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INTEGRATED REMOTE SENSING AND ELECTRICAL GEOPHYSICS FOR GROUNDWATER EXPLORATION IN CRYSTALLINE BASEMENT AQUIFERS OF BURKINA FASO (WEST AFRICAN SAHEL)

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ABSTRACT

Rural communities in Burkina Faso depend almost exclusively on groundwater due to the scarcity and poor quality of surface waters, often affected by diffuse pollution. This resource remains highly vulnerable to the combined effects of climate variability, socioeconomic development, and increasing anthropogenic pressures. Groundwater exploitation in basement terrains is complicated by strong geological heterogeneity, with a drilling failure rate of about 20% based on a dataset of 368 boreholes. The national access rate, targeted at 80% in 2025, declined to 71.9% in 2015 and only slightly improved to 76.4% in 2020.

This study combines remote sensing and 1D electrical geophysical techniques to improve hydrogeological prospecting. The main objective is to determine whether it is possible to correlate geological lineaments with potential preferential groundwater flow zones, and to assess the thickness and nature of weathered zones.

Lineaments were mapped from Landsat imagery through manual and automatic extraction. Results were validated through electrical profiling and vertical electrical soundings (VES) using Wenner and Gradient configurations.

The results reveal a predominance of NE-SW and NW-SE oriented lineaments, correlated with low resistivity zones (100-600 $\Omega \cdot m$) associated with weathered and/or fractured zones. Approximately 25% of successful boreholes coincide with these intersections. Geophysical anomalies of “U” and “H” types were identified as potential drilling targets, although highly conductive anomalies in some cases correspond to clay rich or clogged zones, explaining unproductive boreholes.

This approach provides a useful framework for improving groundwater targeting in basement regions.

Keywords: Groundwater resources; Electrical resistivity; Discontinuities; Remote sensing; Geophysics

1 INTRODUCTION

In Burkina Faso, access to sufficient quantities of and good quality water in rural areas remains low and represents a major challenge [1,2]. Access to safe and reliable groundwater is essential for public health and socioeconomic development due to the scarcity and strong seasonal variability of surface water resources [3]. This situation highlights the urgent need to reliable and efficient methods for locating and characterizing groundwater resources to improve water supply services.

The rapid development of rural areas further complicates this challenge, as it increases water demand for agriculture, livestock, industry, and domestic use [4–6]. This issue is particularly acute in basement regions, where the identification and exploitation of productive borehole zones remain complex due to strong geological heterogeneity and the vulnerability of groundwater resources to both natural and anthropogenic contamination [7–11]. Basement aquifers, developed within weathered and fractured zones overlying and within crystalline rocks such as granites, gneisses, and schists, play a key role in groundwater availability, making structural analysis essential indispensable for identifying favorable drilling sites [12–19].

The Kourwéogo Province, located in the Central Plateau region of Burkina Faso, includes five municipalities, among which Niou and Laye selected as the study areas. The villages of Tangséghin and Goabga (Niou commune) and Laye Centre and Gontodogo (Laye commune) represent local settings where groundwater access remains challenging in basement terrains. These localities host a professional training center in agriculture and livestock and a youth rehabilitation center, both requiring reliable and sustainable groundwater supplies. Despite multiple drilling campaigns, the reported failure rate remains around 20%, reflecting the difficulty of identifying productive aquifer zones in such geological environments. Furthermore, several existing boreholes yield less than 2.5 m³/h, which may limit their ability to meet local water demands.

Faced with these challenges, the following question arises: to what extent can the integration of remote sensing and electrical geophysics improve the identification of favorable drilling sites in basement terrains?

To address this question, a combined approach integrating remote sensing electrical profiling, and vertical electrical sounding (VES) was implemented. Using Landsat 8 OLI imagery, lineaments and geological structures favoring groundwater infiltration were mapped. The electrical methods including profiling and vertical electrical soundings (VES) using Wenner and Gradient configurations were applied to validate and characterize the structural anomalies identified through remote sensing.

The same protocol was applied in both communes but adjusted to their distinct geological contexts to compare their geoelectrical responses and explain possible causes of drilling failures [20–27]. To better understand these failures, the geophysical setups were also applied directly on previously nonproductive borehole sites. This direct comparison provided valuable insights into the causes of unsuccessful drillings and contributed to improving future groundwater exploration strategies.

Although the combination of remote sensing and electrical geophysics is widely used in crystalline basement contexts, predicting borehole success rates remains challenging due to false-positive electrical anomalies. Conductive features often lead to drilling failures when associated with clay-rich weathered horizons, clogged joints, or hydraulically disconnected fracture networks. To address this limitation, this study provides a novel comparative assessment between two distinct Sahelian communes (Niou and Laye, Central Plateau of Burkina Faso) by specifically deploying 1D geophysics directly over known productive and unproductive borehole sites. The main objective is to establish diagnostic geoelectrical criteria capable of differentiating productive water-bearing fractures from non-productive conductive traps, thereby optimizing future drilling strategies in hard-rock aquifers [1,2].

2 MATERIAL AND METHODS

2.1 Study Area

This study was conducted in the rural communes of Niou and Laye, located in the Central Plateau region of Burkina Faso. The region covers an area of approximately 8,600 km² and includes the provinces of Ganzourgou, Ouhritenga, and Kourwéogo. The two study communes lie between 12°30'–12°45' N latitude and 1°50'–2°00' W longitude, encompassing a combined surface area of about 400 km². Administratively, they belong to the Kourwéogo Province, and their population is predominantly rural, engaged mainly in agriculture and livestock farming.

The vegetation cover consists of shrub and tree savannah, dominated by species such as *Vitellaria paradoxa* (shea tree), *Parkia biglobosa* (African locust bean), *Lannea microcarpa*, *Tamarindus indica* (tamarind), and *Adansonia digitata* (baobab). However, vegetation degradation is ongoing due to overgrazing, agricultural clearing, and wildfires.

The climate is Sudano Sahelian, characterized by a short rainy season (June to September) and a long dry season (October to May). Annual rainfall ranges between 700 and 900 mm, with marked interannual variability linked to climate change. Temperatures fluctuate from 18 °C in January to 40 °C in April, while potential evapotranspiration is estimated at around 1,800 mm/year, resulting in a significant water deficit and reinforcing the population's dependence on groundwater resources.

Geologically, the study area is underlain by Lower Birimian formations of the West African Craton, consisting mainly of granites, gneisses, and schists. This Precambrian basement has been affected by several tectonic episodes, resulting in a well developed of fractures and faults predominantly oriented NE-SW and NW-SE. These structural discontinuities may control groundwater flow and storage within weathered and fractured zones. The basement aquifers are discontinuous, with the thickness of the weathered layer varying from 10 to 40 m, depending on lithology and the degree of weathering and fracturing.

The soils are tropical ferruginous types, generally shallow and of low fertility, resting on clayey saprolites, sometimes hardened into lateritic crusts. These soils are sensitive to water erosion and directly influence infiltration processes and aquifer transmissivity.

The hydrographic network is poorly developed and dominated by seasonal streams, including the Nakambé, Massili, and Koulottoko rivers and streams, along with a few artificial reservoirs. In Niou, the hydrology is controlled by the Nakambé watershed, while in Laye, it is influenced by the Koulottoko stream, a tributary of the Pabré reservoir. Because of the intermittent nature of surface flows, local populations depend primarily on boreholes and modern wells for their water supply.

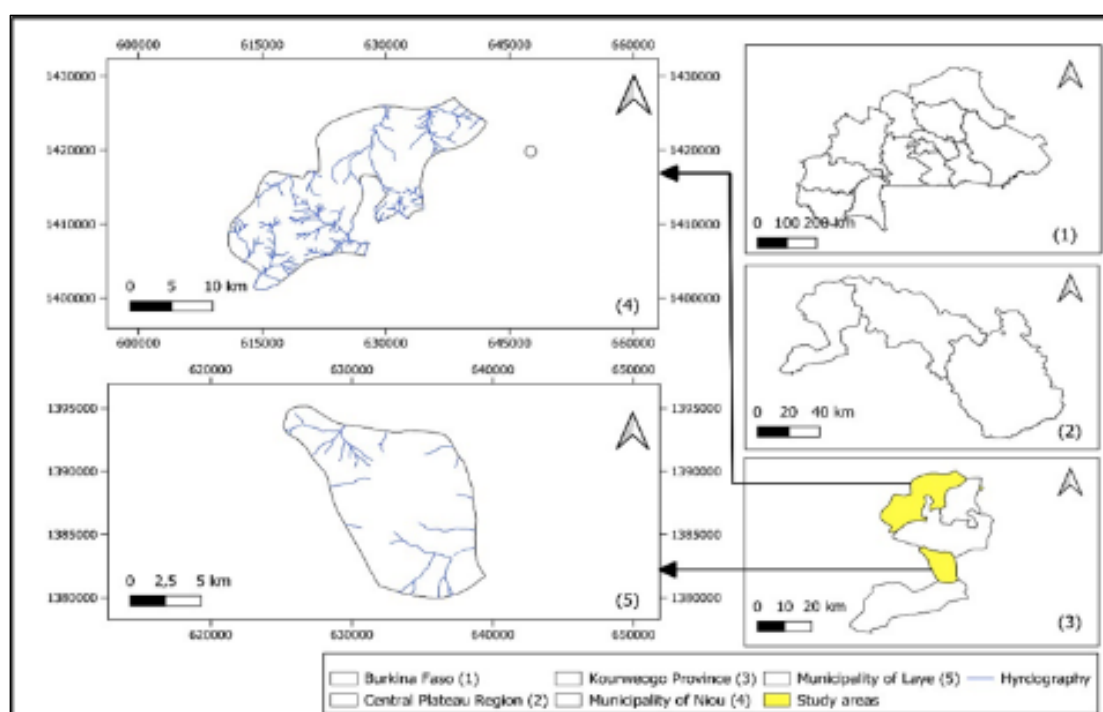


Figure 1: Representative map of the communes of Niou and Laye

The commune of Niou, located about 65 km northwest of Ouagadougou, covers 224 km² and includes 21 villages, among which Tangséghin and Goabga were selected for this study. The relief, typical of a granitic peneplain, is punctuated by residual hills formed from Birimian bedrock. The commune of Laye, about 35 km northwest of the capital and covering 124 km², exhibits a similar geological landscape but with flatter topography composed of lateritic plains and plateaus interspersed with shallow valleys.

The selection of Niou and Laye was motivated by their contrasted geomorphological and hydrogeological settings, their documented drilling success and failure records, and the presence of well-developed crystalline basement aquifers representative of many hard-rock environments in the West African Sahel. This comparative framework provides an

opportunity to evaluate whether similar geoelectrical signatures systematically correspond to productive groundwater targets.

2.2 Remote sensing data processing

2.2.1 Remote sensing data analysis by

The mapping of lineaments in the communes of Niou and Laye was carried out using Landsat 8 OLI imagery, with the objective of identifying structural features potentially influencing groundwater circulation and dynamics. Several studies have demonstrated the relevance of these images for hydrogeological prospecting in basement environments.

The dataset covers well defined areas delimited by the following geographic coordinates: for the commune of Niou, the upper left point (Latitude: 14°3'31.14" N, Longitude: 2°11'35.92" W) and the lower right point (Latitude: 11°58'21.55" N, Longitude: 0°55'35.65" W); and for the commune of Laye, the upper left point (Latitude: 12.9331° N, Longitude: -2.0829° W) and the lower right point (Latitude: 11.8738° N, Longitude: -0.4113° W). The Landsat 8 images, composed of 11 spectral bands with spatial resolutions ranging from 15 to 100 meters, were acquired during the dry season to ensure reduced cloud cover and improved image quality.

Preprocessing involved a Principal Component Analysis (PCA), a statistical method used to reduce spectral redundancy and enhance the discrimination of image features [8,30–32]. This PCA, widely used in previous studies, was applied to selected visible and infrared bands (OLI 2, 3, 4, 6, 7, and 10) to reduce spectral redundancy and enhance the discrimination of linear and lithological features. A secondary processing step involved resampling pixels from to a uniform 30 m resolution [33–35].

To enhance structural discontinuities, band ratio techniques were applied. Several combinations were tested, including OLI5/OLI6, OLI5/OLI10, OLI7/OLI10, OLI6/OLI5, and OLI4/OLI3. In parallel, the ARSIS method was employed to compute the Normalized Difference Vegetation Index (NDVI), while ratios between spectral bands (OLI5/OLI6, OLI5/OLI4, OLI7/OLI4, OLI6/OLI5) helped identify characteristic lineaments from Landsat 8 imagery [36].

RGB composite images were generated by combining different spectral bands and derived products to enhance the discrimination of lithological and structural features. The optimal combination selected was OLI7 (red channel), OLI5/OLI4 (green channel), and the PCA component derived from bands 2 (blue channel). This combination provided better differentiation of geological units and linear structures.

Sobel directional filters, commonly used to detect lineaments, were applied in multiple orientations (N-S, E-W, NE-SW, NW-SE) using a 7×7 matrix with a weight factor of 6 [8,28,29,37–39]. These filters effectively highlighted discontinuities associated with major geological features such as faults and shear zones. The extracted lineament orientations were classified in 10° intervals to generate rose diagrams showing the dominant lineament orientations [40–42].

Lineament extraction was carried out using two complementary approaches. First, automatic extraction was performed after image processing, followed by manual removal of anthropogenic features (roads, tracks, field boundaries). Second, expert visual interpretation was used to validate and refine the automatically extracted lineaments using the same software tools (ENVI, ArcGIS, Geomatica, and RockWorks).

Finally, several methodological limitations should be noted. The spatial resolution of Landsat images (15–30 m) does not always allow the detection of microfractures with limited extension [23]. Furthermore, manual extraction involves a degree of subjectivity, although it remains essential for the interpretation and refinement of remotely sensed lineaments.

2.2.2 Validation of the Lineament Map

The first validation approach was based on the spatial superposition of mapped lineaments with existing borehole locations, categorized according to the CIEH typology (productive and non-productive wells). Positive spatial correlations between fracture zones and high yield boreholes were considered reliable indicators of the accuracy of the interpreted lineaments.

To further confirm the identified structural features, a 1D geophysical survey was conducted. This investigation aimed to characterize subsurface geometry and distinguish alteration and fractured zones based on electrical resistivity contrasts.

The applied geophysical methods relied on measuring soil electrical resistivity by injecting an electric current through a pair of electrodes (A, B) and recording the potential difference between another pair (M, N). This approach enables

the detection of low resistivity zones, typically corresponding to fractured, clay rich, or water saturated horizons [20,43].

Within the Birimian basement context, electrical resistivity methods proved more suitable than seismic or electromagnetic techniques, which are often constrained by the high compaction of lateritic layers and weak lateral contrasts. Two configurations were employed: the electrical profiling (horizontal resistivity survey) and the Vertical Electrical Sounding (VES).

2.2.3 Electrical profiling: principle, measurement setup, and implementation

The electrical profiling method is a geophysical technique used to measure subsurface resistivity variations. It is highly effective for detecting low resistivity zones often associated with structural discontinuities. This approach is particularly useful for identifying subsurface heterogeneities and locating areas favorable to groundwater accumulation [20].

To obtain reliable results, the profiling device should be deployed in topographically low zones, typically downstream of major catchment areas or near permanent streams (such as small rivers) and well-marked geological fractures [8,29,43]. This setup reduces uncertainties and improves measurement accuracy. The array spacing can be adjusted depending on the desired depth of investigation, optimizing data acquisition. In hydrogeological surveys, several electrical resistivity methods are commonly used, each offering specific advantages depending on the study's objectives and the expected geometry of subsurface structures.

In the commune of Niou, measurements were performed using a Syscal *Pro* system with a Wenner Alpha configuration, a commonly used array for electrical resistivity profiling. The Wenner method is particularly sensitive to lateral resistivity variations, although its depth of investigation remains limited, making it well suited for characterizing shallow subsurface heterogeneities. For this study, the distance between the current electrodes (A and B) was set at 120 meters, with a sampling interval of 5 meters. This setup was considered suitable for investigating shallow subsurface targets, with an approximate nominal investigation depth of 30 meters ($AB/4$ to $AB/6$). Geometry facilitates field deployment and minimizes errors, making it ideal for repetitive measurements along extended profiles. The Wenner Alpha configuration's sensitivity to vertical resistivity contrasts makes it effective for identifying buried structures at varying depths.

Electrical profiling lines were oriented along two main directions $N45^\circ$ (NE-SW) and 160° ((approximately $N20^\circ W$)) to investigate subsurface electrical properties along perpendicular axes. This multidirectional approach enhances the detection of geological structures and their spatial continuity, providing a comprehensive view of subsurface heterogeneities and their influence on apparent resistivity distribution.

In the commune of Laye, the geophysical surveys were carried out using a Syscal R1 Plus 72 Switch system in a rectangular Gradient configuration. Unlike the Wenner setup, this configuration uses multi-electrode geometry that allows systematic investigation of lateral resistivity variations across the survey area. It is well suited to investigating lateral resistivity contrasts associated with possible vertical or subvertical structures, such as fractures, faults, and lithological contacts, in the local Birimian basement well suited to investigating lateral resistivity contrasts associated with possible vertical or subvertical structures, such as fractures, faults, and lithological contacts, in the local Birimian basement [23,28]. The adopted geometric parameters for both main and parallel profiles were $AB = 600$ m, $MN = 20$ m, with a measurement interval of 10 m. Profiles were oriented along 150° (approximately SE-NW) and 240° (approximately SW-NE) to intersect major lineaments identified through remote sensing and assess the extent of secondary fractures. Acquired data were processed using D resistivity inversion, providing two-dimensional resistivity models used to support the interpretation of subsurface heterogeneities and potential groundwater-bearing zones.

A comparative analysis between Niou and Laye highlights the importance of adapting profiling configurations to local geological settings. The Wenner Alpha configuration used in Niou provided information on shallow resistivity variations, whereas the Gradient configuration applied in Laye allowed two-dimensional characterization of lateral resistivity variations associated with possible fractured structures. This methodological complementarity facilitates comparison between electrical anomalies, mapped lineaments, and borehole yields, thereby providing an independent basis for assessing potential groundwater-bearing zones. The choice of distinct profiling arrays Wenner Alpha ($AB = 120$ m, nominal depth 30 m) in Niou and Gradient ($AB = 600$ m, nominal depth 70 m) in Laye was tailored to the local geomorphological and overburden conditions of each commune. While the shallow granitic peneplain in Niou required high lateral sensitivity to delineate shallow weathered structures, the deeper lateritic cover in Laye necessitated greater depth penetration to reach the underlying Birimian fractured basement.

2.2.4 Vertical electrical sounding (VES): principle, measurement setup, and implementation

Vertical Electrical Sounding (VES) is a geophysical technique used to investigate the vertical variation of apparent resistivity with increasing electrode spacing. Its principle is based on increasing the electrode spacing according to the selected array geometry, thereby increasing the depth of investigation. This method enables estimation of the resistivity and thickness of subsurface layers by comparing measured apparent resistivity data with theoretical layered-earth models [44].

The resistivity values obtained provide indirect information on subsurface lithology and hydrogeological conditions, although resistivity alone cannot uniquely determine lithology or groundwater occurrence. During measurements, when the signal weakens due to excessive electrode spacing, the interval can be adjusted to improve data quality. The recorded values are used to plot apparent resistivity curves, which are then inverted using theoretical layered-earth models to estimate subsurface resistivity and layer thicknesses. This approach is particularly suited to terrains with a predominantly horizontal geometry and sufficient lateral continuity [45,46].

In the commune of Niou, VES measurements were carried out using a *Syscal Pro* resistivimeter in Schlumberger / Wenner configuration, with electrode spacings (AB/2 OR AB/3) ranging from 1 to 80 m, corresponding to an approximate nominal investigation depth of 0.75 to 60 m. A total of four soundings were conducted. In the field, electrodes were systematically displaced for each measurement point, while the resistivimeter remained fixed. Data analysis a estimation of the resistivity and thickness of the main subsurface layers. However, determining the exact position of the groundwater table proved challenging due to weak resistivity contrasts between saturated and unsaturated zones, combined with lithological variations and the possible presence of clay-rich materials. The interpretation of results provided estimates of resistivity and thickness for each layer, delivering valuable information on subsurface structure and potential aquifer locations.

In the commune of Laye, VES surveys were conducted using the Schlumberger configuration, particularly suited for vertical characterization of geological layers. The spacing between current electrodes (AB/2) ranged from 1.5 to 500 meters, and between potential electrodes (MN/2) from 0.75 to 50 meters, allowing a maximum depth of investigation of about 70 meters. A total of five soundings were performed across two distinct sites, selected based on topographic constraints and the presence of lineaments identified through remote sensing.

Apparent resistivity curves were plotted on a bi logarithmic scale, with the half distance (AB/2) on the X axis and apparent resistivity on the Y axis. This representation facilitates visual interpretation of resistivity contrasts and lithological discontinuities [47]. The observed high resistivity values, sometimes coupled with strong contact resistances, may reflect variations in lithology, degree of weathering, moisture content, and electrode–ground contact conditions.

The VES data were processed using the IP2WIN software, which inverts experimental apparent resistivity curves using layered-earth models to estimate layer resistivities and thicknesses. The results revealed significant basement heterogeneity, with weathering thicknesses varying between 10 and 45 meters depending on lithology and fracture density. Low resistivity zones ($<600 \Omega \cdot m$) were associated with weathered or structurally disturbed zones and were therefore considered as potential groundwater-bearing targets, although low resistivity alone does not confirm aquifer productivity. The integration of VES results with electrical profiling and lineament mapping was used to assess the consistency between geoelectrical anomalies and mapped structures potentially favorable to groundwater occurrence.

However, some uncertainties remain particularly regarding the precise identification of the water table due to weak resistivity contrasts between saturated and unsaturated layers. Moreover, the presence of clay rich facies or mixed materials can produce conductive anomalies unrelated to actual permeability. These limitations were mitigated through cross validation with profiling results and existing borehole data, leading to a more comprehensive understanding of the hydrogeological behavior of basement aquifers in the studied communes.

2.2.5 Integration of remote sensing, geophysical and drilling data

Remote sensing, geophysical and drilling data were integrated to assess the relationship between surface lineaments, subsurface electrical anomalies and groundwater occurrence. The location and productivity of the boreholes were spatially compared to the mapped lineaments, with particular emphasis on boreholes located near the main intersections of the lines.

The boreholes were classified as positive or negative based on their recorded groundwater productivity. Electrical profiling and VES results were then compared to the linear distribution, focusing on areas of low resistivity and significant resistivity contrasts along or near structural structures. These anomalies were considered as potential indicators of weathered or fractured water-bearing zones, while recognizing that low resistivity may also reflect clay-rich materials.

Finally, borehole productivity was used as an independent field reference to assess the consistency of remote sensing and geophysical interpretations. The proportion of boreholes associated with major intersections of the linear was calculated to quantify the contribution of structural information to groundwater targeting.

3 RESULTS AND DISCUSSION

3.1 Processing of Remote Sensing Data

The analysis of the main groundwater corridors was conducted using Landsat 8 OLI satellite imagery combined with spectral, spatial and directional enhancement techniques. This approach not only enabled the mapping of the surface hydrographic network but also revealed its interconnections with geological structures and major tectonic features [8,40,43,48,49].

Principal Component Analysis (PCA) (Figure 2a for Niou and Figure 3a for Laye) played a central role in this process by reducing spectral redundancy and improving the detection of linear discontinuities. This technique effectively distinguished regional lineaments from those related to the drainage network. The results highlighted central and southern zones with gray tonalities, where lineaments trending NW-SE N°45° and N-S correspond to structural discontinuities associated with Precambrian tectonics [50].

To refine the interpretation, several RGB composite images were generated by combining different spectral bands (Figure 2b for Niou and Figure 3b for Laye) and band ratios: OLI5/OLI6, OLI5/OLI10, OLI7/OLI10, OLI6/OLI5, and OLI4/OLI3. Among these, the selected combination OLI7 (red), OLI5/OLI4 (green), and PCA of bands 2 and 3 (blue) proved particularly effective for enhancing rough, dark textured zones interpreted as potentially related to fractured areas. These images also revealed dendritic and trellis drainage patterns, typical of granitic terrains, illustrating the coexistence of weathered (beige tones) and vegetated moist areas potentially associated with higher moisture conditions (bright red tones). These contrasts reflect both the degree of weathering and areas potentially favorable to preferential recharge. The results align with earlier studies conducted in Cote d'Ivoire [10,51] and Burkina Faso [8,40,43,48,49], supporting the interpretation that major fractures can influence aquifer interconnectivity and productivity in basement environments.

To enhance the interpretation of linear features, a Sobel directional filter was applied to the OLI7/OLI10 composite (Figure 2c for Niou and Figure 3c for Laye). This technique successfully identified previously undocumented lineaments interpreted as potentially corresponding to lithological or structural discontinuities. By accentuating local contrasts, the filter produces a shaded relief effect that facilitates the visualization of fractures. The analysis revealed several structural orientations, including E-W, NW-SE (Liberian origin), and NE-SW (Eburnean origin). Some of these features align with parallel mapped structural trends or reoriented drainage channels, suggesting strong interactions between tectonic structures and surface hydrology. Major discontinuities appear as dark or gray elongated zones trending near N°10, indicative of kilometer scale fracture corridors. Additional linear features are potentially related to fault system through composite color analysis [28,33].

A detailed examination of the lineament maps shows that most structures trend NW-SE and NE-SW, orientations that are particularly significant for groundwater exploration. These fractures are considered highly favorable for groundwater occurrence, as they coincide with zones of intense alteration and high hydraulic connectivity. The findings corroborate previous research conducted in similar basement settings, confirming the reliability of lineaments as indicators of tectonic structures and potential aquifers. Moreover, comparisons with other regions highlight that the integration of satellite imagery analysis with specific directional filters such as Sobel represents a robust approach for mapping geological and hydrographic discontinuities, even in areas with dense vegetation cover or complex structural patterns.

However, several uncertainties remain inherent to remote sensing methods. Despite the proven efficiency of Landsat imagery, its moderate spatial resolution (15-30 m) limits the detection of minor fractures that are often critical for infiltration processes [8,29]. In addition, during the rainy season, dense vegetation may obscure structural features, complicating their interpretation [40]. This limitation could be mitigated by the use of multitemporal dry-season imagery, which enhances geological contrast [39]. Finally, automatic detection algorithms, including Sobel filtering, may produce artifacts caused by surface textures unrelated to geological structures or hydraulically active fractures [23].



Figure 2: Results of remote sensing data processing in Niou

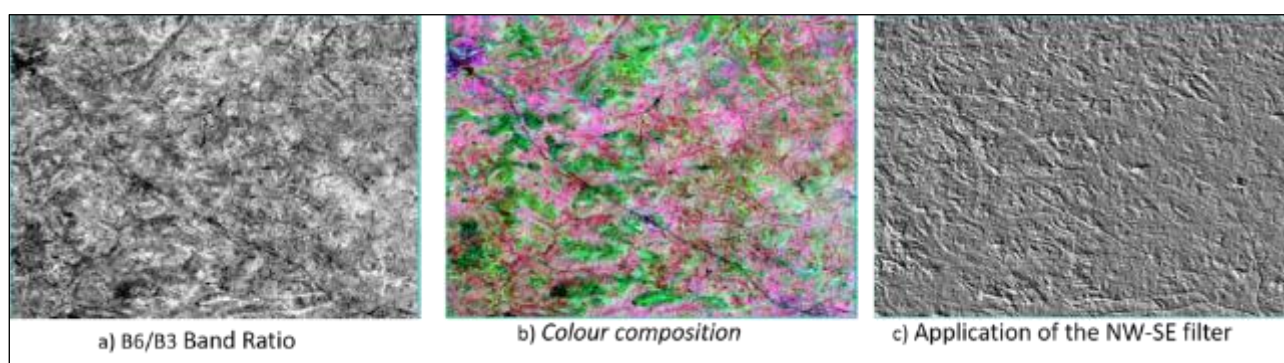


Figure 3: Results of remote sensing data processing in Laye

3.2 Lineament Mapping and Directional Rosette Analysis

The map illustrates the distribution of lineaments identified in the communes of Niou (Figure 4) and Laye (Figure 5). It was used to analyze the spatial organization of the main structural features. The rosette representation highlights both the frequency and the cumulative length of the lineaments extracted from the Landsat imagery.

For the commune of Niou, the dominant orientations identified manually from the directional rose diagram (Figure 4a) reveal a clear predominance of the NE-SW trend, corresponding to the $N40^{\circ}$ - $N60^{\circ}$ and $N220^{\circ}$ - $N230^{\circ}$ axes, which are consistent with regional shear zone orientations. This orientation is commonly associated with fracture systems and faults, indicating a significant degree of structural deformation in the region. A secondary set of lineaments with a NW-SE orientation ($N130^{\circ}$ - $N150^{\circ}$ and $N310^{\circ}$ - $N330^{\circ}$) was also observed, suggesting a subordinate structural expression. Additional orientations ($N45^{\circ}$ - $N135^{\circ}$) are present as well, reflecting the structural diversity within the study area.

In the commune of Laye (Figure 5a), the dominant directions identified manually include the NE-SW ($N40^{\circ}$ - $N60^{\circ}$) and NW-SE ($N130^{\circ}$ - $N150^{\circ}$) trends. These two structural families are consistent with regional tectonic trends and Eburnean tectonic phases, often associated with deep seated fault zones and reactivated fractures. They generally coincide with areas of enhanced secondary permeability, which favor groundwater infiltration and circulation. Secondary orientations along the E-W ($N80^{\circ}$ - $N100^{\circ}$) and N-S ($N0^{\circ}$ - $N20^{\circ}$) axes, though less frequent, likely correspond to additional fracture or reactivation trends related to regional tectonic deformation.

The lineament network shows higher density in the central and northeastern parts of the area, where several structural lineament families intersect, forming zones of potential tectonic connectivity. These intersections represent potential groundwater targets, as they may indicate enhanced fracturing and hydraulic connectivity. Conversely, the southern and southwestern sectors appear less fractured, indicating potentially more competent or less weathered basement rocks.

The mapped drainage network exhibits orientations parallel or coincidence with the main NE-SW and NW-SE lineaments, indicating a direct tectonic control on surface drainage. This correlation confirms the influence of tectonics on both hydrographic morphology and subsurface groundwater flow a pattern typical of fractured basement environments [7,10,51].

From a hydrogeological perspective, fractures must be characterized according to their geometric features, particularly joint aperture. Previous studies in Burkina Faso [8,26] indicate that NW-SE and NE-SW orientations are generally associated with higher borehole productivity. However, in this study, the NW-SE direction is less represented, which may reflect differences in local structural conditions or limitations in lineament detection.

Conversely, the N-S and E-W trends are often linked to non-productive boreholes because of joint closure at depth, reducing permeability. Yet, these directions ($N0^{\circ}$ - $N20^{\circ}$ and $N180^{\circ}$ - $N190^{\circ}$) are well expressed in our data. This could result from local tectonic or geological conditions, such as distinct regional stress regimes or recent fracturing episodes. Chemically or mechanically reopened joints may also enhance permeability along these axes. Fractures oriented $N45^{\circ}$, $N90^{\circ}$ and $N225^{\circ}$ appear to correlate with productive boreholes, suggesting potentially more open or transmissive structures.

The lineament framework provides important structural information for interpreting groundwater circulation and storage. Its orientation strongly influences the siting of boreholes and hydraulic infrastructure (wells, small dams). Although E-W and N-S directions are less dominant, their structural significance should not be underestimated, as they may correspond to adjustment fractures or geomorphological alignments such as valleys or streambeds.

Overall, the lineament network appears dense but spatially heterogeneous, with concentration zones in the center and northeast where multiple families intersect. These intersection zones represent potential priority targets for groundwater exploration, as they may indicate enhanced fracturing and hydraulic connectivity. However, variations in structural density may also reflect limitations related to Landsat spatial resolution and image processing.

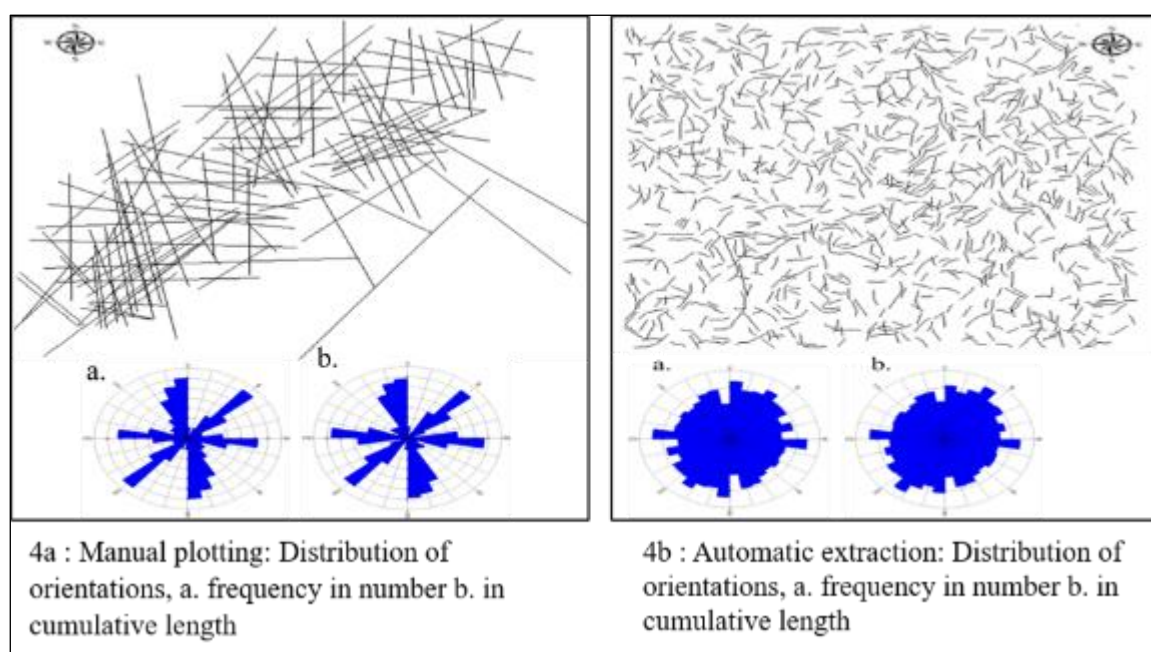


Figure 4:1 Lineaments of the commune of Niou

Figure 4b (Niou) shows a dense network of lineaments extracted automatically from processed imagery. Analysis of orientation frequency and cumulative length diagrams reveals a predominance of N-S ($N0^{\circ}$ - $N20^{\circ}$ and 160° - $N180^{\circ}$) and E-W ($N70^{\circ}$ - $N90^{\circ}$ and $N250^{\circ}$ - $N270^{\circ}$) trends. This distribution suggests the presence of dominant structural trends organized along these two dominant directions. Intermediate NE-SW and NW-SE orientations ($N45^{\circ}$ and $N135^{\circ}$) are also visible, possibly reflecting shear-related deformation or the superposition of multiple structural trends. The presence of intersecting linear patterns may reflect a complex structural framework, potentially related to polyphase deformation.

Figure 5b, corresponding to the commune of Laye, illustrates lineaments automatically extracted from satellite imagery. Statistical analysis of their orientations, based on frequency and cumulative length diagrams, highlights two dominant lineament families: NE-SW ($N40^{\circ}$ - $N60^{\circ}$) and NW-SE ($N130^{\circ}$ - $N150^{\circ}$). These are consistent with structural trends observed in fractured basement zones in the Central Plateau and may be related to regional fault systems. Secondary orientations along ENW ($N80^{\circ}$ - $N100^{\circ}$) and N-S ($N0^{\circ}$ - $N20^{\circ}$), though less prominent, may reflect additional fracture or reactivation trends. This bidirectional organization consists of a polyphase structural history. The high density and continuity of the observed lineaments may indicate enhanced structural connectivity and therefore potential relevance for groundwater flow. These findings are consistent with previous geophysical observations in the region, supporting

the interpretation that NE-SW and NW-SE structures may be important groundwater targets. Thus, the automated analysis provides additional evidence for the presence of major structural trends relevant to hydrogeological prospecting and sustainable water resource management in the commune of Laye.

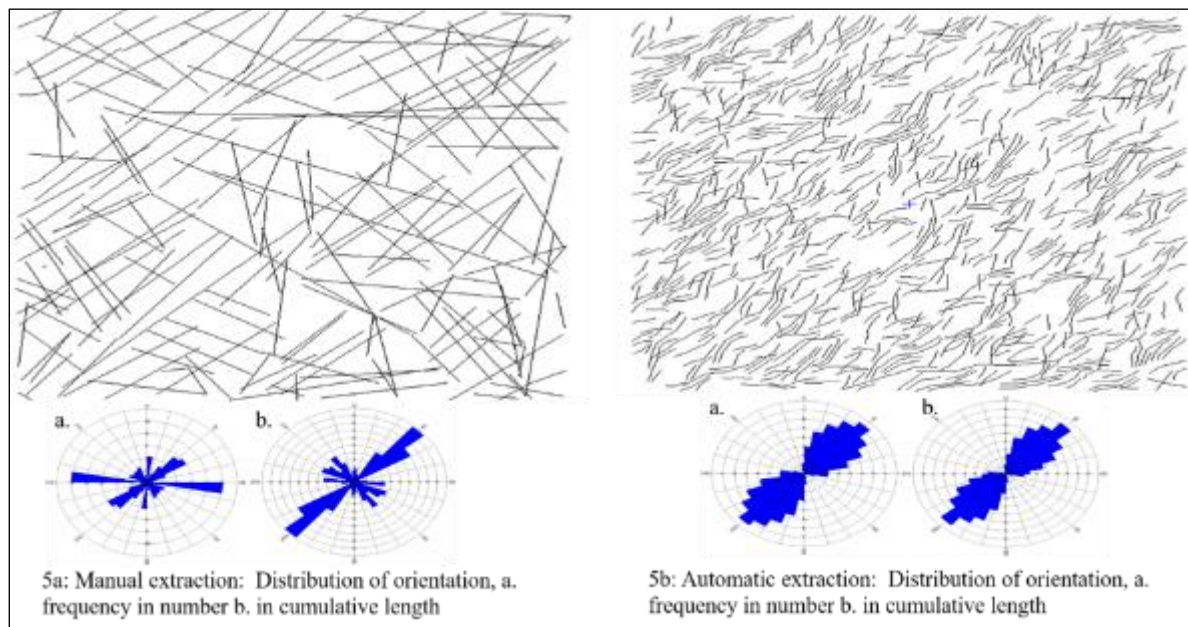


Figure 5:2 Lineaments of the commune Laye

The two lineament extraction approaches applied in the communes of Niou and Laye exhibit distinct characteristics and implications for hydrogeological interpretation.

The method illustrated in Figures 4a and 5a is based on manual extraction, relying on visual interpretation of lineaments and their directional rose diagram representation. This approach emphasizes the hydrogeological significance of the structures, revealing a predominance of NE-SW orientations, generally correlated with deep shear zones and increased rock permeability. Although N-S and E-W trends are also frequent, they appear less favorable from a hydrogeological standpoint due to the progressive closure of joints at depth. This lower productivity may also result from anthropogenic or local factors, such as intensive agricultural practices that can alter or obscure the natural expression of geological structures.

Conversely, the second approach, illustrated in Figures 4b and 5b, relies on automatic extraction using digital processing and quantitative analysis tools, notably through frequency and cumulative length diagrams. This method highlights dominant N-S and E-W orientations, interpreted as reflecting large, continuous regional tectonic structures. Intermediate NE-SW and NW-SE directions are also identified, suggesting superimposed tectonic phases and a more complex deformation history. These results underline the multi-phase tectonic evolution of the region and its structural complexity.

Although both approaches differ in analytical focus, they are highly complementary. Automatic extraction offers advantages in speed, objectivity, and reproducibility; however, it may generate artifacts in areas of strong lithological heterogeneity, where optical contrasts can be misinterpreted as fractures. Manual interpretation, on the other hand, provides better contextual integration of field knowledge and geomorphological observations but remains influenced by operator subjectivity.

Each method presents specific yet complementary limitations. Automatic extraction, while efficient, tends to be less accurate in geologically complex settings, as algorithms may confuse lithological boundaries or surface textures with fractures. Manual extraction, though more nuanced, is prone to interpretation bias. When combined, these two methods provide a more comprehensive understanding of the regional lineament framework. The observed orientations may carry different meanings depending on the analytical context whether aimed at interpreting large scale tectonic structures or identifying zones favorable for groundwater infiltration. This complementarity represents a significant asset for improving the understanding of both geological and hydrogeological systems.

3.3 Validation of the lineament map by drilling overlay

The validation of the lineament map was carried out by superimposing existing boreholes onto the extracted structural map (Figure 6), in order to evaluate the spatial correspondence between the identified lineaments and groundwater-productive zones. This approach aimed to assess whether remotely detected lineaments coincide spatially with preferential subsurface flow pathways.

Out of a total of 73 boreholes, approximately 25% coincide with intersections of major lineaments, indicating a correspondence spatial concordance between surface-observed structures and productive borehole locations. The remaining 75% show no direct correlation, which can be attributed to the presence of secondary or masked fractures concealed beneath weathered formations or limitations in lineament detection at the spatial resolution of Landsat imagery.

It should be noted that this proportion has not yet been statistically benchmarked against the coincidence rate expected under a null model of spatial independence (e.g., based on lineament buffer density), and this comparison is identified as a priority for a dedicated follow-up analysis to confirm the strength of the structural control suggested by this spatial association.

Directional analysis reveals that boreholes correlated with lineaments are distributed as follows: 10% along the NW-SE direction, 7% along NE-SW, 5% along N-S, and 3% along E-W. This ranking suggests the relative influence of structural orientations in the order: NW-SE > NE-SW > N-S > E-W. Such distribution likely reflects the presence of secondary or less visible fractures not fully captured at the analytical scale employed. The predominant lineament orientations, notably N120°-N140° (NW-SE) and N40°-N60° (NE-SW), appear to be potentially important orientations for groundwater exploration, consistent with findings reported in other Birrimian basement contexts across West Africa.

These results align with previous observations by several authors in similar geological settings. The dominant fracture families, mainly associated with granitic and schistose formations, are inherited from Eburnean Pan-African tectonic events that have influenced the morphology of the regional drainage network [8,38,43,51]

The superposition of productive boreholes with areas of high lineament density highlights strong spatial correlations around the Tangséghin and Goabga localities, where lineament intersections coincide with multiple productive water points. From a hydrogeological perspective, these intersections represent zones of concentrated subsurface drainage, generally corresponding to open fracture joints that enhance both infiltration and groundwater flow within the weathered basement [52].

These findings confirm the reliability of lineament mapping as a valuable decision-support tool for siting boreholes in fractured basement environments of the Central Plateau region of Burkina Faso.

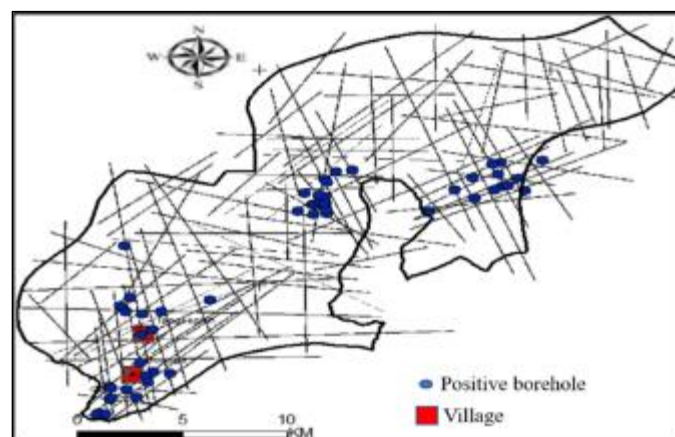


Figure 6: Superposition of positive boreholes with respect to the orientations of the common lineaments of Niou

3.4 Validation of the Lineament Map through Geophysical Investigations

3.4.1 Electrical Profiling Niou Commune

3.4.1.1 Profile 1: Favorable Potential

The interpretation of the electrical profiling data reveals marked heterogeneity in subsurface properties, reflecting significant variations in lithological composition and groundwater saturation. The alignment of lineaments identified from satellite imagery is supported by the geophysical profile. However, it is evident that parallel profiles would be beneficial to better delineate the orientation and direction of validated fractures, identified through low-resistivity contact zones. Nevertheless, the detection of lineaments via satellite imagery broadens the investigation area and, helps guide the positioning of electrical profiles and potential borehole sites.

Resistivity values, ranging from 253.86 to 594.32 $\Omega\cdot\text{m}$ and oriented NW-SE, indicate zones with distinct hydrogeological characteristics. As shown in Figure 5a, additional contacts not visible in the satellite images were identified. The lowest resistivity values (e.g., 255.86 and 253.02 $\Omega\cdot\text{m}$) correspond to highly conductive zones, likely associated with may be associated with weathered or water-saturated formations where the presence of water enhances electrical conduction. Conversely, higher resistivity values (around 592.9-594.32 $\Omega\cdot\text{m}$) are generally indicative of compact or low-permeability geological formations, such as massive granites or weakly fractured metamorphic rocks. Intermediate values (between 320.0 and 343.21 $\Omega\cdot\text{m}$) may represent transition zones between aquifers and impermeable layers, characterized by alternating permeable and non-permeable materials. Sharp resistivity variations such as from 592.9 to 401.11 $\Omega\cdot\text{m}$ suggest the presence of major geological discontinuities, such as faults or lithological contacts, which significantly influence groundwater circulation. Overall, these results highlight the hydrogeological complexity of the study area.

Analysis of anomaly shapes further supports this interpretation. According to [44], three main anomaly types are typically observed along the profiles: “U”, “M”, and possibly “K” anomalies, with the latter being less significant. The “W” and “V” shaped anomalies commonly associated with fractures in granitic environments oriented NE-SW [8] were not observed in this study.

Three points display “U” shaped anomalies with resistivity values of 255.86, 253.02, and 286.9 $\Omega\cdot\text{m}$, which, according to [8], are associated with borehole success rates approaching 100%. However, [8] reported that, in the Sissili region (a similar basement environment), 18% of unsuccessful boreholes also presented “U” shaped anomalies. This comparison highlights that the presence of a “U” shaped anomaly alone does not guarantee borehole productivity. Several factors can explain this discrepancy.

First, the interpretation of geophysical data can vary depending on study context and criteria used to define a “U” shaped anomaly. For instance, clay-rich formations can produce “U” shaped curves without containing exploitable groundwater, since clays are conductive but may not indicate productive aquifers. Secondly, secondary minerals (e.g., clays, calcite) may clog fractures, preventing effective water circulation. Moreover, in isolated or weakly connected fracture zones, apparent geophysical signatures may not correspond to productive water-bearing structures.

External factors such as rainfall variability, seasonal effects, and fracture storage capacity also influence borehole productivity. Differences in measurement protocols, equipment, and field procedures further contribute to variations in reported success rates. Additionally, the array configuration can affect results: the Schlumberger array tends to produce greater discrepancies, whereas the Wenner array, used in this study, provided the measurement framework adopted for the present profiles.

Interestingly, one traditional borehole site, identified through local divination practices (commonly referred to as the “Dowsing method” traditional dowsing practices), was also investigated along the profile. This point shows a resistivity of 366.21 $\Omega\cdot\text{m}$. Based on its location, it likely corresponds to a slope break or transition zone. In this case, slope changes do not necessarily indicate lithological variations but rather differences in water content within the same layer. Vertical electrical sounding (VES) is planned at this site to better understand the subsurface structure and the shape of the anomaly curve.

These results corroborate findings from previous studies conducted in similar geological contexts, where low-resistivity zones are frequently associated with favorable conditions for groundwater accumulation.

3.4.1.2 Profile 2: Absence of Promising Targets

Resistivity values ranging from 334.10 to 781.78 $\Omega\cdot\text{m}$ reveal marked variations, reflecting differences in lithological composition, weathering conditions, and groundwater saturation. This range allows the identification of significant geological discontinuities.

The low resistivity values (334.10-484.51 $\Omega\cdot\text{m}$) correspond to highly conductive zones, which may be associated with water-saturated layers or weathered rocks exhibiting increased permeability. The intermediate values (484.51-617.77 $\Omega\cdot\text{m}$), notably around 508.1 and 561.25 $\Omega\cdot\text{m}$, are typical of transition zones between permeable and impermeable formations. These values suggest alternating geological layers such as sand mixed with clay or partially saturated zones, which influence groundwater flow dynamics.

In contrast, higher resistivity values (617.77-797.29 $\Omega\cdot\text{m}$), including 797.29 and 796.84 $\Omega\cdot\text{m}$, are characteristic of compact and low-permeability formations, such as massive granites or weakly weathered metamorphic rocks. These environments, with limited alteration and low water content, are marked by high resistivity and may have limited water storage and transmission capacity.

Regarding anomaly shapes, five main types can generally be distinguished: “U” shaped, “W” and “V” (often related to minor fractures or major structural accidents), “H” (typically the most productive), and possibly “K”, though the latter are not considered significant in this study. Unfortunately, no borehole could be drilled at this stage, but such investigations are planned for future work.

Along this profile, two negative boreholes were identified (Figure 5b), with resistivity values of 401.54 and 433.52 $\Omega\cdot\text{m}$. Several factors may explain this lack of productivity. Although these resistivity ranges often indicate conductive zones that may correspond to aquifers or saturated layers, they do not systematically guarantee the presence of exploitable groundwater. Conductive materials such as clays may exhibit low resistivity values without representing productive aquifers, as they may be impermeable or contain immobile water.

Similarly, certain weathered or fractured zones may display low resistivity due to conductive minerals, yet these fractures may be clogged by fine materials (e.g., clays, silts) or remain isolated, limiting groundwater movement. The resistivity anomalies identified may also correspond to very shallow aquifers whose productivity is insufficient for sustainable use. In some cases, these anomalies may represent disconnected fractures that do not contribute to groundwater recharge.

External factors such as low rainfall, marked seasonal variations, or insufficient recharge can further reduce water availability, rendering many aquifers temporarily or permanently non-productive. Moreover, limitations inherent to geophysical methods including spatial resolution and depth of investigation may affect the accuracy of interpretations.

In summary, the negative boreholes observed along this profile likely result from a combination of geological and hydrogeological factors, rather than a single cause.

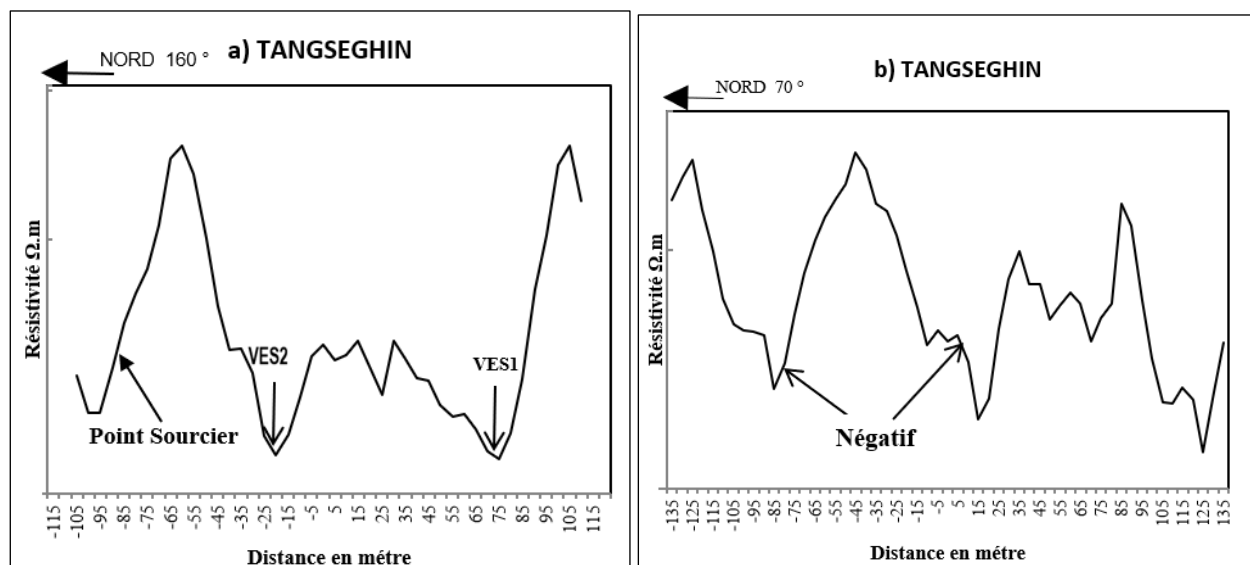


Figure 7: Niou Commune: Electrical profiling transects in Niou commune

3.4.2 Electrical Profiling Laye Commune Miners' Center

3.4.2.1 Profile 1: Low-Potential Zone

The electrical profiling (Figure 8a) reveals a distinct anomaly indicating a significant variation in resistivity along the line. The minimum recorded value, 223.6 $\Omega\cdot\text{m}$, occurs at approximately 70 meters from the starting point (0 m). This

low resistivity suggests the presence of a conductive zone, potentially corresponding to a localized aquifer horizon. The resistivity curve exhibits a “U” shaped anomaly, typically characteristic of fractured or weathered environments. Such a geoelectrical signature is often associated with groundwater storage and flow zones, as previously reported by [44]. Consequently, Profile 1 is considered favorable for groundwater occurrence, based on the combination of low resistivity and concave-shaped geometry, which may indicate a fractured or saturated weathered zone.

3.4.2.2 Profile 2: Favorable Potential

The second profile (Figure 8b), parallel to the first and spaced about 53 meters apart, confirms the trend observed previously. The resistivity curve also exhibits a concave “U” shaped anomaly, with a minimum value of $248 \Omega \cdot m$ recorded near the 70-meter mark. This conductive signature may be associated with water-bearing weathered or fractured materials. The spatial proximity and similar behavior between Profiles 1 and 2 suggest that both anomalies may be a laterally continuous structural or weathered zone, aligned with the principal lineament direction highlighted on the structural map. These profiles therefore indicate a consistent hydrogeological alignment, supporting the reliability of the detected anomalies and justifying the selection of this sector for complementary Vertical Electrical Sounding (VES) investigations.

3.4.2.3 Profile 3: Absence of Promising Targets

In contrast to the first two profiles, Profile 3 (Figure 8c), oriented perpendicularly to them, shows no significant anomaly. The obtained curve is steady and ascending, with high and increasing resistivity values, indicating a more compact subsurface. This geoelectrical behavior corresponds to a fresh, unweathered basement, with low fracture density and limited infiltration capacity. The absence of “U” or “H” type anomalies confirms the non-aquiferous nature of this direction. Such a configuration is typical of massive granitic or migmatitic formations lacking major discontinuities. Thus, Profile 3 is classified as hydrogeologically unpromising, reinforcing the hypothesis that potential groundwater zones are concentrated along directions parallel to Profiles 1 and 2.

Analysis of the three electrical profiles conducted at the Miners’ Center reveals a marked subsurface heterogeneity. Profiles 1 and 2 display geoelectrical anomalies typical of potential aquifer zones, whereas Profile 3 highlights a compact and low-permeability basement. This configuration suggests that the most favorable groundwater circulation zones are located along fractures oriented in the main lineament direction, likely NW-SE. These findings confirm a strong correlation between remote sensing and geophysical measurements, demonstrating the relevance and effectiveness of combining both approaches for groundwater prospecting in crystalline basement environments.

3.4.3 Electrical Profiling Laye Commune: Laye Center

3.4.3.1 Profile 1: Low Potential for Groundwater Occurrence

The electrical profiling (Figure 8d) did not reveal any characteristic anomaly indicative of a potential aquifer. The observed resistivity values, ranging between $163.2 \Omega \cdot m$ and $179 \Omega \cdot m$, show a slightly increasing trend without any significant concave feature. This uniformity reflects a poorly weathered basement, composed of compact, low-conductivity materials, which do not allow significant infiltration or water storage. The absence of notable variations suggests that the profile direction does not intersect any open fracture or major structural discontinuity. This geoelectrical behavior is typical of massive granitic terrains, generally low yielding from a hydrogeological perspective. Consequently, Profile 1 is classified as unfavorable for borehole siting, due to the lack of low-resistivity zones associated with aquifer structures.

3.4.3.2 Profile 2: Homogeneous Subsurface Without Promising Targets

The second profile (Figure 8e), conducted parallel to the first at a distance of 50 meters, also displays a stable resistivity curve, oscillating between $163.5 \Omega \cdot m$ and $177 \Omega \cdot m$. The limited amplitude of variation indicates a homogeneous and weakly fractured medium, with no interpretable anomaly. The absence of any significant depression in the curve rules out the presence of conductive geological discontinuities, such as weathered zones or water-filled fractures. This behavior is characteristic of a compact crystalline basement with negligible porosity, confirming the lateral continuity of the fresh rock observed in the previous profile. As such, Profile 2 is deemed unfavorable for groundwater potential, reinforcing the interpretation of a non-fractured, low-permeability subsurface.

3.4.3.3 Profile 3: Indications of Favorable Groundwater Potential

In contrast, Profile 3 (Figure 8f), oriented perpendicularly to the first two, reveals two concave “U” shaped anomalies located approximately 40 m and 50 m from the origin point. These anomalies correspond to relatively low resistivity values of $114.6 \Omega \cdot m$ and $113.6 \Omega \cdot m$, respectively at VES 1 and VES 2. Such values suggest the probable presence of weathered zones or open fractures with enhanced conductivity due to partial water saturation. The “U” shaped signature, typical of conductive media, indicates a clear contrast with the surrounding fresh basement, pointing to a

localized discontinuous aquifer within the weathered layer or along tectonic fractures. These points thus represent priority targets for Vertical Electrical Sounding (VES) investigations, aimed at confirming the depth and thickness of the identified conductive layers. Overall, the results of this profile highlight the importance of integrating geophysical analysis with lineament mapping to enhance the accuracy of groundwater exploration in crystalline basement terrains.

The six electrical profiling transects conducted in the communes of Niou and Laye illustrate the hydrogeological complexity of the study area. They highlight, on one hand, zones potentially favorable to the occurrence of productive aquifers and, on the other, sectors characterized by natural barriers to groundwater flow. These contrasts reflect the strong heterogeneity of the Birimian basement, where fracturing, weathering, and lithological variability exert a major control on water circulation and storage.

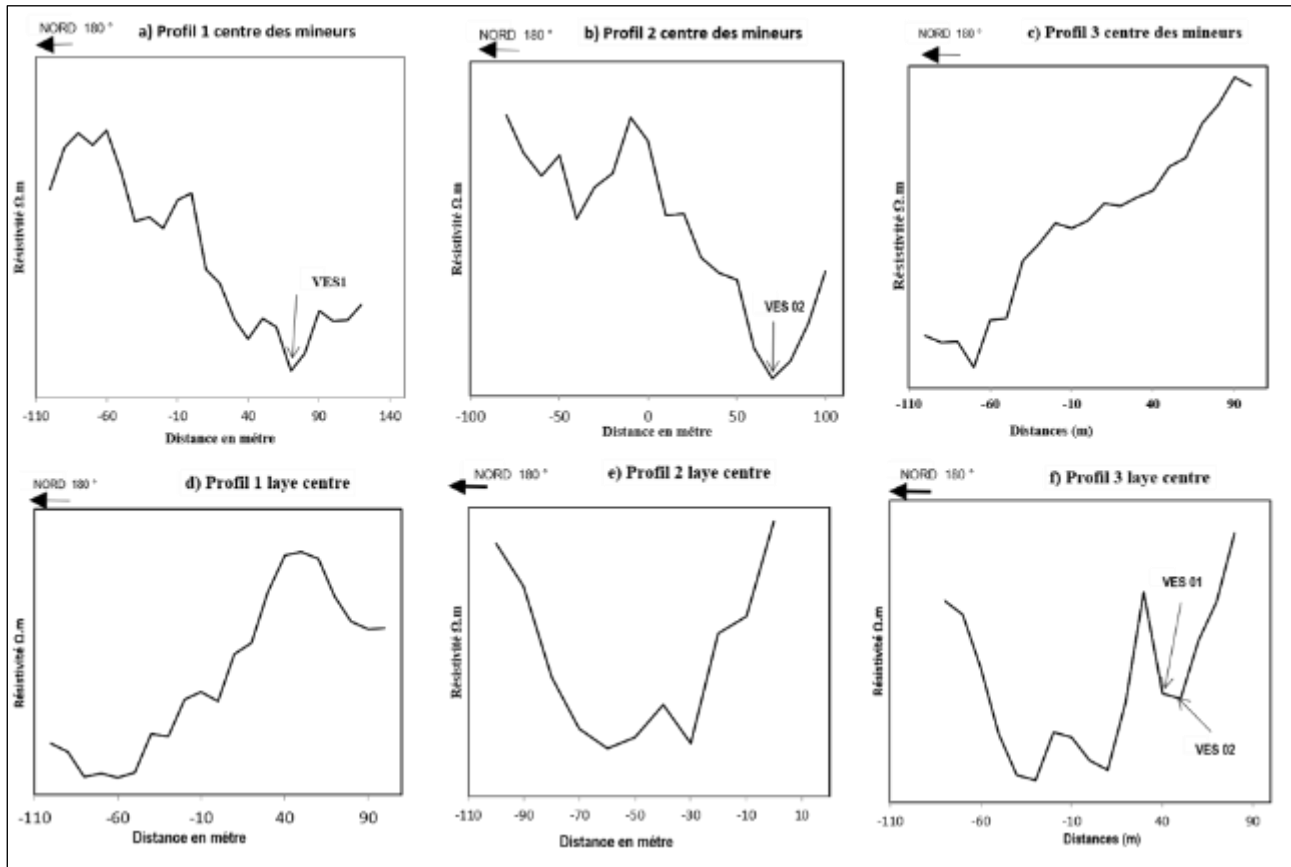


Figure 8: Electrical profiling transects in Laye commune

The “U” shaped anomalies observed on several profiles serve as valuable indicators of conductive subsurface structures, often associated with a high drilling success rate in groundwater exploration [8]. However, their presence does not necessarily guarantee aquifer productivity. Several factors can influence this outcome, including the lithological composition of the medium (presence of fine-grained or compact materials), clay content, which can artificially enhance electrical conductivity without indicating a water-bearing formation, fracture connectivity and aperture, as well as seasonal variations in water saturation.

While geophysical methods remain highly effective for identifying subsurface discontinuities, they require complementary validation through boreholes, and an integrated multidisciplinary approach remains essential to maximize exploration success. Future investigations should therefore include parallel profiling, direct drilling tests, and detailed local analyses to refine interpretations and improve groundwater prospecting in geologically complex environments.

Moreover, uncertainties inherent to geophysical methods must always be acknowledged. In basement terrains, lithological heterogeneity and differential weathering often lead to misinterpretations, particularly when relying on 1D electrical methods, which assume a laterally uniform subsurface a simplification rarely met in reality. The adoption of 2D or 3D Electrical Resistivity Tomography (ERT) would enable a more accurate characterization of subsurface structures [5].

Another major source of uncertainty lies in the influence of clayey formations and natural conductors. Although highly conductive, clays can easily be misinterpreted as productive aquifers, leading to erroneous conclusions [20]. A combined approach, integrating test drilling and downhole electrical logging, would help validate anomalies and better distinguish true aquifer zones [51].

Finally, the limited depth of investigation inherent to the methods used represents a significant constraint. The Wenner configuration adopted in this study depends directly on electrode spacing, restricting aquifer detection to depths shallower than 60 meters (Giot & Seger, 2019). For deeper and more accurate exploration, Schlumberger and Dipole-Dipole configurations offer superior vertical resolution and greater penetration depth.

3.4.4 Electrical Sounding

The Vertical Electrical Soundings conducted in this study were used to analyze the vertical variations of apparent resistivity at specific surface points. These data provide a more accurate representation of subsurface layering and the potential presence of fractures or water-bearing zones. The main objective was to compare the electrical sounding results with field data, such as borehole logs, to verify their consistency and refine the interpretation of geological and hydrogeological structures.

3.4.4.1 Analysis of the First VES Profile (VES 1)

The Vertical Electrical Sounding (VES), conducted using a Wenner configuration, provides key information on the structure and electrical properties of the subsurface. Figure 9a illustrates the resistivity curve, where the red line represents the inverted model and the black line corresponds to the field data collected in the commune of Niou. The inversion parameter table indicates an overall fitting error of 7.73%. The curve displays a “boat-shaped” or “H type” pattern ($\rho_1 > \rho_2 > \rho_3 < \rho_4$), typical of a conductive granite formation where fractures are not clearly distinguishable. The geological structure can be divided into four layers. The first layer, located near the surface, shows a resistivity of 2212 $\Omega\cdot m$ and a thickness of 3.29 m. It corresponds to a slightly clayey soil, probably a mixture of silt and sand, or possibly gravel. The second layer, characterized by a resistivity of 1603 $\Omega\cdot m$ and a thickness of 9.1 m, may indicate the presence of an aquifer. It lies at a depth of about 12.4 m and appears promising for containing groundwater, although its thickness limits the available storage capacity. The third layer, with a low resistivity of 43.7 $\Omega\cdot m$ and a thickness of 11.9 m, suggests a saturated zone or a formation rich in clay. Finally, the fourth layer, with a very high resistivity of 24,950 $\Omega\cdot m$, likely represents the bedrock, slightly fractured and almost devoid of water. The model appears reliable, with a fitting error of only 7.73%. However, factors such as water mineralization or salinity could influence the results. To refine these interpretations, it would be useful to employ complementary methods such as direct borehole investigations.

Figure 10a illustrates the field resistivity curve for the commune of Laye. It shows an H-type curve, characterized by a marked decrease in resistivity followed by a gradual increase. Three main layers have been identified: a surface sandy-clayey layer with an average resistivity of 180 $\Omega\cdot m$, a second, more conductive layer of 114 $\Omega\cdot m$ probably corresponding to weathered and fractured materials, and a deeper horizon of higher resistivity indicating the compact and slightly permeable basement. This structure suggests the possible presence of a shallow aquifer, but with limited lateral extension.

3.4.4.2 Analysis of the Second VES Profile (VES 2)

The second Vertical Electrical Sounding (VES), shown in Figure 9b and also conducted using a Wenner configuration, exhibits an “H type” curve with a well-defined “boat-shaped” feature ($\rho_1 > \rho_2 > \rho_3 < \rho_4$). Based on the data processing results, the inversion produced an overall fitting error of 10.2%, with resistivity ranges of 2402 $\Omega\cdot m$ for the first layer, corresponding mainly to a dry or slightly clayey superficial horizon. The second layer, with a resistivity of 1156 $\Omega\cdot m$, likely represents a more consolidated level composed of partially water-saturated rock or sand. The third layer, showing a significantly lower resistivity of 312 $\Omega\cdot m$, is distinctly conductive and suggests the presence of an aquifer. This is the layer forming the bottom of the curve, often referred to as a “trough.” Its greater thickness in this profile provides a better guarantee of groundwater availability compared to VES 1, even though it occurs at a greater depth. The fourth layer, with a resistivity of 44,285 $\Omega\cdot m$, likely represents the geological basement, which is slightly fractured and practically devoid of water. With a fitting error of 10.2%, the model is considered acceptable. However, factors such as water salinity or effective porosity may influence the results. To confirm these interpretations, further validation using complementary geophysical methods (such as boreholes or gravimetric surveys) would be necessary.

The second VES profile (Figure 10b) for the commune of Laye also presents an H type curve, but with a more pronounced anomaly. The minimum resistivity values reach 113 $\Omega\cdot m$ for the conductive layer located between 30 and 50 meters deep. This signature is typical of a fractured zone filled with fine materials or saturated sands. The fitting error, which remains below 10%, confirms the reliability and internal consistency of the model.

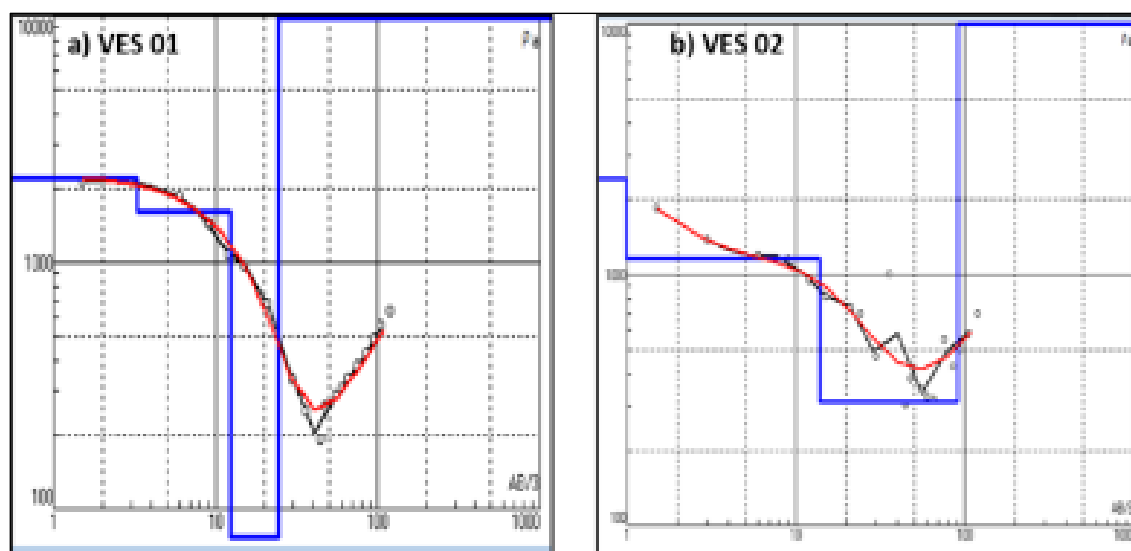


Figure 9: Niou3 Commune: a) Sampling profiles a; b) Parallel sampling profiles b

Both soundings exhibit “boat-shaped” curves, characteristic of granitic formations where fractures are not clearly identifiable. These curves are frequently observed in regions with a superficial lateritic crust. The typical three-layer structure, with a 45° rise at the level of the fresh basement, evolves into a five-layer structure when additional layers are present, such as buried laterite or arenaceous materials. The conductive zones located at the bottom of the curve are often composed of clayey, flowing materials or fractured rocks. However, their small thickness can make them difficult to detect, complicating the calculation of true resistivities. In granitic areas, clayey weathered materials are often moisture-saturated and highly conductive, even when they do not contain exploitable water, hence the relatively low resistivity. In schist zones, resistivity is generally higher than in granitic zones. The field data and the sounding curves correlate well, which corresponds to a higher drilling success rate. In such cases, it is desirable that the alteration thickness varies between 20 and 30 m, as many authors have shown that this range yields more reliable success rates [26,44,51]. Therefore, it is important to take into account local characteristics and geological conditions when interpreting the data. However, the interpretation of results and the drilling failure rate are influenced by several uncertainties. The complexity and interconnection within the basement zone play a key role, but the detection of a fracture does not necessarily mean it contributes to groundwater flow, as it may be open, closed, or even clogged. Moreover, the capacity of an aquifer to store and transmit water depends not only on the presence of fractures but also on their interconnection and effective aperture. Thus, a simple low-resistivity anomaly does not guarantee a productive borehole. The success rate of boreholes remains a source of uncertainty, even with prospecting methods. A low success rate may indicate that some boreholes were drilled on favorable geophysical anomalies but failed to intercept exploitable water, which could explain negative results along the profile. Several other factors may explain these failures, such as seasonal variations in groundwater levels, irregular aquifer recharge, and the impact of climatic conditions on water availability. Errors in borehole siting such as poor estimation of optimal depth or inaccurate positioning relative to identified hydraulic structures may also play a role. These methods would help refine the criteria for selecting drilling sites and improve the likelihood of success. To synthesize the geoelectrical and hydrogeological findings obtained across Niou and Laye, Table 1 summarizes the key diagnostic criteria established to distinguish true water-bearing targets from false-positive conductive anomalies that lead to unproductive boreholes.

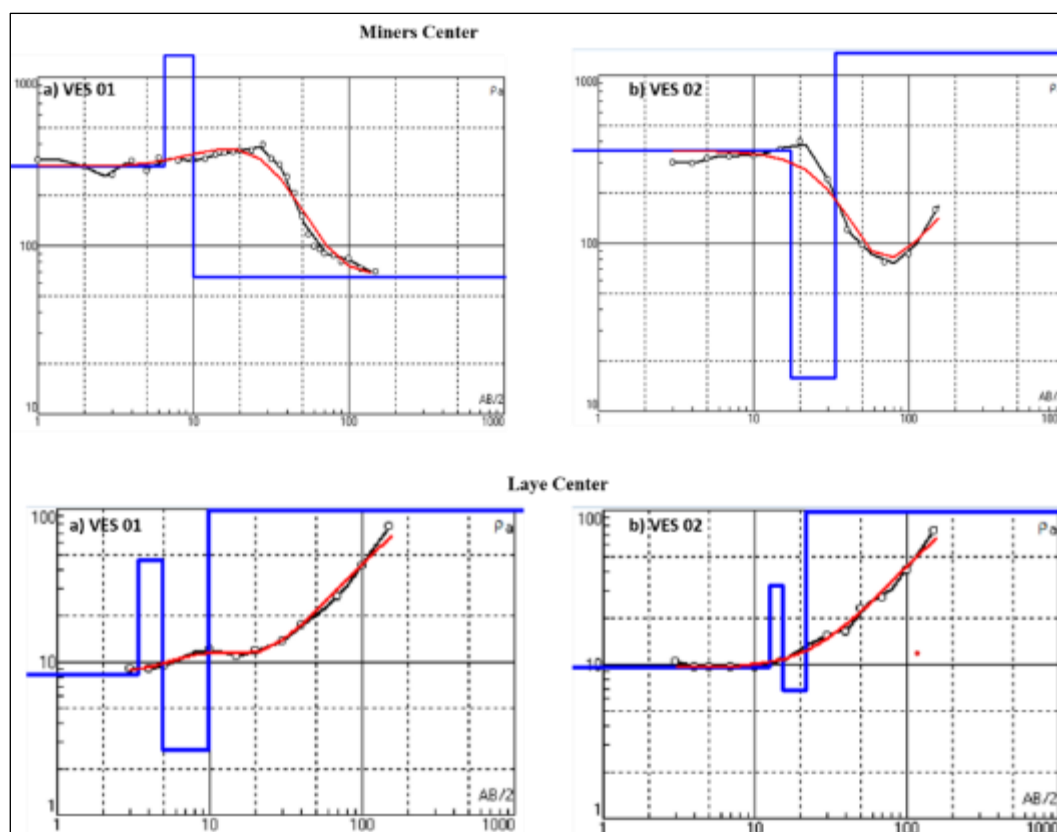


Figure 10: Laye 4 Commune: a) Sampling profiles a; b) Survey profiles b

Table 1: Geoelectrical diagnostic criteria for distinguishing productive aquifers from non-productive conductive traps in hard-rock settings.

Hydrogeological & Geophysical Parameter	Productive Aquifer Target (Positive Borehole)	Non-Productive Conductive Trap (Negative Borehole)
Apparent Resistivity ($\Omega \cdot m$)	Moderate values (100–600 $\Omega \cdot m$) [5]	Very low (<100 $\Omega \cdot m$) or highly resistive bedrock [6]
Profiling Anomaly Geometry	Well-defined "U" or "H" shaped anomaly [5,7]	Flat/featureless curve or erratic noise spikes [8,9]
Weathering Thickness (VES)	Optimum weathering depth between 20 and 30 m [3]	Very thin overburden (<10 m) or thick impervious clay layer [3,6]
Structural & Spatial Setting	Intersection of major lineaments (NE-SW / NW-SE) [5,10]	Isolated, non-intersecting lineaments or reoriented surface features [11]
Physical/Lithological Cause	Water-saturated open fractures / coarse saprolite [5,10]	Impermeable clay filling, clogged joints, or disconnected fractures

4 CONCLUSION

This study highlights the effectiveness of integrating remote sensing and geophysical methods to optimize the localization of aquifers in the Precambrian basement regions of Burkina Faso. By combining lineament analysis from satellite imagery with vertical electrical soundings, it was possible to identify low-resistivity zones potentially rich in groundwater while revealing the hydrogeological complexity of the region. The "U" and "H" shaped anomalies helped to target structures favorable to water accumulation. However, factors such as the presence of clay, fracture connectivity, and seasonal variations may limit the productivity of boreholes. These results emphasize the importance of a rigorous methodological approach adapted to the local context for interpreting geophysical data and maximizing success rates in groundwater prospecting. Table 1 synthesizes these diagnostic criteria into a practical decision-support framework that can guide field teams in prioritizing drilling sites based on resistivity range, anomaly geometry, and structural setting. Going further, future work should include parallel profiles, direct drilling, and an in-depth analysis of

local conditions. This would help refine interpretations and improve the accuracy of hydrogeological models. This study contributes to a better understanding of groundwater resources in rural areas of the Sahel and proposes a model adaptable to other regions facing similar challenges. Finally, it highlights the need to continue research to further integrate geological and hydrogeological data. Such an approach is essential to ensure sustainable water resource management, especially in a context of increasing climatic variability.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data and Code Availability

All the data (raw or generated) used during the study are available upon reasonable request from the corresponding author.

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