity depending on natural conditions .

Plate I: Profile display along north to south in the cultivated land of the Gada–Mshegu area

RESULTS AND DISCUSSION

The data were analyzed and inverted using the software RES2DINV64, which produced three sections, measured, calculated and inverse model sections. The model sections were used to interpret all the five profiles (Fig. 6a to 6e). Table 1 revealed the results of the probed profiles. The low resistivity values ranging from 0 – 50 (Ω-m) in the topsoil is an indication of being conductive according to Reynolds, (1997) assertion, similar results was obtained by Bawa *et al*, (2020).

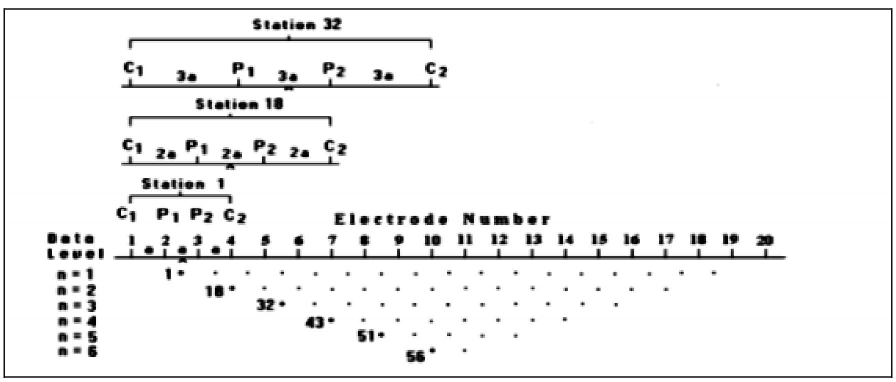

Figure 5: Electrode sequence buildup

Table 1: Results of the probed profiles

profile	coordinate	Profile direction	Apparent resistivity (ρa)	Profile length (M)	Depth probed (M)	Remark
1	N9^{0}48'40'' E6^{0}9'37''	N - S	184 – 542	200	36.9	Topsoil slightly saline
2	N9^0 4840 E6^{0}93'7'''E	N - S	0.590 – 106	200	36.9	Topsoil severely saline (probably the effects of chemical applications)
3	N9^{0}5853 E5^{0}482'	N - S	2.49 – 449	200	36.9	Partly saline (probably the result of decomposed matter)
4	N9^{0}5856 E5^{0}4811	N - S	0.267 – 401	200	36.9	Slightly saline (probably leachate salinity)
5	N9^{0}58'57'' E5^{0}4812	N - S	114. - 955	200	36.9	Not saline mostly sandy

Figure 6a shows the2D inversionresult of Profile 1 (cultivated land).

A depth of 39.6m was probed at a lateral distance of 200m from N-S. The model has resistivity of 184-542Ωm. The top soil has a thickness of about 12m with apparent resistivity between 100-300Ωm. It is generally conductive, especially between 2-12m deep. This indicates that the soil is mostly clay with high moisture content, low porosity, and relatively high organic matter. These regions of the profile are considered to be saline, which could be as a result of fertilizer and herbicides application during farming period. Beneath the topsoil is the weathered rock at a depth of 20m with resistivity of between 390-540Ωm. This is interpreted as sand/coarse sand. The fresh basement was not reached.

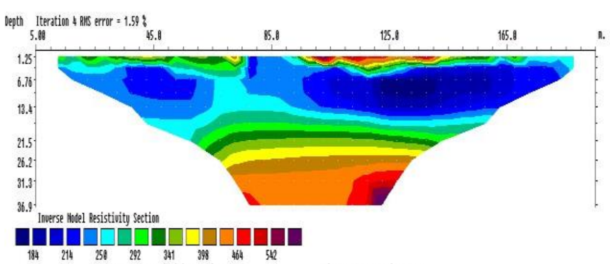

Figure 6a: Result of 2D inversion of the Wenner-Schlumberger array data along profile 1

Profile 2 (figure 6b, cultivated land) shows a very low resistivity contrast (5-10Ωm) which constitute the topsoil with a varying thickness between 6-13m from N-S. The low resistivity contrast indicates the presence of high saturated water/clay materials which is saline in nature. This could be also as a result of excess application of fertilizer and herbicides within the region. Underlie the topsoil is region of relatively high resistivity (>50Ωm) materials at a depth of 14-15m. This is interpreted as sand. The fresh basement was not reached.

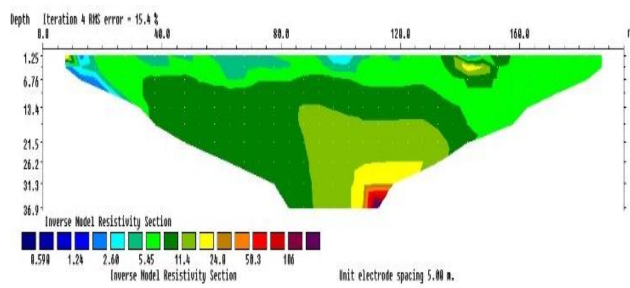

Figure 6b: Result of 2D inversion of the Wenner-Schlumberger array data along profile 2.

The inverse section of profile 3 (Fig. 6c, uncultivated land) showed low anomaly areas of resistivity (5-25Ωm) along different points (N-S) of distance; 5-90m at depth 21m and points 120-200m at the depths of 14m respectively. These regions were observed to be saline which could be as a result of the observed decomposed organic matter (leaves and trees). However, the high resistivity zones (>200Ωm) at the center of the profile could be as a result of the observed gravel.

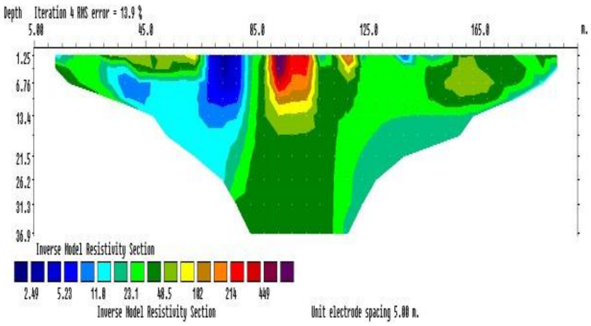

Figure 6c: Result of 2D inversion of the Wenner-Schlumberger array data along profile 3.

The resistivity inversion of profile 4 (figure 6d, deserted land) stretches 200m along N-S direction. A depth of 36.9m was probe. The topsoil has an apparent resistivity between 140-400Ωm with thickness of about 3m. The relatively high resistivity contras of the topsoil indicate the presence of the observed sandy soil in the region. At a distance; 55-90m at depth 6m and points 120-160m at the depths of 4m respectively is a low resistivity zone (4-20Ωm). This could be a leachate of salinity. The fresh basement is not reached.

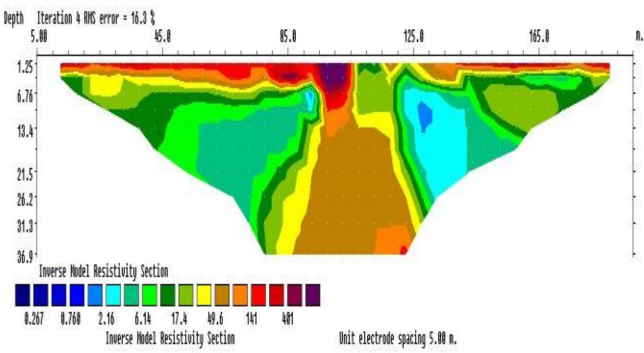

Figure 6d: Result of 2D inversion of the Wenner-Schlumberger array data along profile 4.

The inversion model resistivity section of profile 5 (figure 6e, deserted land), shows a resistivity range between 114-955Ωm, with length of approximately 200m. A depth of 39.6m was also probed. The profile stretches from N-S. The topsoil is characterized with resistivity >200Ω with relative thickness of 10-14m which is mostly sandy soil. Underlie this zone is the weathered rock at a depth of 16m with resistivity between 290-850Ωm. this is interpreted as sand/coarse sand. The fresh basement was not reached.

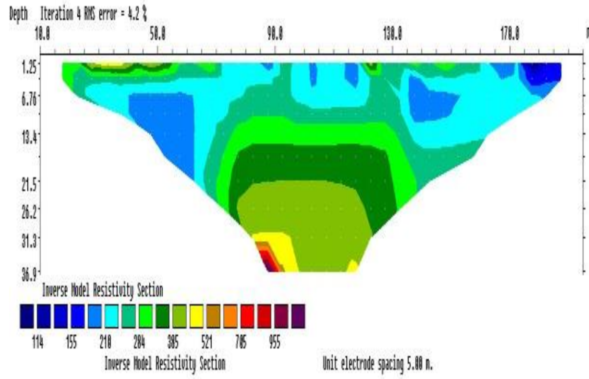

Figure 6e: Result of 2D inversion of the Wenner-Schlumberger array data along profile 5.

The histogram below displays resistivity trend for each profile, the lower the resistivity the higher the salinity level. Profile 2, has the highest, followed by profile 4, profile 3, 5 and 1 respectively.

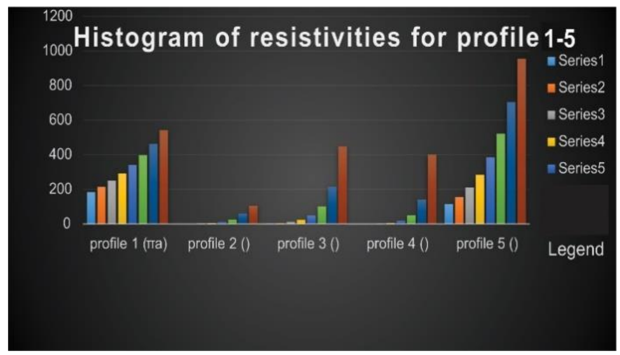

Figure 6f: resistivity trend for each profile, the lower the resistivity the higher the salinity level.

NB: Series on the legend represents profiles and the colours represents salinity trend, light blue stands for areas with highest salinity levels (low resistivity areas).

Table 2: Salinity Levels Used in Interpretation (Adopted from Reynolds, 1997).

ρa (Ω-m)	Remark
> 1000	Normal
100	saline
10	Moderate saline
1	Severe

CONCLUSION

The use of electrical resistivity method has proved to be successful in delineating the subsurface salinity levels. The application of the 2D electrical resistivity method using Werner Schlumberger array, helped in identifying areas that are adversely affected by agrochemicals in the study area. The subsurface salinity levels in the study area based on the apparent resistivity levels profile are as follows:

ρa (184 – 542 Ω-m) topsoil slightly saline, profile two ρa (0.590 – 106 Ω-m) topsoil severely saline, profile three ρa (2.549 – 449 Ω-m) partly saline, profile four ρa (0.247 – 401 Ω-m) slightly saline probably leachate salinity and profile five ρa (114 – 955 Ω-m) not saline mostly sandy. Based on the research results profiles one and two conducted at the cultivated land are more saline followed by vegetative uncultivated land and deserted uncultivated land is not saline except in a small portion of profile four which could be a leachate salinity. The high levels of salinity in the cultivated area is possibly the effect of fertilizer, herbicides and pesticides application in the area. The areas with high salinity levels in sol pose a serious threat in agricultural production by impairing plant growth, degradations of soil health, and increasing production costs. Insecurity was one of the limiting factor that was faced while conducting the survey. It is recommended that laboratory analysis of the soils of the surveyed areas is conducted to calibrate resistivity results, 3D resistivity, electromagnetic survey should be conducted for better spatial resolution.

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