



Assessment of Saline/Sodic Soils within Zauro Fadama Irrigation Farm Land NW Nigeria, +using 2D Electrical Resistivity Method

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Abstract

This study evaluates saline/sodic soils in Zauro Fadama Irrigation Farm Land, Kebbi State, Nigeria using 2D Electrical Resistivity Imaging with a Wenner array configuration with 3m electrode spacing within two profiles of 100m. Clay, sandy-silt, alluvial sand, shale/sandstone, and clay/limestone/gravel were the five lithological units identified by data processing software RES2DINV64 and SURFER13. The resistivity distribution indicated distinct salinity patterns, with clay layers at profile one (P1) labelled as zones A along the lateral length of 0-10m at depth 5.56m, 24-48m at depth 2.25-5.56m, and 72-100m at depth 5.56m. Similarly, the major zones of saline/sodic soils along the P2 are 24-72 m at 5.56 m, 80-83 m at 5.56 m, and 96-99 m at 5.56 m. These locations have low resistivity anomalies ranging from 6.59 Ω m to 30.1 Ω m. Saline soils' low resistivity zones are caused by high electrical conductivity, which could have an impact on crop growth. Sand/gravel deposits were found to be associated with high-resistivity zones (>700 Ω m), indicating high-permeability aquifers. These findings, which identify both severe saline zones and beneficial water-bearing formations, provide critical geophysical information on soil salinity distribution as well as helpful recommendations for irrigation management and sustainable agricultural planning in the study area.

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Introduction

Salinization, a significant type of soil degradation, has been identified as one of the key causes of desertification. It is caused by the creation of salt and other compounds from fertilisers and irrigation water (Environment and Development, 2016). Soil salinity is defined as the amount of significant dissolved inorganic solutes present in the soil's aqueous phase, which includes soluble and rapidly dissolvable salts (Corwin and Lesch, 2003). Soil salinity tends to rise over time due to a variety of natural and artificial factors. Soil salinity limits the amount of water and nutrients that plants can absorb from the soil by significantly lowering the osmotic potential, making it difficult for plants to extract water from the soil. As a result, the plants produce meagre yields or are completely destroyed (Corwin and Lesch 2003).

Globally, salinisation poses a concern to soil, water, and human health. It is the main issue with irrigation agriculture because it has a negative impact on crop growth stages and limits phosphorus and water uptake from the soil (Shrivastav and Kumar 2015). The salts that influenced the soils were either saline or sodic. Saline soils are those with electrical conductivity more than 4ds/m, which impair crop development (Adewin and Akomolofe 2013). Soluble salt consists primarily

of sodium chloride and sulphate, as well as calcium and magnesium. Salinity is classified into two categories: main salinity and secondary salinity. The former happens naturally as a result of salt accumulation, whereas the latter is caused by irrigation or dry land. Sodic soil is defined as soil with an exchangeable sodium percentage above 15 and contains sodium salts such as alkaline hydrolysis and sodium carbonate (Adewin and Akomolofe 2013). Natural influences include mineral weathering and saline water intrusion, whereas manmade factors include irrigation, fertilizer application, and other human activities. Soil salinity has been proven to have a negative impact on plant growth, resulting in stand loss, diminished and impeded plant growth, decreased yield, and crop failure (Rhoades and Corwin, 1990; Rhoades and Loveday, 1990). Plant growth is vital to humans and ecosystems because plants provide a variety of services such as food supply, soil erosion protection, desertification prevention, oxygen provision for respiration, and the decrease of carbon dioxide in the atmosphere through photosynthesis. Soil salinity can produce particular toxicity, disrupting the nutritional balance of plants (Munns and Tester, 2008; Parida and Das, 2005). Furthermore, the salt composition of soil water changes the composition of cations on soil particle exchange complexes, hence

influencing soil permeability. Aside from restricting crop productivity and negatively altering soil hydraulic parameters, soil salinity can also have a detrimental impact on the groundwater system and cause corrosion damage to local infrastructure (Munns and Tester, 2008).

Authors such as Rhoades *et al.* (1990 & 1999), Bawa *et al.* (2020), Augie *et al.* (2020), Zhaoyong *et al.* (2014), Aizebeokhai *et al.* (2014), and Ibrahim *et al.* (2018) used different geophysical methods to assess soil salinity. Traditionally, soil salinity is assessed by visual crop observation and soil contaminants. The results demonstrated the efficacy of the 2D electrical resistivity method in determining salinisation level. These reveal soil qualities that may be beneficial for agricultural practices and environmental impact studies. Agricultural practice has long shown that soil variances exist between adjacent parcels of land; these differences are typically represented in crop production (Zhaoyong *et al.*, 2014). The assessment of soil salinity using electrical resistivity imaging combined with the induced polarisation method is critical in determining the spatial variability of physical parameters in subsurface soil (Aizebeokhai *et al.*, 2014).

The study of soil salinity and its effects can indicate the amount of soil salinity by employing geophysical methods such as electrical resistivity (Gopalkrishnan and Kumara, 2020). According to Gopalkrishnan and Kumara's (2020) study, the salt affects 32.8% of the land and 45% of paddy lands in the Jaffana Peninsula. Mnassri Soumaia (2017) conducted study on the salinisation risk assessment of soil and groundwater. A case study in the Sodi El Hani basin (central eastern Tunisia) was conducted using the electrical resistivity method with the goal of assessing the major process of soil and ground water salinisation through a combination of physical, chemical, and mineralogical analysis, in order to gain a general understanding of the soluble salt availability in the system soil ground water. According to the study, the degradation of ground water quality is primarily caused by natural factors such rock weathering and other pogenic variables related to irrigation water return.

However, the aim of this study is to assess the saline/sodic soils in the Zauro fadama irrigation agricultural land region utilising a 2D electrical resistivity imaging approach with the Wenner setup. The Wenner array is a more reliable method for reducing the effect of lateral variations on sounding

data than the offset Wenner method. The method takes advantage of the fact that the influence of an inhomogeneity on the apparent resistivity value is inverse if it lies between two potential electrodes or between a potential and a current electrode. The study evaluates saline/sodic soils by determining the pattern of dispersion for clay soil level, delineating the layering extent that is adversely affected by salt content, assessing the spatial variability of the subsurface soil's physical properties, and making necessary recommendations on the best location for agricultural activities in the study area.

1.1 Location and Geological setting of the study area

The study site (Zauro Fadama Area) is located at an altitude of approximately 200m above sea level between Latitude 12° 30' 15" N to 12° 31' 00" N and Longitude 4°18' 0" E to 4° 18' 45" E in the Sudan savannah agro-ecological zone of North-western Nigeria, Zauro town, which is located in the northern part of Kebbi State and underlying with the sedimentary basin of North Western Nigeria. The region is a 100-hectare irrigation scheme located in the Fadama sector of the Sokoto Rima river system. It is bordered by a 2.62-kilometer flood-protected dyke and features a 545-meter-long main canal with four lateral takeoffs.

These lateral canals are unlined and transport water to the field, where farmers install syphon tubes to basins or boundary plots, according to Wakuti Consulting Engineers. The average annual rainfall is around 650mm, falling largely between June and September, with a significant dry period the rest of the year (Graham WBR 2017). The soil in the vicinity has been identified as Eutric/Dystric fluvisols FADALR (28). The principal crops planted in the research region include vegetables such as water melon (*Citrullus lanatus*), green maize (sea mays), and onions (*Allium cepa*) in the dry season and rice (*Oriza sativa*) in the wet season (Ukabiala *et al.*, 2022; Panti *et al.*, 2023).

Geologically, Kebbi state is situated in the Basement Complex and some regions of the Sokoto Basin, which include the Gwandu Formation (Tertiary), the Nufe Formation (Cretaceous), and the Pan-African Older Granitoid (Pre-Cambrian to Cambrian). The northern part of Kebbi is covered by major sedimentary basin zones, which consist of sands, clays, limestones, sandstones, and siltstones (NGSA, 2006). The basement complex region occupies the southern part of Kebbi and is made up of Granite Gneiss, Medium to Coarse-Grained Biotite, Quartz-Mica Schist, and Amphibolite (Figure 2).

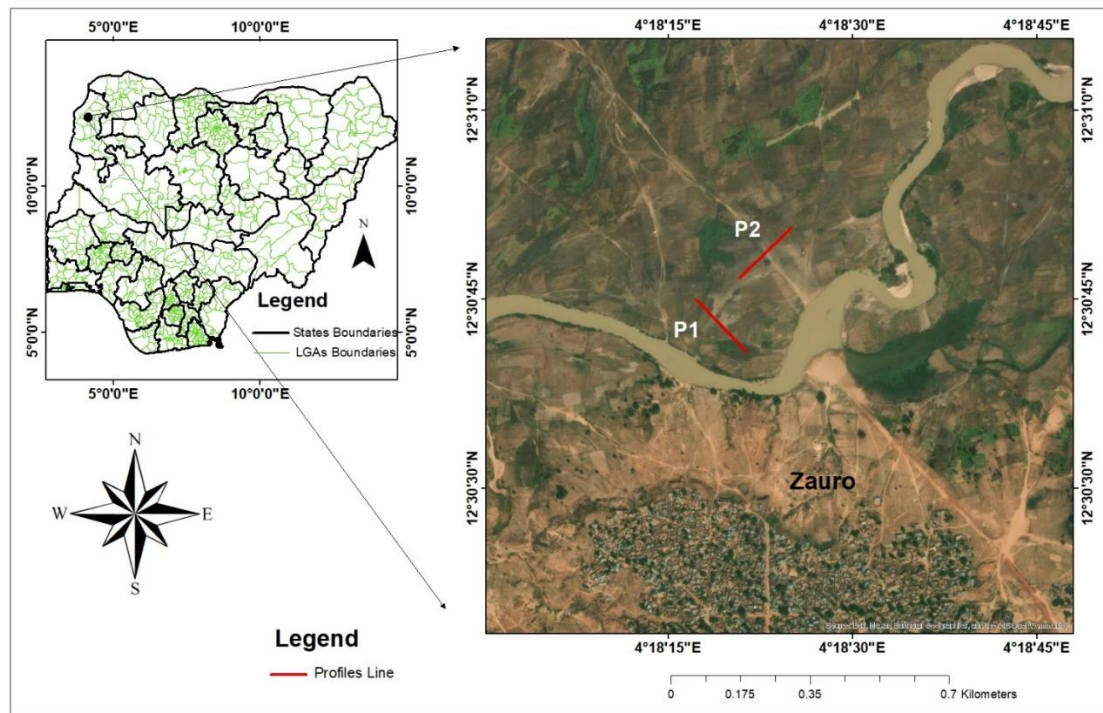


Figure 1: Location and field layout map of the study area

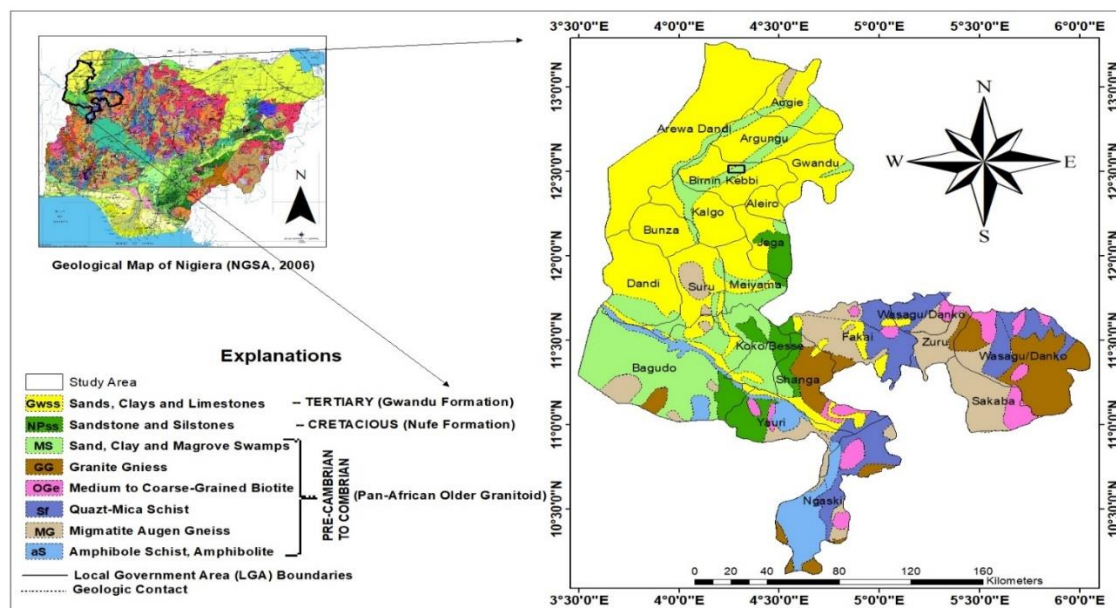


Figure 2: Geological setting map of the study area (Modified after: NGSA, 2006)

Materials and Methods

Materials

The materials used in carrying out this assessment are Omega resistivity meter, electrodes, cables, measuring tape, geologic hammer, Global positioning system (GPS), recording sheet, umbrella and power source.

Methods

A 2D electrical resistivity study was conducted around Zauro Fadama in Kebbi State, Nigeria, using an Ohmega resistivity meter and its accessories to obtain

resistivity data. Two profiles were covered, and an imaging technique was applied to the profiles utilising a Wenner array (Augie *et al.*, 2022), with profile lengths ranging from 0 to 100m.

Initially, four electrodes were spaced 3m apart along the transect, symmetrically around point 0 (x-position). The outer electrodes are the current electrodes, and the inside electrodes are the potential electrodes. The measured resistance in ohms was recorded, and the apparent resistivity in ohms-meter was calculated by multiplying the observed resistance (ohms) by the corresponding geometrical factor (K). The electrodes were shifted by 3m, therefore, the x-position (distance along the profile) was also shifted by 3m, and the reading was repeated until the x-position reached its maximum of 100m. The same methods were followed while the four electrodes were spaced 6m and 9m apart in each of the two profiles. The apparent resistivity was recorded at each measurement.

Results

Table 1 shows the results of a 2D electrical resistivity survey conducted in the research area in connection to saline levels based on resistivity common rock (Table 2). The data was processed and inverted using the software RES2DINV64, which resulted in three sections: measured, calculated, and inverse model (Fig. 3 and 4). The inverted section was converted into the equivalent geologic section utilising software

SURFER 13 for the profile's sections (P1&P2), as shown in Figs. 5 to 6, using lithologic layers generated from the area's geology.

Model Sections

Figures 3 and 4 depict model sections of two profiles from the analysed data. Geoelectric interpretation of Profile 1 model sections revealed low resistivity anomalies (6.59 to 30.1 Ωm) at different distances (Fig. 3). These occupied a distance of 0-12 m along the profile at a depth of 5.56 m. P2 extends from 21m to 28m at depths of 3.82m and 5.56m, respectively (Fig. 4). Table 2 shows low resistivity values ranging from 6.59 to 30.1 Ωm, indicating a clay area. These regions show that the topsoil in this area is generally conductive, soil moisture, less porosity, degree of consolidation, and organic matter are the dominant factors determining the observed inverse resistivity model with low resistivity, and these sections of profiles were classified as saline.

However, high resistivity anomalies at P1 range from 632 Ωm to 8128 Ωm at different distances (Fig. 3). These occupied a 75-100-m long profile at a depth of 0-5.56 meters. For P2, the high resistivity zones extend along the lateral length of the profile from 98m to 103m, with a depth of 4.02m (Fig. 4). When the high resistivity zones are compared to Table 2, the region is identified as Sandy.

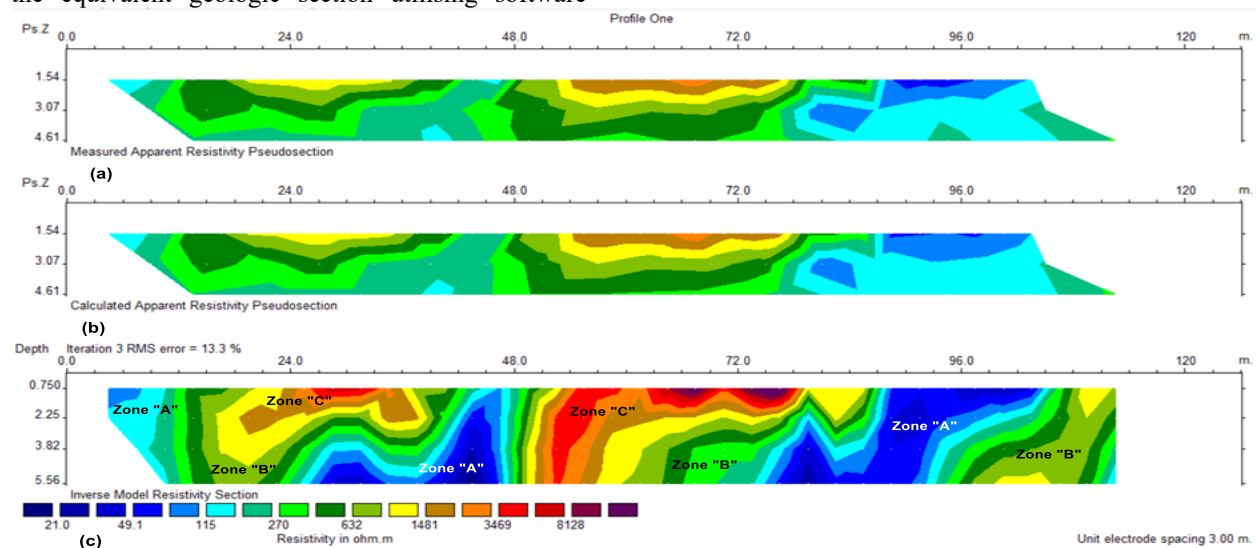


Figure 3: a) calculated (b) measured (c) Inverse model of profile one

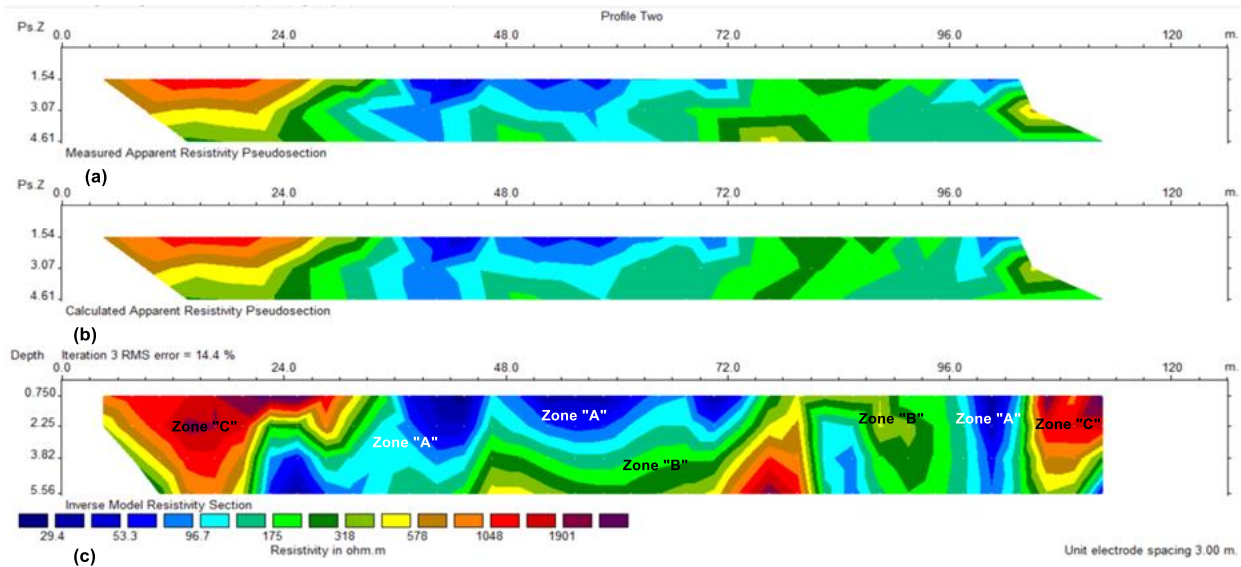


Figure 4: a) calculated (b) measured (c) Inverse model of profile two

The inverted sections of profiles P1 and P2 were transformed into corresponding geologic sections, as shown in Figs. 5 and 6, using lithologic layers generated from the area's geology. These revealed that the soil comprises five layers: clay (top layer), sandy-silt, alluvial sand, shale/sandstone, and gravel. The profiles have varying layer thicknesses at different points.

The major zones of saline/sodic soils along the P1 are as follows: 0-10m at 5.56m depth, 24-48m at 2.25-5.56m depth, and 72-100m at 5.56m depth. Similarly, the principal zones of saline/sodic soils along the P2 are as follows: 24-72 m at 5.56 m depth, 80-83 m at 5.56 mdepth, and 96-99 m at 5.56 mdepth.

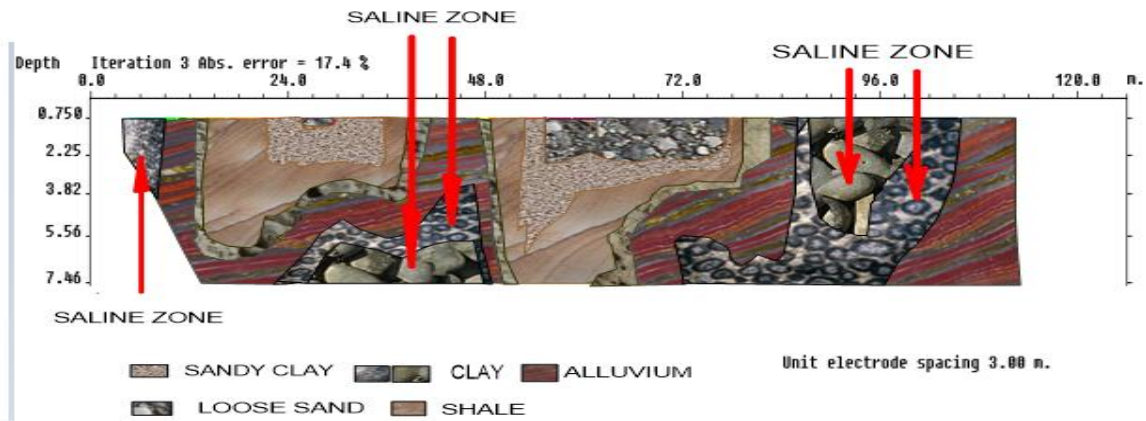


Figure 5: Geologic Sections of Profile one showing Saline Zones

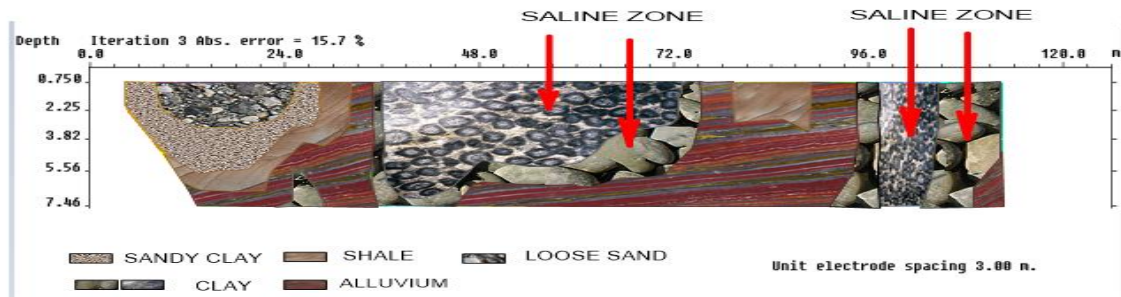


Figure 6: Geologic Sections of profile two showing Saline Zones

Table 1: Summary of Electrical Resistivity Profiles: Lithological Interpretation and Salinity Zonation

S/No.	Profile	Zone	Resistivity Values (Ωm)	Lithology	Lateral Length (m)	Depth (m)	Remark
	P 1	Zone A	6.59-30.1	Clay	0-10, 24-48, 72-100	5.56, 2.25-5.56 and 5.56	Saline Zone
		Zone B	49.7-65.4	Sandy Clay	22-48	2.25-5.56	lower Salinity
		Zone C	632-8128	Clay	75-100	0-5.56	Saline Zone
	P 2	Zone A	22.4-41.4	Clay/silt	24-72, 80-83 and 96-99	5.56 each	Less Saline
		Zone B	53.3- 175	Clay	36-73.5	0-2.25	Saline Zone
		Zone C	318-1901	Clay	98-103	0-4.02	Saline Zone

Table 2: Classification of Salinity Levels Based on Resistivity Range

S/No.	Resistivity Range (Ωm)	Salinity Inference
1	<20	Severe Salinity
2	20-40	Moderate Salinity
3	>40	Low/Marginal Salinity

Discussion

The findings of this 2D electrical resistivity investigation in Zauro Fadama Irrigation Farm Land as systematic documented on table 1 and 2 provides critical insights into the spatial distribution of saline/sodic soils and their implications for agricultural productivity. The resistivity distribution patterns clearly delineate zones of varying salinity intensity, with low resistivity values (6.59-30.1 Ωm) corresponding to clay-rich saline zones and higher resistivity values (>700 Ωm) indicating more favorable sandy/gravelly aquifers. These results align with previous studies in similar environments, particularly the work by Aizebeokhai (2014) in southwestern Nigeria and Zhaoyong *et al.* (2014) in China's Yanqi Basin, demonstrating the consistent effectiveness of electrical resistivity methods in salinity assessment.

The identified saline zones particularly at 0-10 m (5.56 m depth), 24-48 m (2.25-5.56 m depth), and 72-100 m (5.56 m depth) along P1, and 24-72 m (5.56 m depth), 80-83 m (5.56 m depth), and 96-99 m (5.56 m depth) along P2 pose significant challenges for conventional agriculture due to their high salt content. This observation supports Munns and Tester's (2008) findings on how soil salinity disrupts plant water uptake and nutrient balance. However, the study also reveals areas of lower salinity (resistivity values 49.7-65.4 Ωm) that could potentially support salt-tolerant crops, as suggested by Qadir *et al.* (2007) in their work on marginal land utilization.

The geological interpretation of the resistivity data, revealing layers of clay, sandy-silt, alluvial sand, and shale/sandstone, corresponds well with the established understanding of the Sokoto Basins hydrogeology (Kogbe, 1979). The high-resistivity zones associated

with sandy/gravelly deposits confirm their potential as water-bearing formations, similar to findings by Bawa *et al.* (2020) in Kurfi Fadama.

For agricultural management, these results suggest a need for differentiated land use strategies:

Severely saline zones (resistivity <20 Ω m) may require remediation approaches such as improved drainage and organic amendments (Amezketta, 2007) Areas of moderate salinity could benefit from salt-tolerant crop cultivation methods (Parida and Das, 2005)

High-resistivity zones represent optimal locations for conventional irrigation agriculture, though requiring careful monitoring to prevent secondary salinization (Corwin and Scudiero, 2019)

The findings offer practical guidance for irrigation planning in Kebbi State while contributing to the broader understanding of soil salinization processes in Sudan savannah agro-ecosystems. They particularly reinforce Graham's (2017) observations regarding soil quality challenges in the Sokoto-Rima Basin. Future studies should focus on seasonal monitoring of salinity patterns and their relationship to irrigation practices, building on Rhoades *et al.* (1999) framework for dynamic salinity assessment.

Conclusion

This study demonstrated the effectiveness of 2D Electrical Resistivity Imaging in characterizing saline/sodic soils and aquiferous formations within Zauro Fadama Irrigation Farm Land. The identification of low-resistivity anomalies corresponding to high soil salinity highlights areas at risk of reduced crop productivity, while the delineation of high-resistivity sand/gravel deposits indicates favorable aquiferous formations with irrigation potential. These results provide both a scientific basis for understanding soil salinity distribution and practical guidance for sustainable irrigation management, soil remediation, and agricultural planning in the study area.

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