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Contribution of Electrical Resistivity Tomography to the Characterization of Aquifers in a Sub-Outcrop Context in the Basement Zone of the Oubri Region (Burkina Faso)

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Abstract

Population growth and climate change are putting drinking water resources at risk, making groundwater a key solution to these challenges. In Burkina Faso, more than 80% of the geology consists of crystalline bedrock, which necessitates the search for bedrock aquifers for water supply. The complexity of these aquifers has led to numerous unsuccessful water drillings. Electrical resistivity tomography (ERT) profiles were therefore conducted in the cities of Loumbila and Ziniaré using the resistivity-meter SYSCAL Pro system, in a Wenner-Schlumberger configuration, to better identify the characteristics of potential aquifer zones. ERT field measurements use a series of electrodes spaced 5 m apart to measure electrical resistivity along the profile. The inversion results are presented as cross-sections showing the distribution of the subsurface's true resistivity as a function of depth along each profile. The (2D) inversions reveal four geoelectric zones: a first zone characterized by low resistivities (<150 Ω·m), indicating a favorable zone containing water, followed by a second layer with values ranging from 150 to 400 Ω·m, representing weathered zones, a third layer with values ranging from 400 to 2000 Ω·m, representing zones of fissured and fractured bedrock, and a fourth layer with resistivities greater than 2000 Ω·m, indicating sound bedrock. The study demonstrates that the use of the Wenner-Schlumberger array improves the characterization of aquifers in bedrock terrain.

Keywords

Burkina Faso, Bedrock, Aquifer, Tomography, Water Drilling

1. Introduction

Water exists in three states (liquid, solid, and gas); the form suitable for consumption is liquid, known as freshwater, and it is a scarce resource. The term "scarce resource," which is often associated with it, may seem paradoxical given that the total volume of water in our planet's seas and oceans is approximately 1.33 billion km^3 [1]. The fact is that the water needs commonly cited refer to freshwater (non-saltwater), which accounts for only 3% of the volume mentioned earlier. Moreover, from this small percentage, we must subtract the share of permanent snow and ice, which amounts to 1.7%, leaving only 1.3% available [2]. According to projections by the Intergovernmental Panel on Climate Change (IPCC), beyond a 2˚C increase in temperature compared to 1990 levels, each additional degree could result in a 20% reduction in renewable water resources for at least 7% of the world's population [3]. A situation that could therefore explain the growing scarcity of water resources in many countries [4]. According to studies, it is estimated that each resident will be able to consume 20 liters of fresh water per day [5]. The scarcity of surface water, especially in intertropical countries such as Burkina Faso, is driving the use of groundwater, which accounts for 30% of the planet's freshwater. Consequently, to meet water needs, people are turning to groundwater. The exploitation of deep bedrock aquifers is considered a promising solution because they offer a water resource that is potentially more sustainable over time and is generally of good quality. [6]. To exploit these resources, it is necessary to construct water collection structures similar to water drilling, since the resources are trapped by rock formations or impermeable layers.

In West Africa, particularly in Benin, Burkina Faso, and Ivory Coast, the failure rate of water drilling in crystalline bedrock areas is estimated to be between 30 and 40 percent, according to [7]-[9]. The study area for this project is located on a granitic aquifer bedrock in the Oubri region. A distinctive feature here is the environment in which geological formations are at or near the surface. Numerous drilling surveys have shown that the city of Ziniaré, northern Ouagadougou, is known to be a very "hard" area. However, during operations at a granite aggregate quarry in 2005, an aquifer was discovered in this outcrop setting, creating an inexhaustible water reservoir. The reasons for the presence of a water body in an area known to be hard have prompted research aimed at finding a scientific explanation, with the goal of unraveling the mystery, understanding the circulation phenomenon, and enabling the exploitation of this groundwater resource. The objective of this study is to use electrical resistivity tomography (ERT) measurements in variable-flow drilling to understand and identify key characteristics of aquifers. This method was chosen because it allows for more precise determination of the exact location of geological discontinuities and for the identification of areas of major hydrogeological interest [7] [10] [11]. As an extremely interesting approach for characterizing the various compartments of bedrock aquifers while providing accurate imaging of the weathering profile [12]. It also makes it possible to characterize the target while avoiding structures that are highly unfavorable from a hydrogeological standpoint (such as clay-rich zones) [13].

ERT provides an integrated and consistent view of how bedrock aquifers function, thereby reducing the uncertainties inherent in conventional two-dimensional interpretations [14] [15]. The originality of this study lies in the use of tomography on boreholes in outcrop and sub-outcrop settings in Burkina Faso to characterize aquifers based on resistivity, lithology, and yield.

2. Geographic, Geological and Hydrogeological of the Study Area

The study area is located between Loumbila and Ziniaré and covers an area of approximately 102 km^2. According to the WGS 1984/UTM Zone 30 North coordinate reference system, it is bounded by the following coordinates: Xmax: 688711.182 m; Ymax: 1392460.625 m and Xmin: 677172.517 m; Ymin: 1383588.916 m in Bassitenga Province, Oubri Region, in central-western Burkina Faso (West Africa) (**Figure 1**). The climate is of the Sudano-Sahelian type, characterized by a dry season from November through May/June and a rainy season from June/July through October. The vegetation consists of open shrubby savanna, dominated by thorny shrubs and sea-grape trees. In addition, vegetable farming takes place along the edges of the reservoirs, creating a verdant view from satellite imagery during the growing season. The elevation of the area ranges from 280 to 360 meters, with an average of 304 meters.

Geologically, the formations found include granite, porphyroid granite, leucogranite, and basalt. The most dominant formation is granite. (**Figure 1**). The Ziniaré granite is a massif that extends from Loumbila to Ziniaré in a N60˚E direction. It is a leucocratic biotite granite, with surrounding rocks consisting of porphyroid granodioritic and monzogranitic facies [16].

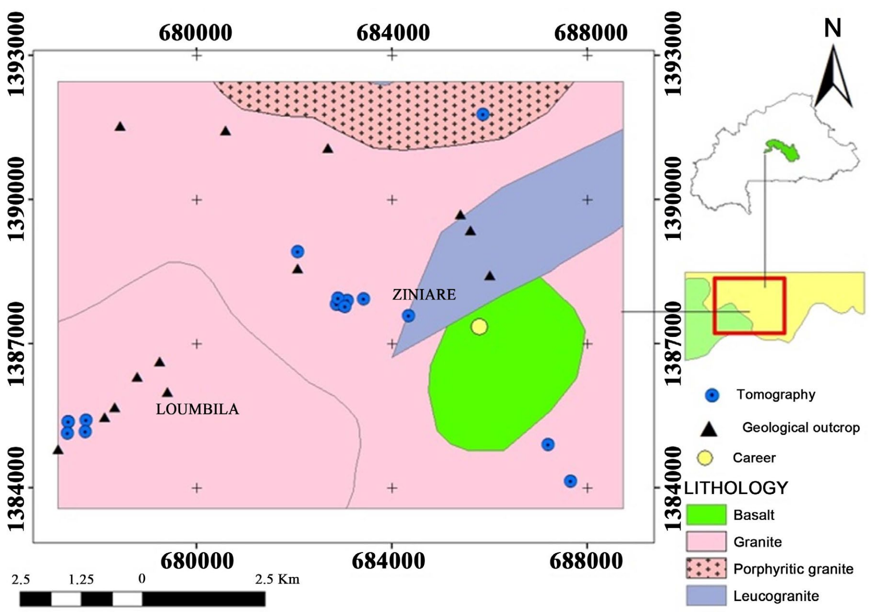


Figure 1. Location and geology of the study area (modified from [17]).

Aquifers are classified primarily according to their confinement regimes (unconfined, confined, and semi-confined) or their types of porosity. Their geological composition, in turn, determines their ability to store and transmit groundwater. In the bedrock, generally speaking, the water reservoir is related to the degree of fracturing within it.

In the crystalline bedrock zone of Burkina Faso, there are three major hydrogeological units (granitoids, granites, and weathered volcano-sedimentary formations) capable of containing water (**Figure 1**). These formations are distributed throughout the country by region and can serve as good water reservoirs [17]. The types of aquifers encountered are primarily shallow alterites contained within the weathered layer of the granitic bedrock and deep fracture zones located within the fissures and faults of the granite. In the study area, granitoids are the most prevalent and are characterized by a thin layer of alterites and an abundance of fractures.

3. Materials and Methodology

3.1. Materials

Electrical resistivity tomography (ERT) measurements were conducted between June 2025 and June 2026 on boreholes previously selected based on technical data sheets and geological information. The equipment used consisted of a Syscal Pro resistivity-meter with a 48-electrodes Switch (Iris Instruments) and its accessories (connection coils, electrodes, GPS, alligator clips, 12 V battery). The geophysical data obtained were processed using the following software:

- Electro Pro: This software allows users to create the measurement sequence by specifying the spacing between electrodes, defining the injection time and measurement type (500 ms, Rho, or Rho and IP), the quality control or deviation parameters (Qmax 3%, Stack min 4, Stack max 6), and the voltage type (minimum 50 mV and maximum 800 V);
- Prosys II: This software allows you to transfer the created sequence to the Syscal Pro device. Prosys II handles data transfer and the removal of outliers once the measurements have been done;
- Res2dinvx: This software allows you to perform resistivity inversion using data obtained from the filtering process in the Prosys II software.

3.2. Methodology

Electrical resistivity tomography is a combination of electrical surveys conducted side by side in a quadratic configuration. It consists of two current electrodes (A and B) that inject a direct current of intensity I, and two potential electrodes (M and N) that measure the resulting potential difference Δv.

The Wenner-Schlumberger array used (**Figure 2**) is a hybrid configuration combining two Wenner and Schlumberger arrays. The AM and NB distances are equal to the number (n) times the spacing between the two measurement electrodes, M and N. For a heterogeneous subsurface (*i.e.*, one with real geological conditions), the apparent resistivity, as a parameter, can be calculated from the current I and the potential difference Δv using the following formula:

$$\rho_a = k \cdot \frac{\Delta v}{I} \quad (1)$$

K est appelé facteur géométrique et peut être calculé à partir de l'espacement des électrodes selon la formule:

$$k = \pi \cdot n \cdot (n+1) \cdot a \quad (2)$$

- ρ_a : Apparent resistivity (in Ω·m);
- k: Geometric factor of the device;
- Δv: Potential difference or measured voltage (in volts);
- I: Injected current (in amperes);
- a: The basic spacing between the electrodes of the potential measurement dipole (MN = a);
- n: The ratio of the distance between the current electrode and the adjacent potential electrode (AM = NB = $n \cdot a$).

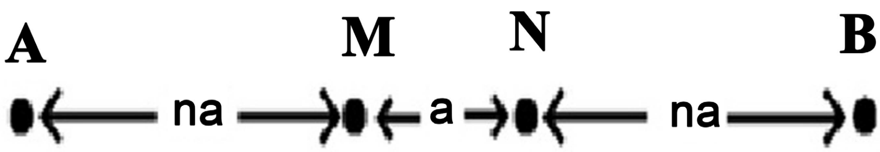


Figure 2. Configuration of the modified device (modified from [18]).

The ERT method was applied to eight profiles from seven productive and non-productive boreholes with a maximum depth of 80 meters. The boreholes were selected based on lithology and site accessibility. Of the seven boreholes, only one had a verifiable lithological log available. Most flow rates were obtained from the database and verified in the field by calculating the time required for the polyethylene reservoirs to fill with water. Before beginning any measurements, a pre-programmed sequence must be loaded into Syscal Pro. Once this step is complete, the system must be checked using a network of electrodes arranged along a straight profile, spaced 5 meters apart, to ensure good contact between the electrodes, the ground, and the connectors. The Wenner-Schlumberger method was chosen because it provides equivalent sensitivity to horizontal, vertical, and deep structures during measurement studies. A summary of the profile measurement parameters is recorded (**Table 1**).

The electrical tomography data inversion was performed using the RES2DINV software. The apparent resistivity data measured in the field were first imported into the Prosys II software and checked to identify outliers or measurements with significant errors. Data filtering did not reveal any outliers. The selected data were then used to construct pseudo-sections of apparent resistivity. Topographic data for the electrodes were available, and the profiles generally showed flat terrain. The inversion followed an iterative process, such that each apparent resistivity

Table 1. Profile creation settings.

	Ziniare site 1				Ziniare site 2		Loumbila site	
	Profil a	Profil b	Profil c	Profil d	Profil a	Profil b	Profil a	Profil b
Number of electrodes	48/roll long	48	48	48	48	48	48	48
Electrodes spacing	5 m	5 m	5 m	5 m	5 m	5 m	5 m	5 m
Flow rate	2 m^3/h	12 m^3/h	2 m^3/h	6 m^3/h	0 m^3/h	0 m^3/h	2.4 m^3/h	2.7 m^3/h
Total depth of borehole	74 m	70 m	79 m	76 m	80 m	80 m	67 m	71 m
Orientation	NE-SW	NW-SE	E-W	NW-SE	NE-SW	NW-SE	NE-SW	N-S
Final length of the profil	475	235	235	235	235	235	235	235
Surface conditions	Rock out	Rock out	Rock out	Rock out	Rock out	Rock out	Rock out	Rock out

value calculated from the model was compared. The calculation was terminated once the adjustments became negligible or the maximum number of iterations was reached. For each resistivity model, the error, the number of iterations, the variation in the adjustments, and consistency with the geological, structural, and hydrogeological characteristics of the study area were taken into account in the fit statistics. The results are presented as pseudo-sections of apparent resistivity as a function of position along the profile and pseudo-depth (Figure 3).

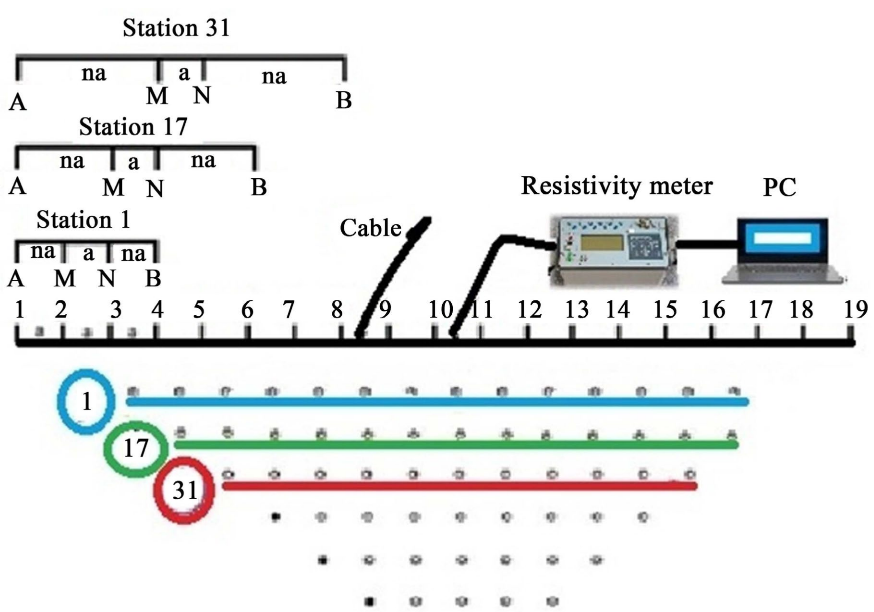


Figure 3. Diagram of the Wenner-Schlumberger array (adapted from [19]).

The profile lengths range from 235 to 475 m. The profiles were designed so that the boreholes coincide with the measuring device at least once.

4. Results

Tomography measurements were conducted at two sites, Loumbila and Ziniaré. Resistivity values may vary depending on the degree of saturation of the formations (**Table 2**).

Table 2. Example of a resistivity value [20].

Values for saturated formations (Ω·m)	
Clay	5 - 10
Sand	50 - 400
Gravel	150 - 500
Crystalline schists	100 - 10,000
Basalt	10 - 50,000
Granites	100 - 50,000
Limestone and dolomite	100 - 10,000
Seawater	<0.2
Surface and groundwater	10 - 300
Water cones	0.05 - 10
Potability Limit	2 - 6

Tomographic surveys of the various sites show a range of resistivity varying from 10 to over 2810 Ω·m. This range can be divided into subranges (<150 Ω·m; 150 Ω·m to 400 Ω·m; 400 Ω·m to 2000 Ω·m; >2000 Ω·m) corresponding to three distinct major geological layers in the subsurface.

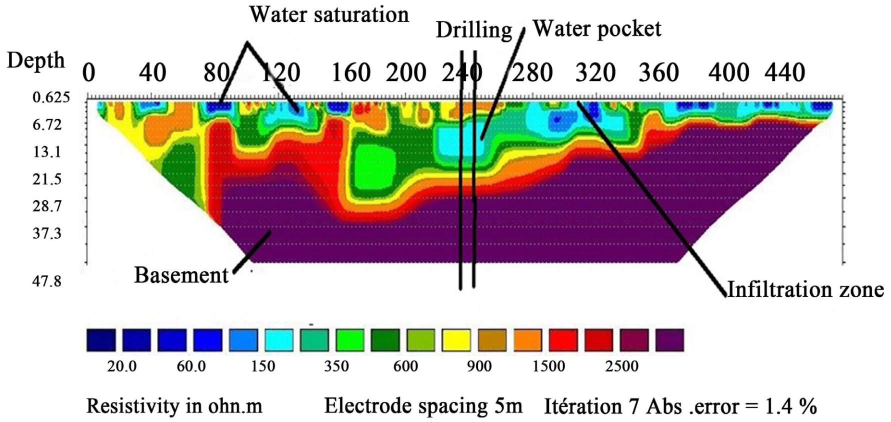
4.1. Ziniaré Site 1

Analysis of the electrical resistivity map at the first location on this site (water drilling with a yield of 2 m^3/h) (**Figure 4(a)**) shows an initial layer generally 5 m thick, with a resistivity of less than 150 Ω·m, a value that falls within the range characteristic of surface and subsurface freshwater (**Table 2**). A second layer with a resistivity between 150 and 400 Ω·m, varying in thickness from 15 to 30 m along the profile. The third layer has a resistivity ranging from 400 Ω·m to 2000 Ω·m has a thickness ranging from 6 to 20m. The fourth layer, on the other hand, has a resistivity greater than 2000 Ω·m. A borehole located 240 m along the profile was drilled through a layer with a resistivity of more than 1000 Ω·m. It passes through a layer with a resistivity of 150 Ω·m at a depth of approximately 13 m before continuing into the high-resistivity zone. The tomography also shows areas of infiltration between the outcrops and the bare ground, thereby creating a water reservoir within the high-resistivity layers.

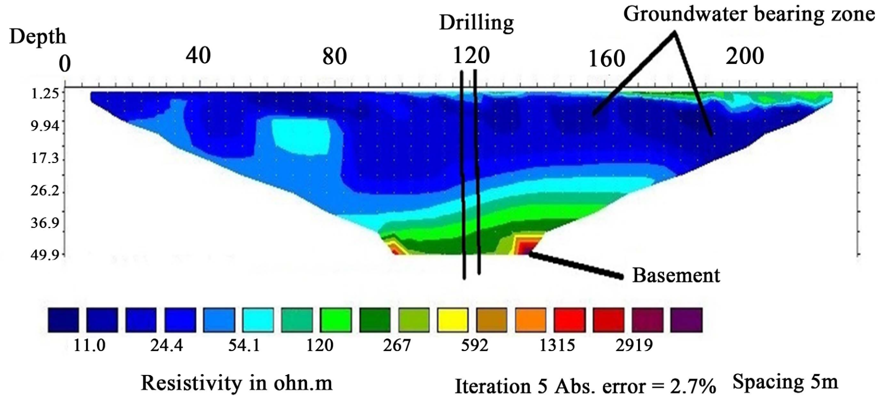
For the second drilling at the Ziniaré site (with a yield of 12 m^3/h), the imagery shows an initial layer 36 to 42 meters thick with a resistivity of less than 150 Ω·m (**Figure 4(b)**). The second layer has a resistivity ranging from 150 to 400 Ω·m, with a thickness varying from 6 to 19.9 m along the profile. The third layer has a resistivity ranging from 400 to 2000 Ω·m, with a thickness varying from 4 to 6 m. As for the fourth layer, it has resistivities greater than 2000 Ω·m.

The third image of the Ziniaré 1 site (2 m^3/h borehole) (**Figure 4(c)**) shows a first layer with a thickness ranging from 8 to 36 m and a resistivity of less than 150 Ω·m. A second layer, with a resistivity ranging from 150 to 400 Ω·m, has a thickness ranging from 2 to 16 m. The third layer, with a thickness ranging from 2 to 19, has a resistivity between 400 and 2000 Ω·m. The fourth layer, meanwhile, has a resistivity greater than 2000 Ω·m. Infiltration zones are observed between the outcrops and the bare ground, thereby creating zones of weathering within the high-resistivity layers.

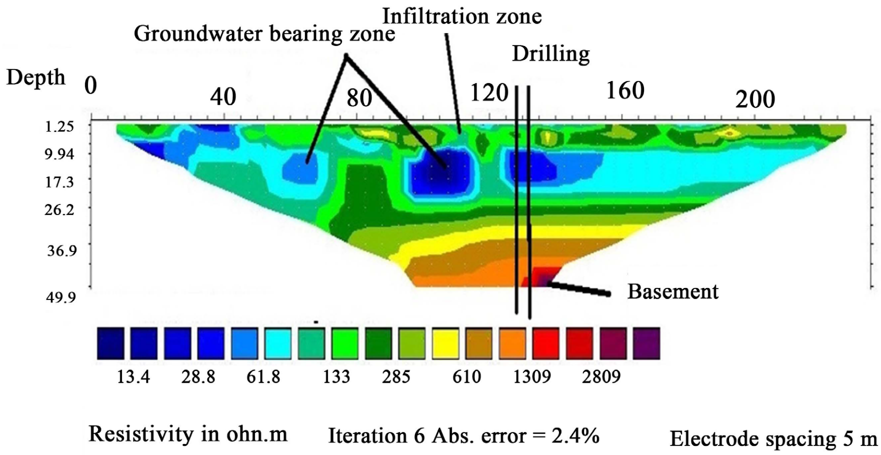
The fourth and final point studied at the Ziniaré 1 site (**Figure 4(d)**) shows a first layer with a thickness ranging from 1 to 16 m, with a resistivity of less than 150 Ω·m. This is followed by a second layer with a resistivity ranging from 150 to 400 Ω·m and a thickness ranging from 2 to 16 m along the profile. The third layer has a resistivity ranging from 400 to 1359 Ω·m.



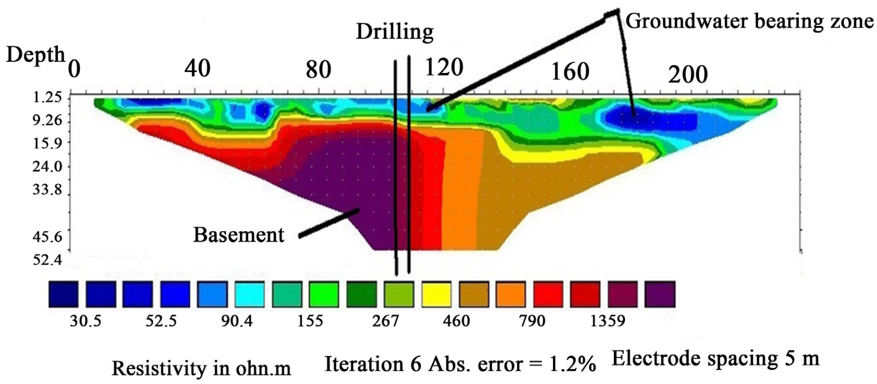
(a)



(b)



(c)



(d)

Figure 4. (a) Imaging of productive drilling (2 m^3/h); (b) Imaging of productive drilling (12 m^3/h); (c) Imaging of productive drilling (2 m^3/h); (d) Imaging of productive drilling (6 m^3/h).

4.2. Ziniaré Site 2

Two electrical resistivity surveys were conducted at this site. The first survey at the Ziniaré 2 site was performed on a dry well. Figure 5(a) shows a first layer with a thickness ranging from 1 to 5 m, with a resistivity of less than 150 Ω·m. The next layer has a resistivity ranging from 150 to 400 Ω·m and a thickness varying from 2 to 24 m along the profile. The third layer has a resistivity ranging from 400 to 2000 Ω·m, with a thickness ranging from 5 to 50. As for the fourth layer, it has a resistivity greater than 2000 Ω·m. The non-productive drilling was drilled at the 120-meter station along a NE/SW-trending profile and is located in an area with a resistivity greater than 450 Ω·m.

To better characterize the site, a second profile oriented NW/SE was conducted. The tomographic data obtained differ slightly from those of the first profile, which was oriented NE/SW (Figure 5(b)). The first layer here has a resistivity of less than 150 Ω·m and a thickness ranging from 1 to 9.26 m. The next layer has a resistivity ranging from 150 to 400 Ω·m and a thickness ranging from 3 to 24 m.

The third layer has a resistivity ranging from 400 to 2000 Ω·m, with a thickness ranging from 8 to 40 m. As for the fourth layer, it has a resistivity greater than 2000 Ω·m.

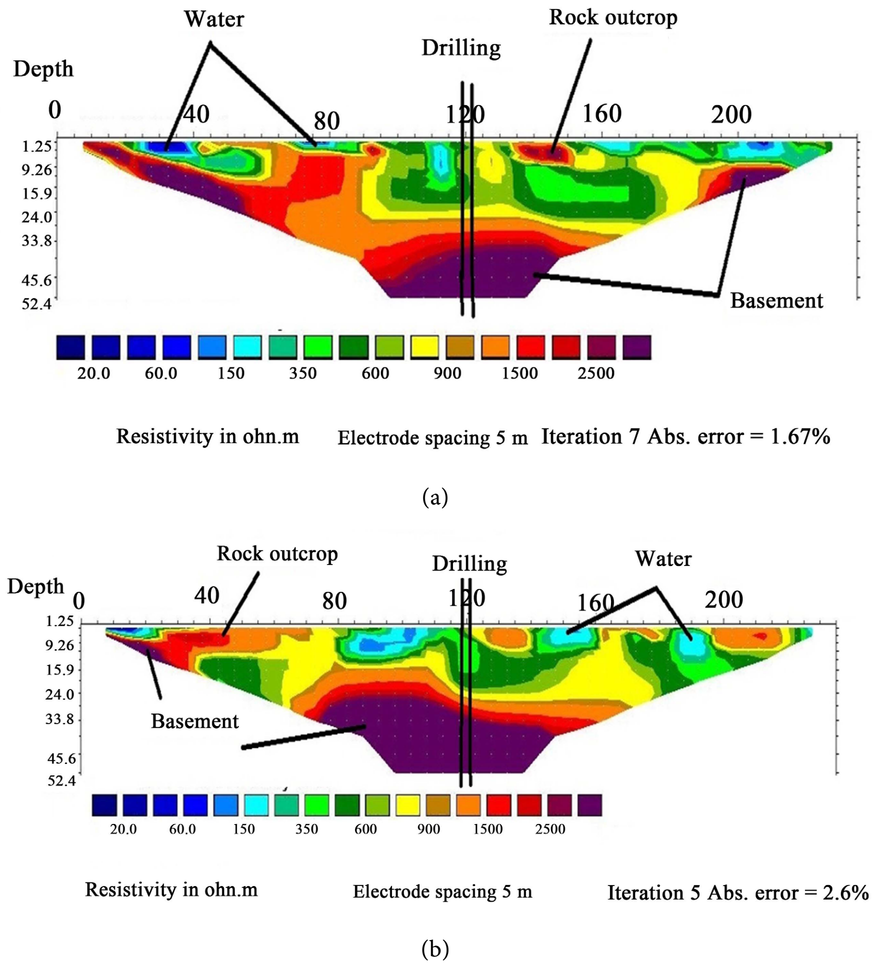
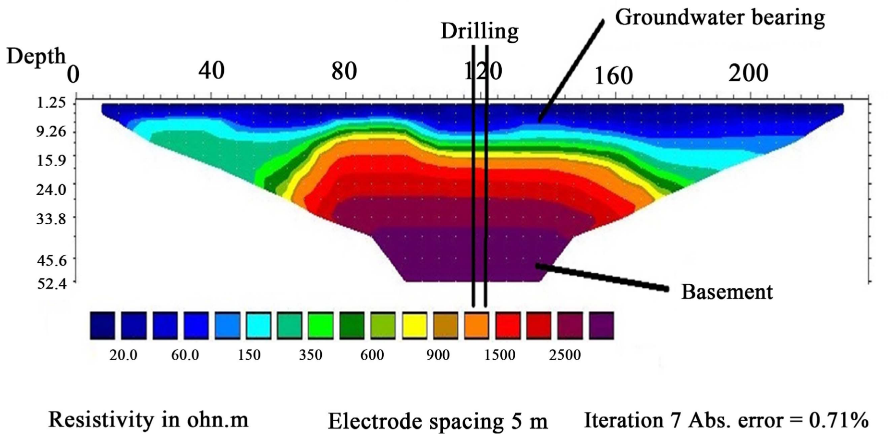


Figure 5. (a) Imaging of unproductive drilling; (b) Imaging of unproductive drilling.

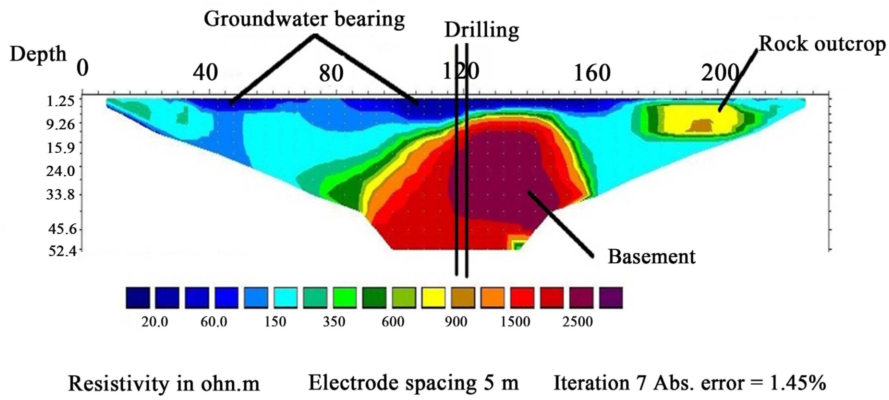
4.3. Loumbila Site

At the Loumbila site, two ERT profiles were acquired. The results of the first acquisition at a water well with a flow rate of 2.4 m^3/h show a stratified distribution of resistivities, resulting in multiple responses (**Figure 6(a)**). The first layer has a resistivity of less than 150 Ω·m, with a thickness ranging from 10 to 15 m along the profile. The next layer has resistivity values ranging from 150 to 400 Ω·m, with a thickness of 6 to 15 m. The third layer has resistivities ranging from 400 to 2000 Ω·m, with a thickness of 17 to 23 m. As for the fourth layer, it includes all resistivity values greater than 2000 Ω·m.

The second image shows a borehole with a flow rate of 2.7 m^3/h (**Figure 6(b)**). The first layer has resistivities below 150 Ω·m and a thickness ranging from 6 to 8 m. The second layer has resistivities ranging from 150 to 400 Ω·m, with a thickness ranging from 15 to 24 m. The third layer has a thickness ranging from 15 to 43 m and resistivities ranging from 400 to 2000 Ω·m. The fourth layer, meanwhile, has resistivities greater than 2000 Ω·m.



(a)



(b)

Figure 6. (a) Imaging of productive drilling (2.4 m^3/h); (b) Imaging of productive drilling (2.7 m^3/h).

5. Discussions

The study conducted at the Loumbila and Ziniaré sites in the Oubri region identified the key geophysical parameters for optimal drilling placement. Geophysical methods based on electrical tomography using the Wenner-Schlumberger array serve as a tool for characterizing subsurface geological formations. Consequently, the selection of locations for tomographic measurements was based on information from the boreholes. In light of our overall results, it is crucial to examine them carefully to ensure an accurate characterization of the aquifers in both outcrop and sub-outcrop contexts within the bedrock zone.

The tomography watch on Ziniaré's Site 1 (Figure 4(a)) a water pocket at the 240 meter station, which corresponds to the borehole containing a probable layer of weathered granite with a resistivity between 600 and 800 Ω·m. This value falls within the range typical of granite (Table 2), superimposed at the top of the water pocket. In the imagery (**Figure 4(b)**) conducted on the fracture detected during satellite image processing, resulting in a productive drilling yielding 16 m^3/h. The imagery (**Figure 4(c)**) shows, at station 90 m, a zone of alteration ranging in thickness from 3 to 5 m with resistivities between 150 and 400 Ω·m, which serves as a source of infiltration creating aquifers. **Figure 4(d)** shows aquifers with layers that may consist of fractured granite, ranging in thickness from 5 to 40 m and oriented vertically. At the Ziniaré 2 site, the imagery reveals areas of water and rock outcrops (**Figure 5(a)** & **Figure 5(b)**). Non-productive wells are located in areas where resistivity ranges from 400 to 2500 Ω·m, but high resistivity alone does not explain the absence of water. The most promising location would be the station 100 meters away, where the resistivity is less than 150 Ω·m; given the presence of water in the production well, a resistivity value of less than 150 Ω·m is indicated at our study site. The Loumbila site is shown in the imagery (**Figure 6(a)** et **Figure 6(b)**) a zone of weathered granite with resistivities ranging from 150 to 400 Ω·m and a thickness ranging from 1 to 10 m, and a fractured zone with resistivities ranging from 400 to 2000 Ω·m and a thickness ranging from 9 to 35 m.

The tomography shows that the majority of non-productive wells intersect zones with low conductivity or no conductive zones, as well as dry or unfed fractures. A comparison of data from productive and non-productive wells makes it possible to define a range of resistivity values conducive to obtaining a productive well at the study site. The resistivity must be less than 150 Ω·m, which confirms that a favorable zone is linked to its conductivity; however, low resistivity is sometimes due to clay or other materials. To ensure good performance, all implementation steps must be carried out meticulously, from site selection using satellite imagery to analysis of the site's environment and geophysical surveys. The study identified four zones: the first exhibits resistivity values below 150 Ω·m, characteristic of a favorable zone containing water; followed by a second layer with values ranging from 150 to 400 Ω·m, representing altered zones; a third layer with values ranging from 400 to 2000 Ω·m, representing zones of fissured and fractured bedrock, and a fourth layer with resistivities greater than 2000 Ω·m, characterizing the sound bedrock. The results obtained are consistent with those of [13], stipulating that the resistivity values of the weathered zone and the fractured zone traversed by the boreholes are, for all sites, between 150 and 400 Ω·m and between 800 and 2000 Ω·m, respectively which are the target ranges for acceptable hydrodynamic properties.

ERT is capable of accurately characterizing the various structures, accurately determining the depth of the sound bedrock, and thus the thickness of the aquifers [7] [11] [21] and the identification of potential infiltration areas [22]. Across all ERT images, it is evident that resistivity increases with depth, and the bottom layer appears to have higher resistivity, as indicated by other geophysical methods [23].

To achieve saturation, water must be stored; to ensure adequate storage capacity, the storage zone must be extensive. Thus, resistivity alone does not guarantee a sustainable, productive water drilling a fracture is needed to feed the low-resistivity zone.

In fact, the presence of a significantly thick weathered layer is essential for achieving and maintaining good flow rates during operation [22]. Crystalline rocks are generally highly fractured because they are prone to breaking, but the rock's texture and structure play a key role in their productivity [24]. For bedrock aquifers in general, the thickness of the weathered zone is a factor in productivity. The weathered zone should not only be as thick as possible, but also as sandy as possible, rather than clayey. [13].

The fluid-filled sac in the imaging (**Figure 4(a)**) behaves like a confined aquifer, whose hydrogeological conditions are shaped by geological structures, aquifer characteristics, and land-use practices. These factors influence permeability and recharge rates [25]. However, it is essential to consider not only the amount of precipitation but also its timing and distribution, as these factors significantly influence groundwater potential [26] [27].

6. Conclusion

The objective of this study was to demonstrate the value of tomography in characterizing the rock aquifers of Ziniaré and Loumbila in order to improve the selection of drilling sites. The imaging profiles made it possible to identify indicators by grouping them into four classes. The first class has resistivity values below 150 Ω·m, characterizing a favorable zone containing water. The second class, with values between 150 and 400 Ω·m, represents weathered zones. The third class, with values ranging from 400 to 2000 Ω·m, represents areas of fissured and fractured bedrock. The fourth class, with resistivities greater than 2000 Ω·m, characterizes sound bedrock.

The results show that combining tomography data with drilling data improves the identification of areas suitable for new drilling placements.

For future drilling placements in the basement zone, several factors such as geology, structure, lithology, and existing drilling data must be examined. In order to select a drilling site not solely based on resistivity, thickness, and weathering, but by combining all of this information while taking into account the type of faults or fractures to predict the drilling performance.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

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