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Contribution of Electrical Resistivity Tomography to the Characterization of the Hydrogeological Target of the Continental Terminal Aquifer in Lower Casamance, Senegal

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Abstract: Lower Casamance, a key agricultural zone in southern Senegal, is increasingly affected by climate variability and groundwater salinization, which threaten irrigation development. This study applies Electrical Resistivity Tomography (ERT) to characterize the hydrogeological potential of the intermediate Continental Terminal aquifer and to guide the siting of hydro-agricultural boreholes for small-scale market gardening. Geophysical surveys conducted at multiple sites reveal aquifer thicknesses ranging from 10–20 m along the Gambian anticline and 5–10 m near the Sédhiou structural high, with recommended investigation depths generally below 50 m. Estimated exploitable yields range between 12 and 14 m³/h, indicating that the aquifer can sustainably support localized irrigation schemes.

Resistivity values between 0.2 and 5.8 Ω·m reflect lithological heterogeneity and groundwater mineralization, allowing differentiation between clean sandy aquifers, sandy-clayey reservoirs, and saline or clay-rich horizons. These findings confirm the presence of accessible freshwater resources in most surveyed sectors, although areas near coastal influence remain vulnerable to saline intrusion. Recommended borehole depths between 37 and 40 m provide optimal abstraction conditions while minimizing drilling costs.

Overall, the study demonstrates the effectiveness of ERT for hydrogeological assessment and groundwater development planning in Lower Casamance. While the identified aquifer resources can support small irrigation projects, careful monitoring and sustainable management practices are essential to prevent overexploitation and salinization, ensuring long-term water security for agricultural communities.

Keywords: Tomography, electrical resistivity, aquifer, irrigation, hydro-agricultural structures

1.INTRODUCTION

Lower Casamance, located in southern Senegal, is one of the country's most important agricultural regions, where groundwater plays a critical role in sustaining irrigated farming and rural livelihoods. However, climate variability, reduced recharge, and increasing salinization of soils and aquifers are threatening water availability and agricultural productivity. In coastal and estuarine environments such as the Casamance Basin, saline intrusion into shallow aquifers is a well-documented phenomenon linked to sea-level rise, reduced river discharge, and over-abstraction of groundwater [1,2]. These pressures make it essential to identify reliable groundwater resources and optimize borehole siting through appropriate hydrogeological investigations.

The hydrogeological framework of the region is controlled by the southern extension of the Senegal–Mauritania sedimentary basin, which contains several superposed aquifer systems, including the deep Maastrichtian aquifer, intermediate Miocene formations, and the shallow Continental Terminal aquifer [3,4]. Among these, the Continental Terminal aquifer is widely exploited for domestic and agricultural water supply because of its relatively shallow depth and sandy lithology. Nevertheless, its heterogeneity, variable thickness, and susceptibility to mineralization require detailed characterization before groundwater development. Previous hydrogeological studies in West Africa have shown that geophysical prospecting methods, particularly electrical resistivity techniques, are effective tools for locating aquifers, estimating their thickness, and assessing groundwater quality in sedimentary environments [5,6].

Electrical Resistivity Tomography (ERT) has become a widely used method for subsurface investigation because it provides high-resolution images of lithological variations and water-bearing formations. By analyzing contrasts in electrical resistivity related to porosity, saturation, and mineralization, ERT allows the identification of aquifers and saline horizons without extensive drilling [7]. In Lower Casamance, where geological formations are complex and borehole drilling is costly, the integration of geophysical data with existing hydrogeological information can significantly improve groundwater resource assessment and management.

The present study aims to characterize the hydrogeological potential of the intermediate Continental Terminal aquifer in Lower Casamance using Electrical Resistivity Tomography. Specifically, it seeks to determine aquifer thickness, depth, and expected yields, and to identify optimal locations for hydro-agricultural boreholes that can support small-scale irrigation systems. By providing reliable data for groundwater development while highlighting the risks of saline intrusion, this work contributes to sustainable water resource management and climate-resilient agriculture in southern Senegal [8,9].

2.MATERIALS AND METHODS

2.1 Study Area: The investigation was conducted in Lower Casamance, southern Senegal, within the departments of Bignona, Oussouye, and Ziguinchor. The region lies within the Senegal–Mauritania sedimentary basin and is characterized by alternating sandy, clayey, and marly formations belonging mainly to the Continental Terminal and Miocene units. These deposits form shallow to intermediate aquifers that are widely used for domestic supply and irrigation. The study area experiences a tropical sub-humid climate with strong seasonal rainfall variability, which influences groundwater recharge and salinity patterns.

The geological context is marked by structural highs and depressions that control aquifer thickness and groundwater flow. Previous borehole data indicate that the Continental Terminal aquifer becomes thinner and more clay-rich toward coastal zones, where salinity risks increase. The aim of this study was therefore to identify favorable drilling zones for hydro-agricultural boreholes at nine selected locations representing different geomorphological settings.

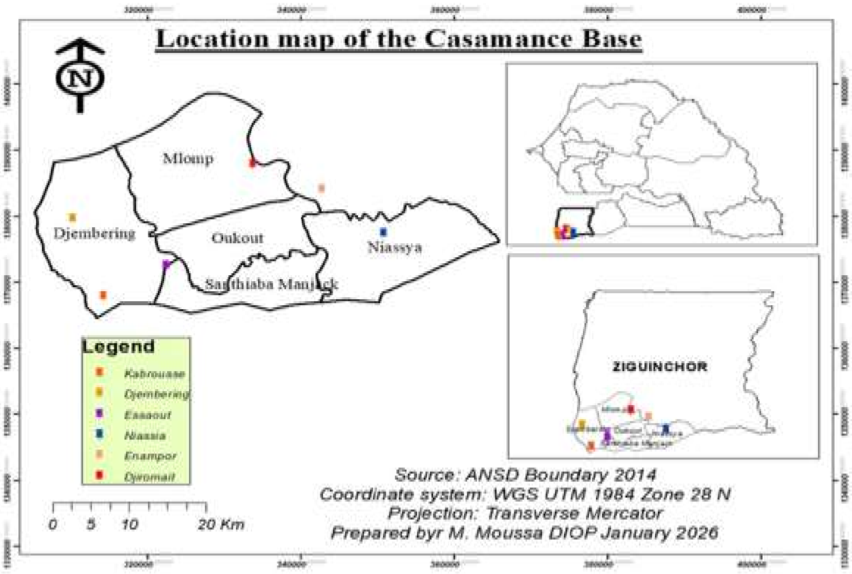

Figure 1: Location map of the study area showing surveyed sites and administrative boundaries

2.2 Equipment: Geophysical prospecting was carried out using an ADMT ZN-series rapid groundwater detector, a multi-channel instrument capable of high-resolution electrical resistivity measurements. The system allows configurations ranging from single-channel to 60-channel acquisition and provides rapid data collection with high measurement density. The equipment measures variations in apparent electrical resistivity using an AMNB quadripole configuration, where investigation depth increases with electrode spacing.

Additional tools included:

- Stainless steel electrodes and insulated cables for field measurements
- GPS receiver for site positioning.

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- Laptop with Aidu Water software for data processing.
- ArcGIS and Surfer software for mapping and visualization.

ADMT ZN equipment

2.3 Data Collection Procedure: Geophysical surveys were conducted along profiles of 60 m length at each site. Measurements were performed down to depths of approximately 100 m. Two electrodes were installed initially, and after each reading, electrode spacing was increased to probe deeper layers. Each profile was repeated at least twice to ensure reproducibility. If significant differences occurred between measurements, additional readings were taken until consistent results were obtained. The ADMT system utilizes natural electromagnetic fields of the Earth in the frequency range 0.1 Hz to 5 kHz. These fields propagate through subsurface materials according to their electrical resistivity, allowing detection of geological structures such as sandy aquifers, clay layers, and saline zones.

2.4 Mathematical Background: Wave propagation in the subsurface was modeled using the Helmholtz equation, which describes the behavior of harmonic electromagnetic waves in conductive media:

$$\nabla^2 H + k^2 H = 0$$

$$\nabla^2 E + k^2 E = 0$$

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where H and E represent magnetic and electric fields, respectively, and k is the complex wave number. Variations in measured resistivity values are interpreted in terms of lithology, porosity, saturation, and groundwater mineralization.

2.5 Data Processing and Interpretation: Raw measurements were processed using the Aidu Water software embedded in the ADMT system. The software generated pseudo-sections and iso-resistivity maps representing subsurface structures. These results were then exported to ArcGIS and Surfer for interpolation, mapping, and cross-section analysis.

Interpretation criteria were based on typical resistivity ranges:

- 5 Ω·m: clean sands with low clay content and fresh groundwater
- 2–5 Ω·m: sandy-clayey formations with moderate mineralization
- <1.5 Ω·m: clayey or saline horizons

These interpretations were compared with available borehole data and regional geological information to improve reliability.

2.6 Estimation of Aquifer Parameters: Aquifer thickness and expected yield were estimated using resistivity contrasts, depth of saturated zones, and previous pumping-test results from nearby boreholes. Porosity was assumed to be approximately 15%, consistent with sandy-clayey formations in the region. Recommended drilling depths and borehole diameters were determined according to aquifer thickness and anticipated irrigation needs.

Table 1: Summary of geophysical survey parameters.

Parameter	Value
Number of sites	9
Profile length	60 m
Maximum investigation depth	100 m
Equipment	ADMT ZN-series
Software used	AiduWater, ArcGIS, Surfer

2.7 Recommended Borehole Design: Based on interpreted aquifer geometry, boreholes were recommended with diameters of approximately 6 inches, depths ranging from 35 to 40 m, and screened intervals located within the main saturated sandy layers. Estimated exploitable yields were calculated between 12 and 14 m^3/h, suitable for small-scale irrigation systems. Monitoring of abstraction rates and periodic water-quality analysis were proposed to reduce risks of saline intrusion and aquifer degradation.

RESULTS AND DISCUSSION

3.1 Resistivity Profiles and Lithological Interpretation: Electrical Resistivity Tomography surveys carried out at the selected sites in Lower Casamance, southern Senegal, revealed significant spatial variability in resistivity values, ranging from 0.2 to more than 5.8 Ω·m. These variations reflect differences in lithology, porosity, saturation, and groundwater mineralization.

High resistivity values (>5 Ω·m) were interpreted as clean sandy formations saturated with weakly mineralized freshwater, indicating favorable aquifer zones. Intermediate values (2–5 Ω·m) correspond to sandy–clayey formations, suggesting moderate permeability and possible mineralization. Very low resistivity values (<1.5 Ω·m) indicate clay-rich layers or saline water horizons, often associated with coastal influence or poor recharge conditions.

These results are consistent with hydrogeological interpretations of sedimentary basins in West Africa, where resistivity contrasts are commonly used to differentiate aquifer lithologies and identify saline intrusion zones [1,5].

3.2 Aquifer Thickness and Spatial Distribution: ERT profiles revealed variations in aquifer thickness depending on structural position:

- **10–20 m thickness** along the Gambian anticline.
- **5–10 m thickness** near the Sédhiou structural high.
- **Up to 30 m thickness** in depressional zones such as Djembering.

These variations are controlled by structural highs, sedimentary depressions, and clay content within the Continental Terminal formations. Similar structural control on aquifer geometry has been reported in sedimentary basins of West Africa [3,4].

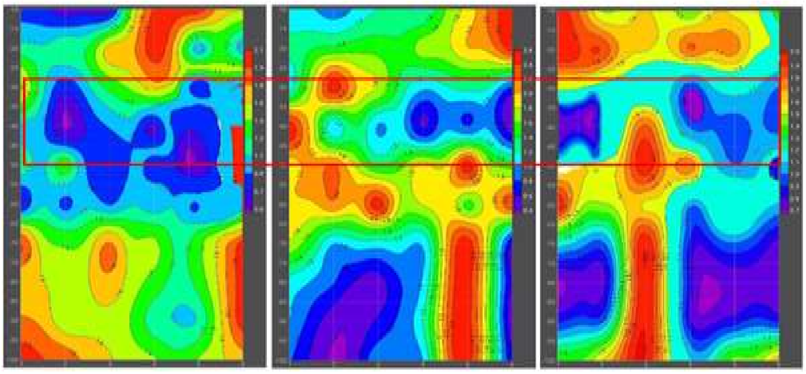

Figure 2: Example ERT sounding profile showing resistivity distribution and interpreted aquifer zones.

The saturated zone was generally observed between **17 and 40 m depth**, suggesting that optimal drilling depths should remain within 35–40 m to reach productive freshwater zones while minimizing drilling costs.

3.3 Site-Specific Results:

- **Essaou Site:** Two overlapping ERT profiles revealed a continuous sandy–clayey aquifer with a saturated thickness between 25 and 50 m. Groundwater quality appears generally good except near surface drainage channels influenced by saline intrusion. Recommended borehole depth is approximately 40 m, with expected yields around 14 m³/h.
- **Niassia Site:** Two aquifers were detected within 100 m depth. The shallow Continental Terminal aquifer lies between 17 and 35 m depth. The saturated zone between 17 and 40 m suggests yields of approximately 12 m³/h.
- **Djembering Site:** The aquifer thickness varies between 10 and 30 m. A central piezometric depression indicates groundwater flow toward a hydraulic low, possibly caused by natural evaporation or permeability variations rather than over-exploitation. However, the site remains sensitive to salinity risks due to proximity to coastal environments.

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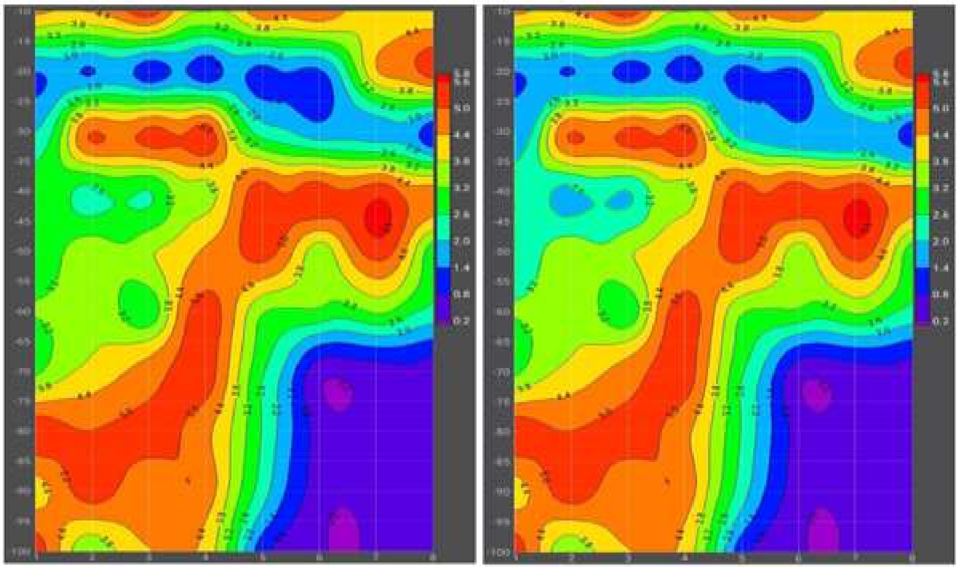

Figure 3: Comparison of resistivity profiles at Essaou, Niassia, and Djembering showing aquifer depth variations.

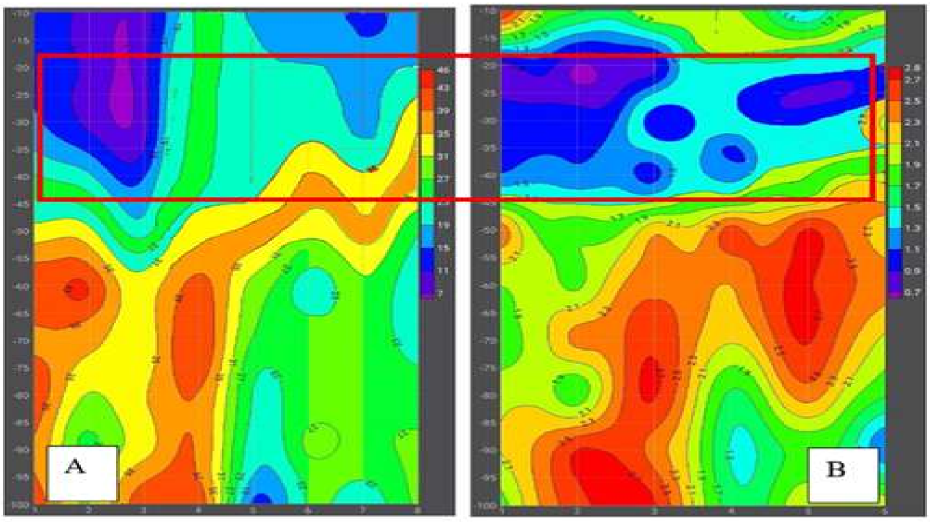

Figure 4: Sounding profile – ADMT ZN600 measurement at Djembering, dated 26/05/05

3.4 Estimated Aquifer Productivity: Aquifer productivity was estimated using resistivity interpretation combined with regional pumping-test data.

Table 1: Summary of Recommended Borehole Parameters

Site	Recommended Depth (m)	Aquifer Thickness (m)	Expected Yield (m³/h)	Borehole Diameter
Essaou	40	20–30	14	6 inches
Niassia	37	17–23	12	6 inches
Djembering	35–40	10–30	12–14	6 inches

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Table 2: Summary of water collection results.

Designation	Water intake structure
Intake Recommended	6 inches
depth Upper strainer	40 m
Upper strainer depth	25 m
Minimum depth	35 m

These results confirm that the Continental Terminal aquifer can support small-scale irrigation systems such as vegetable gardens and local farming schemes. Similar yield ranges have been reported in shallow sandy aquifers of West Africa [6].

3.5 Salinity Risk and Groundwater Quality: Low resistivity values observed near surface watercourses and coastal zones indicate saline intrusion risk. The mineralization gradient toward the coast reflects reduced recharge and seawater mixing, consistent with previous studies on groundwater salinization in Senegalese coastal aquifers [2].

Therefore, sustainable groundwater management is essential, including:

- Controlled pumping rates
- Periodic monitoring of water salinity
- Combined use of surface water storage
- Artificial recharge where possible

These strategies are widely recommended in sedimentary coastal aquifers worldwide to prevent degradation of groundwater quality.

3.6 Implications for Hydro-Agricultural Development: The study demonstrates that Electrical Resistivity Tomography is a reliable method for locating productive groundwater zones in complex sedimentary environments. Identifying optimal drilling depths between **35 and 40 m** reduces drilling costs and increases success rates for irrigation boreholes. With estimated yields of **12–14 m^3/h**, the Continental Terminal aquifer can support small irrigation schemes, improving agricultural resilience and food security in Lower Casamance. However, long-term sustainability depends on integrated groundwater management and monitoring programs.

CONCLUSION

The application of Electrical Resistivity Tomography provided a clear and reliable characterization of the Continental Terminal aquifer in Lower Casamance, southern Senegal. The geophysical surveys enabled the identification of aquifer geometry, lithological variations, and groundwater mineralization patterns across different structural zones. The results confirm that resistivity methods are effective tools for locating groundwater resources in heterogeneous sedimentary environments and for guiding borehole siting in regions where drilling costs are high and hydrogeological data are limited.

The study revealed aquifer thicknesses ranging from 5 to 20 m depending on structural context, with productive saturated zones generally located between 17 and 40 m depth. Recommended borehole depths between 35 and 40 m are expected to yield between 12 and 14 m^3/h, sufficient for small-scale irrigation systems and market-gardening schemes. These findings demonstrate that the Continental

Terminal aquifer represents a viable water resource capable of supporting local agricultural development and improving water security in rural communities. Despite these encouraging results, the investigation also highlighted areas vulnerable to saline intrusion, particularly near coastal zones and surface watercourses. Low resistivity values associated with clayey formations and mineralized water indicate the need for careful groundwater abstraction. Sustainable management strategies—including controlled pumping, periodic monitoring of water quality, and integrated use of surface water resources—are essential to prevent aquifer degradation and ensure long-term resource availability.

Overall, this research contributes valuable hydrogeological knowledge for groundwater development planning in Lower Casamance. By integrating geophysical techniques with regional geological information, the study provides practical guidance for hydro-agricultural infrastructure while emphasizing the importance of environmental protection. Continued monitoring, additional borehole testing, and expanded geophysical surveys are recommended to refine aquifer models and support climate-resilient water management strategies in southern Senegal.

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