International Journal of Geosciences, 2025, 16(9), 620-635
https://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

Anisotropy and Characterization of Aquifer Geometry by Electrical Resistivity Tomography in Togoniéré (Department of Ferkessédougou, North of Côte d'Ivoire)

Moussa Ouedraogo[1]*, Léréyaha Coulibaly[1], Ismaïla Ouattara[1], Kouadio Assémien François Yao[1], Zié Ouattara[1], Ismael Sylla[1], Salam Sawadogo[1], Marc Pessel[2], Bamory Kamagate[3]

[1]Geology Laboratory/Faculty of Geological and Mining Sciences, University of Man, Man, Côte d'Ivoire
[2]Paris-Saclay Geosciences Laboratory (GEOPS), Paris-Saclay University, Orsay, France
[3]Geosciences and Environment Laboratory, Nangui Abrogoua University, Abidjan, Côte d'Ivoire
Email: *moussa.ouedraogo@univ-man.edu.ci

How to cite this paper: Ouedraogo, M., Coulibaly, L., Ouattara, I., Yao, K.A.F., Ouattara, Z., Sylla, I., Sawadogo, S., Pessel, M., Kamagate, B. (2025) Anisotropy and Characterization of Aquifer Geometry by Electrical Resistivity Tomography in Togoniéré (Department of Ferkessédougou, North of Côte d'Ivoire). *International Journal of Geosciences*, **16**, 620-635.
https://doi.org/10.4236/ijg.2025.169030

Received: September 5, 2025
Accepted: September 22, 2025
Published: September 25, 2025

Abstract

Côte d'Ivoire is made up of more than 97% bedrock. The majority of water resources are contained in the fractured bedrock, where drilling has a high failure rate. It is therefore important to better understand these water reservoirs, as their hydrogeological significance is considerable. This study is conducted from this perspective and covers the sub-prefecture of Togoniéré (North of Côte d'Ivoire) where the water problem is acute. Its objective is to characterize the geometry of the aquifers in the sub-prefecture by using electrical resistivity tomography. The results highlight an anisotropy of the underground formations, more pronounced with depth, represented by a succession of resistant-conductive-resistant terrains. They reveal conductive formations interpreted as lateritic aquifers, located between 20 and 75 m deep and generally with thicknesses of 30 to 50 m. They have a triangular shape and lateral extensions of about 85 m. Other conductive formations (3 to 10 m), which have a NW-SE and NE-SW dip and a 45˚ inclination, suggest a network of fractures facilitating the infiltration and storage of water. Their reach does not exceed 85 m but can extend to 185 m in length. These aquifers result from regional tectonics or local alteration.

Keywords

Anisotropy, Electrical Resistivity Tomography, Aquifers, Geometry, Togoniere, Côte d'Ivoire

1. Introduction

Water is an essential resource for life and human activity, and as such, it is used by everyone. The term "rare commodity" often associated with it may seem paradoxical considering the total volume of water in the seas and oceans of our planet, which is approximately 1.33 billion km^3 [1]. Freshwater accounts for only 3% of the previously mentioned volume [2]. This freshwater is susceptible to pollution and sensitive to climate change, making groundwater the preferred source of freshwater. In Africa, for example, the main source of Drinking Water Supply (DWS) is groundwater [3].

In West Africa, and more specifically in Côte d'Ivoire, access to drinking water remains a major challenge. This observation applies despite an abundance of surface water, which makes the exploitation of groundwater all the more strategic. Apart from the coastal area, 85% of the inland localities are supplied by groundwater. For four decades, numerous studies [4]-[7] have been conducted in West Africa to better understand aquifers in bedrock environments. At the same time, studies on geometry have also been carried out [6] [8]-[11]. These works reveal that fractured aquifers are interesting reservoirs for drinking water supply because they are less vulnerable to pollution and are the most sought-after and exploited reservoirs in bedrock areas. According to [12], in Côte d'Ivoire, determining an aquifer in bedrock formation is very delicate due to the complexity of the underground environment. For example, in the central and northern regions of Côte d'Ivoire, particularly in Bouaké, Niakara, Ferkessédougou, and Doropo, the availability of drinking water for the total coverage of the population remains a difficult equation to solve [13].

Furthermore, drilling campaigns record a high failure rate, making living conditions for the population difficult. In addition to local challenges, North Côte d'Ivoire faces notable pressures on water resources linked to population movements caused by the deterioration of the security situation in Mali and Burkina Faso [14]. To limit failures during drilling, a good understanding of hydrogeological and environmental contexts, coupled with appropriate technology, is essential [6]. Among these techniques and disciplines, the geophysical approach has continued to develop and demonstrate its importance in characterizing aquifers [10] [15] [16] [11].

In response to these challenges, this study aims to characterize the geometry of aquifers with a view to establishing a drinking water well in the sub-prefecture of Togoniéré. Specifically, it involved:

—Studying the spatial distribution of the electrical resistivity of underground formations using pseudo-sections obtained through electrical tomography;

—Identifying formations favorable to the accumulation of groundwater that could be aquifers;

—Characterizing the geometry (depth, thickness, shape, structural direction) of these aquifers.

2. Study Area

The department of Ferkessédougou, the capital of the Tchologo region, is located in the North of Côte d'Ivoire, 574 km from Abidjan. It is situated between latitudes 9˚12' and 9˚57' North and longitudes 4˚42' and 5˚23' West. It consists of 3 sub-prefectures, including that of Togoniéré. Togoniéré is located 22 km from the department. It is bordered to the North by Burkina Faso, to the South by the sub-prefecture of Koumbala, to the East by that of Sikolo, and to the West by the sub-prefecture of Ferkessédougou (**Figure 1**). Its population is 15,342 inhabitants [17]. The climate of the department is tropical, characterized by two main seasons: a dry season from November to April, marked by the harmattan that extends from December to February, with temperatures approaching 40˚C in March and April, and a maximum of precipitation observed in August and September in recent years. Annual rainfall varies between 1000 and 1200 mm [18]. The hydrographic network is dominated by temporary watercourses, which reflect the marked influence of the long dry season. The region's vegetation is that of a wooded savanna. Like in all of northern Côte d'Ivoire, this region features a plateau relief, with slight peaks around 400 m in altitude.

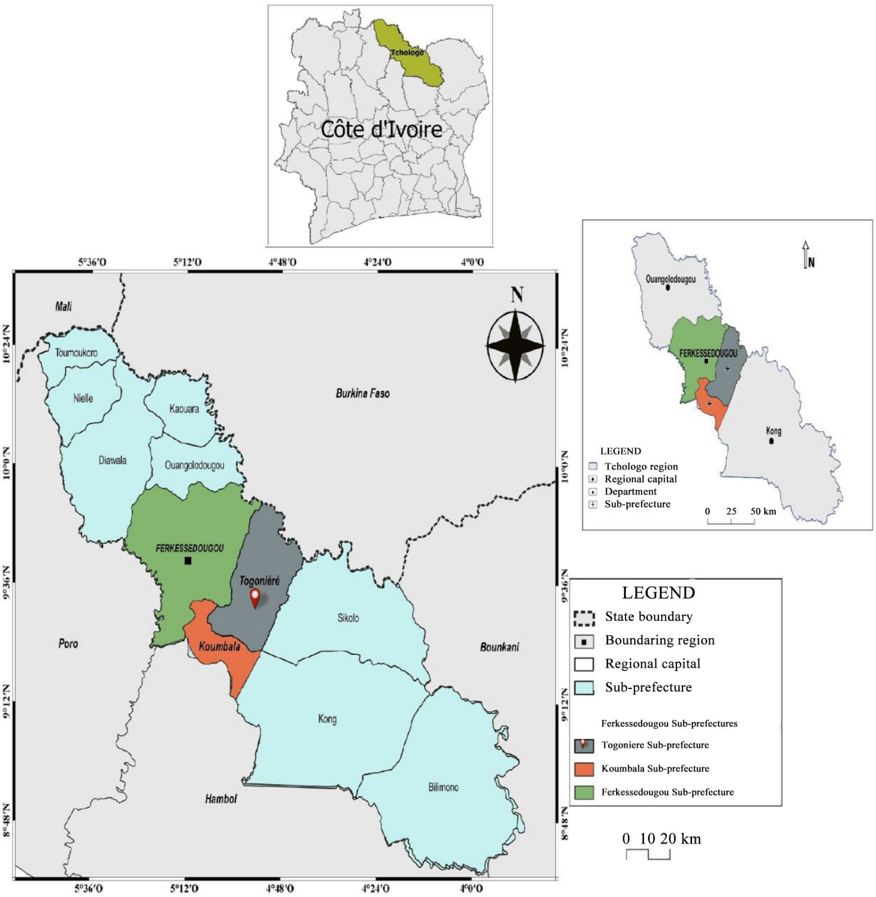

Figure 1. Localization of the study area (sub-prefecture of Togoniéré). (Source: the authors)

2.1. Hydrological and Geological Context

The Tchologo region is primarily drained by two major rivers, the Comoé to the East and the Bandama to the West, along with their main tributaries. In Togoniéré, the watercourses are of first, second, and third order (Strahler order), representing the hierarchy of the hydrographic network, from the smallest streams (order 1) to the first structuring tributaries (order 3) (**Figure 2**). It is important to note that this network is dominated by temporary watercourses, reflecting the significant influence of the long dry season on the entire hydrographic network [19].

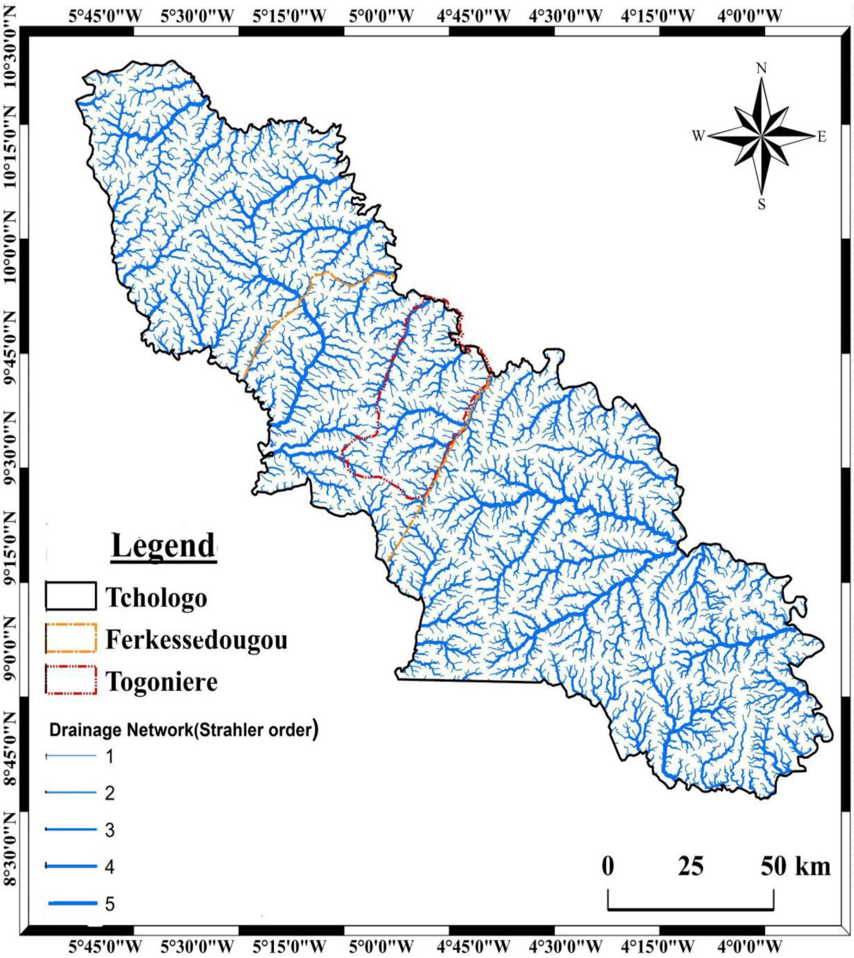

Figure 2. Hydrographic network of the Tchologo region.

The geology of Côte d'Ivoire is composed of 97.5% crystalline and crystalline-phyllitic basement rock. It is located at the heart of the Man Ridge, whose lithological units are affected by three orogenies (Leonian (3.5-2.9 Ga), Liberian (2.9-2.4 Ga) and Eburnean (2.4-1.6 Ga)). The geological formations in northern Côte d'Ivoire consist of a succession of bands of schistose rocks, migmatitic rocks, and plutonic rocks. These are primarily granites, granodiorites, formations of undifferentiated schists, and sericitic schists. This observation is the same in the sub-prefecture of Togoniéré, where granitoids and schists are dominant (**Figure 3**).

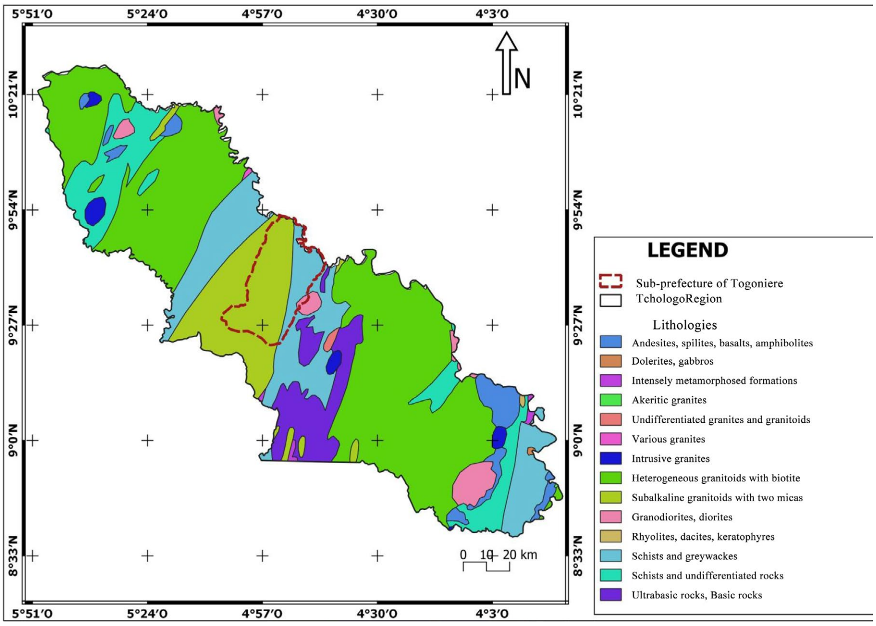

Figure 3. Geological map of the Tchologo region. (Source: the authors)

2.2. Hydrogeological Settings

In Côte d'Ivoire, which is predominantly made up of bedrock, several studies attest to the fracturing of this environment. It can, therefore, be likened to a porous medium [12]. Groundwater reservoirs are found both at the level of laterites, in the formations of the coastal sedimentary basin, and in the rocky formations. In the bedrock area, such as in the sub-prefecture of Togoniéré, we encounter laterite aquifers and fractured reservoirs.

Crystalline rocks, once exposed to the surface, are subjected to chemical and physical weathering processes [20]. These begin with the infiltration of water into the cracks and fractures initially present in the parent rock. This infiltration of water leads to the alteration of the minerals in the parent rock, favoring the development of a weathering profile consisting of loose laterites at the surface, a consolidated and fractured formation at depth, and finally the intact rock (**Figure 4**). Several factors favor the establishment of weathering profiles. Among these factors, we can cite, for example, the composition (parent rock), type of climate, and exposure time of the rock [6]. The weathering profile can be defined as the set of lithological sequences above the intact, unfractured rock [20].

The alteration of crystalline rocks, which are massive and electrically resistant when they are healthy, is accompanied by an increase in water and clay content when they are fractured and altered, which manifests as abnormally low resistivities [21].

2.2.1. Laterite Aquifers

Laterites are formations resulting from the physico-chemical alteration of the bedrock (**Figure 4**). Their profiles and thicknesses vary according to the nature of the rock, the climate, the topography, and the season. The laterite aquifers, tapped by traditional or modern wells, have a capacitive function and a variable thickness, often composed of several layers: from saprolite (weathered rock at the surface) to saprock (partially weathered rock at depth).

The laterites of the Ferkessédougou department are composed from top to bottom of lateritic crust, clayey sand, and gritty arenas [22].

2.2.2. Fissured Aquifers

The crystalline and metamorphic basement can be affected by cracks or fractures of tectonic origin, which determine the presence of aquifers (**Figure 4**). These fissured environments are heterogeneous, and their hydraulic characteristics depend on the geometry, density, and interconnection of the cracks [6]. These aquifers are irregular, located at variable depths, and are exploitable by drilling. Not all fractures are hydraulically active [6]. These reservoirs have a conductive function and can be detected by geophysical methods.

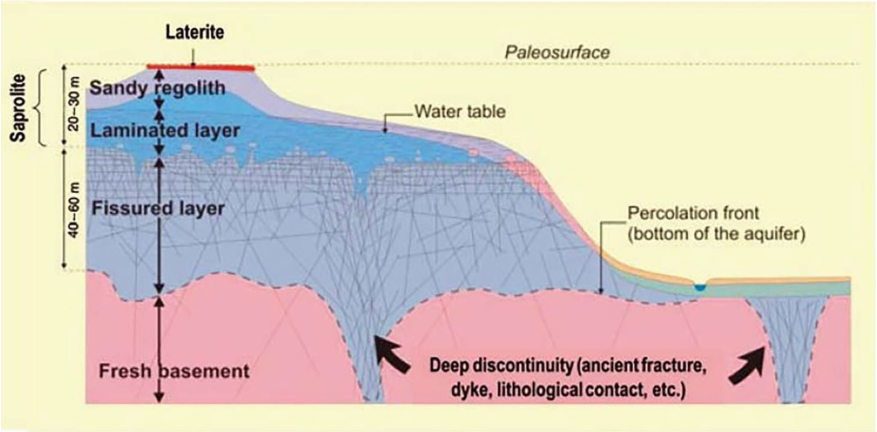

Figure 4. Typical weathering profile developed within basement rocks. [23]

3. Materials and Methods

3.1. Array and Method for Electrical Resistivity Tomography (ERT)

The method adopted is based on an electrical method, in particular, the resistivity method, implemented through the electrical resistivity tomography technique. There are many measuring arrays. The choice of one or more arrays should be guided by the behavior of the target and the objectives of the study. However, some arrays stand out more often than others in the literature. In this study, the dipole-dipole array was used because, in addition to benefiting from greater vertical coverage and greater depth of investigation, it is widely used in the basement, and this array is particularly suitable for imaging vertical or oblique structures (fractured environments) and 3D structures [24]. Its disadvantage is that its deployment in the field is tedious due to the number of electrodes that must be implanted over long distances.

The purpose of tomography is to image the properties of a medium based on a series of measurements taken around and within it [16]. Electrical resistivity tomography (ERT), also called "electric panel" or "electrical resistivity imaging (IRE)", allows for measurements of soil resistivity according to a vertical plane (2D) or within a volume of soil (3D).

In the case of 2D imaging, it is assumed that resistivity does not change in the direction perpendicular to the profile. Theoretically, a 3D study is more accurate as the different dimensions of the investigation space are taken into account. However, it requires significantly more acquisition time, higher equipment costs, and more complex data interpretation. As a result, 2D imaging seems to be a good compromise between obtaining reliable data and maintaining reasonable acquisition and processing costs. The implementation of the ERT consists of implanting a significant number of electrodes (24, 48, 72, 96 or more) spaced at a constant distance "a" and connected by a multi-conductor cable to a resistivimeter and connected to a multi-contact or multi-electrode cable. Each electrode can be used as an emission electrode (A or B) or as a measuring electrode (M or N). The GRX, therefore, receives the potential difference from electrode to electrode (**Figure 5**).

Electrical panels allow for highlighting possible lateral heterogeneities of resistivity through a 2D or 3D image of the subsurface structure.

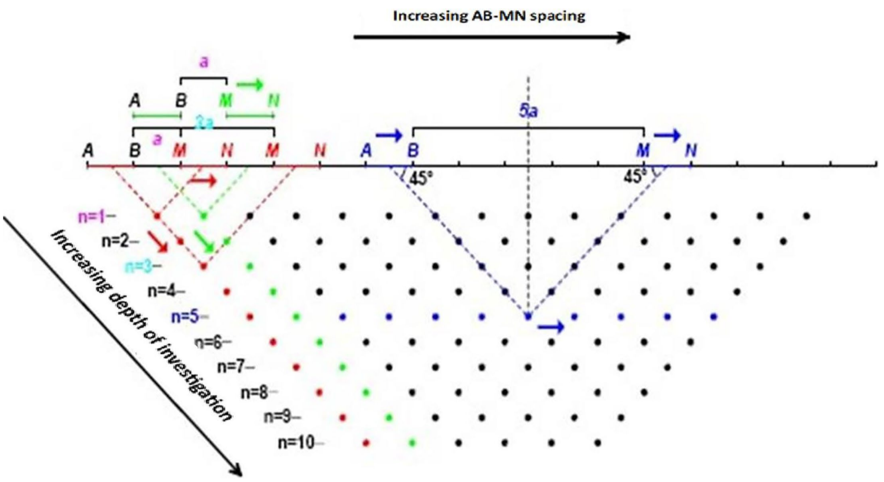

Figure 5. Acquisition diagram of an electrical panel and a pseudo-section. Case of a dipole-dipole array. [15]

3.2. Data Acquisition and Processing

Electrical resistivity tomography was implemented on the site using a TxII transmitter and a GRx8-32 receiver associated with its portable digital assistant (Personal Digital Assistant, PDA).

The orientation of the line, the device, and the deployment of the equipment were completed; data acquisition began by preparing the measurement sequence with the PDA. It should be noted that the dipole-dipole device consists of acquiring data with a successive configuration of two injection electrodes, A and B (injection dipole) and measurement channels formed by receiving electrodes arranged in dipoles: R1 and R2, R3 and R4, R5 and R6, and so on. This arrangement allows for exploring different depths for the same measurement, with the depth increasing from one channel to another. Once the first measurement is completed on the measurement line, electrodes R1 and R2 are disconnected, and electrodes A and B are connected, involving a shift in the direction of the profile. On the GRX, the first disconnected electrode is replaced by the next one, and the other electrodes will follow this movement. On the PDA, a new configuration is prepared. Then, a new measurement is performed, and the same manipulation is repeated for the measurements until the end.

This deployment made it possible to carry out four (4) lines for this study. For each line, 30 electrodes, including 2 for transmission and 28 for reception, were implanted in the ground, respecting a regular spacing of 10 m and a total length of 290 m (**Figure 6**).

Measurements were taken on 20 channels, which allowed for reaching depths of up to 105 m. Of the four layers, the last three oriented at N200˚, separated by an inter-layer distance of 20 m, intersected the first layer at an angle of 90˚, resulting in an orientation of 290˚.

The data processing was done using the IP Post Process software. Before this step, filtering the data is essential to eliminate outlier values related to measurement errors; the software generates a pseudo-section of results in 2D, representing resistivities in the form of color ranges. This is the pseudo-section of apparent resistivities.

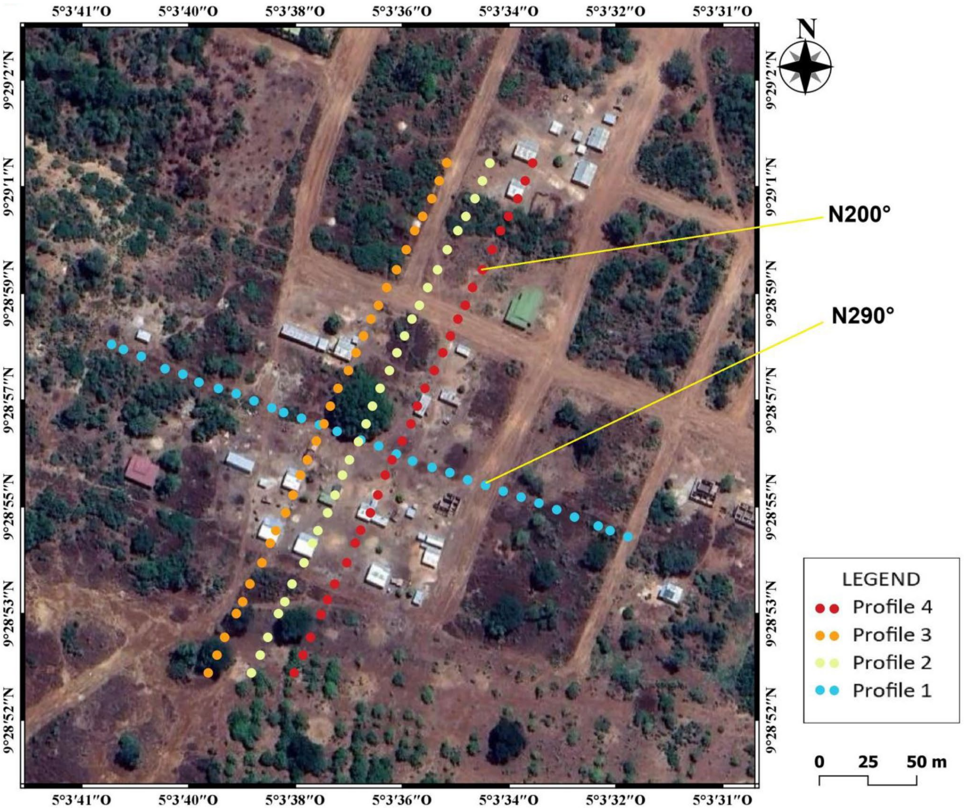

Figure 6. Layering grid of the study area.

4. Results and Discussion

4.1. Results

The results are presented as a range of apparent resistivity on the V-section. They are illustrated by a color canvas ranging from cool colors (low values: blue to green) to warm colors (high values: orange to purple), passing through average values (yellow to yellow-orange).

On profile line 1 (Figure 7), the analysis reveals lateral (horizontal) and vertical (depth) heterogeneity, reflecting significant variations in the underground formations. Three major formations are identified:

The first formation is the low-resistivity formation (light blue to green), with values below 900 Ω.m. It is located between 20 and 60 m deep and 50 to 80 m along the profile; another is between 130 and 180 m along the profile and at depths ranging from 30 to 75 m; and a third is between 220 and 250 m long and 25 to 50 m deep. All conductive formations are located between 10 and 75 m deep.

The second is the medium-resistivity formation (yellow to orange-yellow) with values ranging from 900 to 2290 Ω.m. It is distributed throughout the section, but with a predominance toward the center of the section, between 85 and 160 m in length and a depth ranging from 15 to 75 m.

And finally, high-resistivity formations (orange to purple) with resistivities greater than 2290 Ω.m. They appear at the ends of the profile: A first formation on the far left between 10-15 m depth, a second from the middle to the end of the profile at a depth ranging from 20 m, and finally a third at the end of the depth.

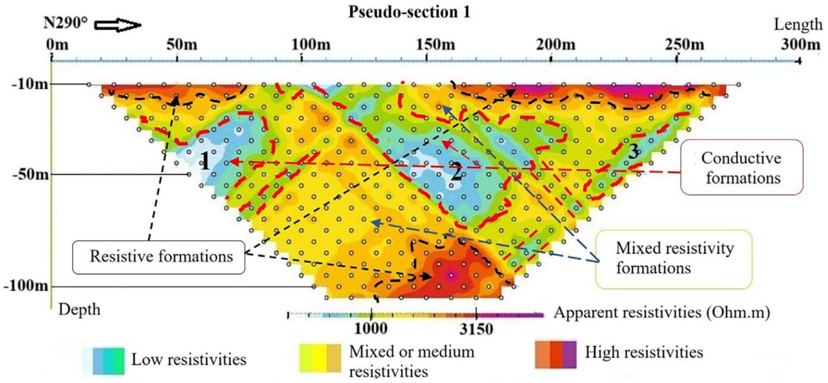

Figure 7. Pseudo-section of the apparent resistivities on profile line 1.

On profile line 2 (Figure 8), at the surface (down to approximately −20 m), resistivities are generally higher (close to or greater than 3150 Ω.m), particularly at the left and right ends (red to purple formations) and finally at depth.

On the depth scale, we observe an alternation of formations with high resistivities (red/purple), formations with low resistivities (blue to green), and formations with high resistivities (red), indicating a more pronounced heterogeneity in the vertical plane of the geoelectric structures.

Formations with low apparent resistivity (blue to light green) appear toward the center of the section between 75 m and 250 m in length and between 20 m and 80 m in depth.

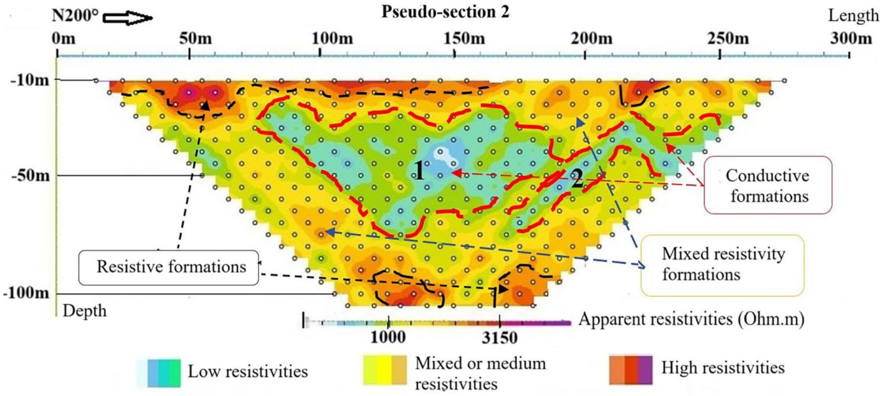

Figure 8. Pseudo-section of the apparent resistivities on profile line 2.

On profile line 3 (**Figure 9**), the section is substantially identical to the previous one, except that this one, in addition to presenting a low anomaly in the center, also presents a conductive facies at the beginning of the profile, that is to say, between 40 and 90 m in length and around the first 70 meters in depth. All the conductive formations are between 20 and 80 m in depth. The transition between formation 1 and formation 2 is manifested in the form of an inclined boundary (thin band) which plunges N245˚. Also, formation 2 has an extension inclined N155˚, resembling a thin band (3 m thick).

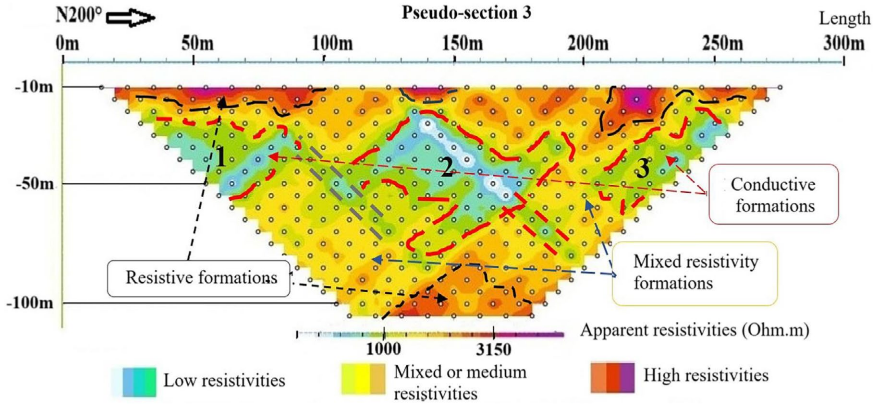

Figure 9. Pseudo-section of the apparent resistivities on profile line 3.

On profile line 4 (**Figure 10**), the resistivity distribution is essentially identical to pseudo-sections 2 and 3. In addition, the conductive formations extend from 60 m to the end of the profile, considering the length, and have a depth of up to 90 m. Here, a connection between these conductive formations is observed.

Overall, this pseudo-section reveals a network of elongated, inclined, and partially interconnected bands. These structures intersect primarily in the center, forming an X-shaped geometry with lateral and vertical extensions. The potential aquifers, of moderate thickness (5 to 10 m), are intersected and oriented along two dominant directions: N245˚ and N155˚. Formation 8 has an irregular shape and a thickness of 30 m. All these conductive formations are located between 15 and 90 m deep, and the highly conductive formations are located around 20 and 70 m deep.

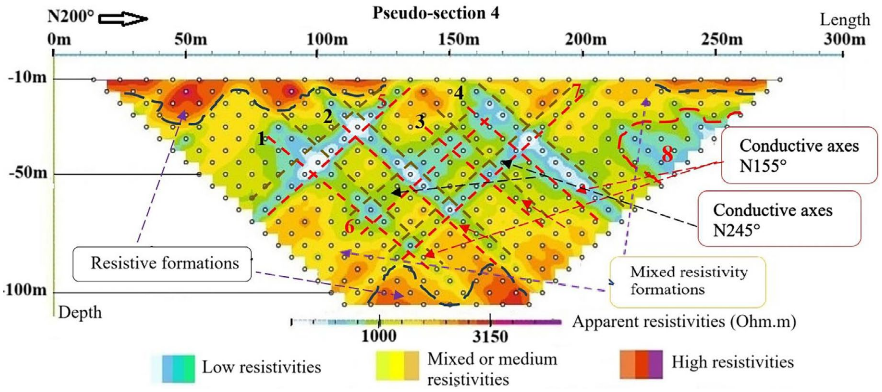

Figure 10. Pseudo-section of the apparent resistivities on profile line 4.

4.2. Discussion

There are limitations inherent in the method itself, but also in the data inversion algorithm: the resolution of the method decreases with depth. The results reveal lateral heterogeneity (horizontally) and are more pronounced vertically (in depth), highlighting a more pronounced anisotropy with depth, thus reflecting a variation in underground formations, as confirmed by [25], which highlights the vertical anisotropy of aquifers developed on a granite weathering profile. Across all sections, this variation is reflected by the alternation of high-resistivity terrains at the surface (up to 20 m deep), conductive terrains, and terrains with medium resistivities in the center, and very resistant terrains at depth. The surface formation (about 20 meters deep) exhibits moderate to high resistivities (orange-yellow to red formations), suggesting the presence of low-conductivity materials such as dry, compact, or lateritic soils. Indeed, the terrain recognition confirms this through the observation of lateritic crusts and lateritic soils in some places on the surface. The formations represented in light blue to green (apparent resistivities of 900 Ω.m) are typically interpreted as altered geological formations, which may contain clay material or water-saturated altered formations, indicating the potential presence of aquifers. In addition to these massive conductive formations, there are extensions in bands oriented according to two preferred dips (N245˚ and N335˚), all with a dip of around 45˚ across all sections, but more pronounced on line 4. These oriented anomalies may be attributed to structural control, such as fractured formations, which have favored the infiltration and storage of water from the underlying aquifers.

Stronger resistivity formations are also observed at depth (red to purple), interpretable as more massive or less altered rock formations, such as sound rock, potentially acting as impermeable boundaries. Thus, the overall variation in resistivities allows for the distinction of a more conductive central formation framed by two more resistant formations. This variation is corroborated by [26], who defines the succession of resistant-conductive-resistant terrains in the basement domain.

The geometry of potentially aquiferous formations is rather irregular, and this is manifested in several ways.

The first three geophysical sections (**Figures 7-9**) show several notable geometric similarities. They all reveal the presence of conductive formations with low resistivity, often in elongated shapes, sometimes in a V shape. In these figures, a triangular shape, in V (**Figure 7** and **Figure 8**) and inverted V (**Figure 9**), is observed in the central formation of the sections. These shapes could correspond to highly altered and water-saturated formations, resembling pockets of water, thus leading to the presence of lateritic aquifers. The average depths are around 20 - 70 m, with an average thickness ranging between 55 - 65 m. The lateral extensions reach up to 80, 100, and 70 m for pseudo-sections 1, 2, and 3, respectively. Particularly in pseudo-section 3, a connection of a V-shaped lateritic aquifer to the central lateritic aquifer (**Figure 9**) is noted by a thin band (3 m thick), which would likely be a fracture. Indeed, Lasm et al. (2012) were able to show that the alteration thickness varies from 8 to 63 m, with an average of 26 m according to drilling data in the Ferkessédougou region. These depths and thicknesses are similar to those obtained by the majority of authors who have worked on drilling productivity, such as [27] in the Daoukro region and [28] in the Dimbokro region. Their results confirm the presence of lateritic aquifers, with the most productive thicknesses ranging from 8 to 50 m deep. In Katiola, a neighboring region, these thicknesses vary between 20 and 50 m [29]. Similarly, the optimal depths for the most productive groundwater are between 40 and 70 m for granites and between 40 and 80 m for schists in the Boungouanou region [30]. All of this is part of a broader context where [5] showed that the thickness of weathering profiles is about 50 to 60 meters on granitoids and can reach up to 80 meters on schists in certain regions of Côte d'Ivoire. In addition to these lateritic aquifers, recurring low-resistivity band-shaped plunges, such as N155˚ (NW-SE), suggest fractures impacting the circulation and storage of groundwater.

Such formations of immersion are typically interpreted as fractured aquifers with variable thicknesses (slices of 3 - 10 m) and lengths of 20 to 70 m. As for pseudo-section 4, which is distinguished from the others, these structures mainly intersect at the center, forming an X geometry with lateral and vertical extensions. It suggests the existence of several bands that could correspond to moderately thick fractured aquifers (3 to 10 m) arranged in a network. These are interwoven and oriented according to two dominant directions (N155˚ and N245˚). These conductive corridors, preferentially oriented NW-SE and NE-SW, were recorded by [31] using traces and electrical soundings in Bouna, and in Bounkani by [32]. The NE-SW (N66˚) and NW-SE (N130˚) directions have proven to be very productive. They confirm that these fractures are located around 40 - 50 m deep, thus confirming our results obtained (20 - 60 m). Additionally, [33] stated that in Côte d'Ivoire, fractured formations can descend up to 70 to 90 m. Furthermore, [34] showed that the thickness of the cracked horizon ranged between 20 and 70 m in the Bélier region. The different orientations of these bands (N155˚ and N245˚) could indicate a permeability network influenced by the fracturing of the bedrock on a local (alteration) or regional (tectonic stress) scale. Generally, these directions fit perfectly into the brittle tectonics of Côte d'Ivoire. Indeed, in the Korhogo region, [35] identified, based on drilling data, three main directions of groundwater productivity: N-S, NE-SW, and NW-SE. These orientations are directly related to the major tectonic deformations of Côte d'Ivoire. The N-S direction reflects local structuring, while the NE-SW and NW-SE directions correspond, respectively, to the Eburnean and Liberian structures. Across all sections, the fractured aquifers (deeper) do not exceed 85 m. Furthermore, statistical studies between productivity and the depth of a well have shown that the probability of encountering open fractures beyond a depth of 90-100 m is negligible (Faillat, 1986). Indeed, the pseudo-sections (**Figure 9** and **Figure 10**) highlight deep fractures, although they seem to narrow with depth. Also, [25] showed that at the level of the fractured horizon, the frequency of fractures decreases with depth, which would explain the average resistivities observed along fractures 1, 2, or 3 at the level of pseudo-section 4. The latter indicates that the development of fracturing is related to the process of local alteration, mainly the alteration of phyllitic minerals (biotites in particular), whose swelling causes fracturing.

All pseudo-sections reflect vertical anisotropy as well as the presence of aquifer formations of laterites and fractured aquifers, attributed to the processes of local and regional alteration.

5. Conclusions

The use of electrical resistivity tomography has allowed for the characterization of the aquifers in the sub-prefecture of Togoniéré (Department of Ferkessédougou), revealing a marked anisotropy with depth. The lateritic aquifers exhibit a triangular V morphology, with thicknesses ranging from 30 to 60 meters and lateral extensions between 35 and 85 meters. As for the fractured aquifers, they appear as thin to wide bands (thickness of 3 to 10 meters), intercrossing to form a network structure, particularly on pseudo-section 4. These structures have two directions: N245˚ and N155˚ and a dip of 45˚. The average depths are around 20 - 70 m for all sections. The origin of these aquifers results from local weathering processes and regional tectonic influences specific to the basement of Côte d'Ivoire.

In light of the results obtained, recommendations can be made to improve water resource management in this locality: Target production at the level of formations 2 (between the abscissas 135 - 140 m on pseudo-section 2, and at the abscissa 140m for pseudo-section 4) where conductive anomalies and dense fractures have been detected, aiming for a depth of 70 m. This will refine knowledge about these aquifer formations and contribute to the water supply of the area.

Acknowledgements

The authors gratefully acknowledge the Society of Exploration Geophysicists (SEG) and the Geoscientists Without Borders® (GWB) program for their financial support and commitment to this project.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Charette, M. and Smith, W. (2010) The Volume of Earth's Ocean. *Oceanography*, **23**, 112-114. https://doi.org/10.5670/oceanog.2010.51

[2] Gleick, P.H. (1996) Basic Water Requirements for Human Activities: Meeting Basic Needs. *Water International*, **21**, 83-92. https://doi.org/10.1080/02508069608686494

[3] Calow, R.C., MacDonald, A.M., Nicol, A.L. and Robins, N.S. (2010) Ground Water Security and Drought in Africa: Linking Availability, Access, and Demand. *Groundwater*, **48**, 246-256. https://doi.org/10.1111/j.1745-6584.2009.00558.x

[4] Faillat, J.P. (1986) Hétérogénéité et effet d'échelle dans les aquifères fissurés. Approche par pompage d'essai sur station expérimentale (Afrique de l'Ouest). *Hydrogéologie*, **1**, 65-76.

[5] Biémi, J. (1992) Contribution à l'étude géologique, hydrogéologique et par télédétection des bassins versants subsahéliens du socle précambien d'Afrique de l'Ouest: Hydrostructurale, hydrodynamique, hydrochmie et isotopie des aquifères discontinus de sillons et aires granitiques de la haute Marahoué (Côte d'Ivoire). Thèse d'Etat, Université de Cocody, 408 p.

[6] Lasm, T. (2000) Hydrogéologie des réservoirs fracturés de socle: Analyses statistique et géostatistique de la fracturation et des propriétés hydrauliques. Application à la région des montagnes de Côte d'Ivoire (domaine Archéen). Thèse de doctorat unique, Université de Poitiers, 274 p.

[7] Kouamé, K.F., Lasm, T., De Dreuzy, J.R., Akaffou, A.G., Bour, O. and Davy, P. (2010) Contribution d'un modèle hydrogéologique à fractures discrètes à l'étude des aquifères fracturés du socle Archéen de Touba (Nord-Ouest, Côte d'Ivoire). *Revue des sciences de l'eau*, **23**, 41-56. https://doi.org/10.7202/038924ar

[8] Sylla, I., Ouedraogo, M., Soro, D.D., Diaby, A.J., Yeo, S.J., Bamba, C.A.K., *et al.* (2025) Aquifers Characterization for the Location of Drinking Water Supply Points in Gbangbégouiné-Yati, in the Department of Man (West of Côte D'ivoire). *International Journal of Geosciences*, **16**, 287-301. https://doi.org/10.4236/ijg.2025.165015

[9] Ouédraogo, M. (2016) Caractérisation des aquifères de socle pour l'amélioration de la productivité des forages d'hydraulique villageoise dans le bassin versant du Bandama blanc amont (Nord de la Côte d'Ivoire). Thèse de Doctorat, Sciences mécaniques et énergétiques, matériaux et géosciences (SMEMAG), Université Paris Saclay (Paris, France), 241 p.

[10] Allé, I.C. (2019) Évaluation de l'implantation géophysique des forages d'eau en zone de socle en milieu tropical (Bénin, Afrique de l'Ouest): Apport de la tomographie de résistivité électrique pour la caractérisation de la cible hydrogéologique. Thèse de

Doctorat, Hydrologie et Gestion Intégrée des Ressources en Eau. Spécialité: Hydrogéophysique, Université d'Abomey-Calavi, 178 p.

[11] Vouillamoz, J.M. (2003) Caractérisation des aquifères par une méthode non-invasive: Les sondages par résonance magnétique protonique. Thèse de doctorat, Université Paris-Sud, 236 p.

[12] Sombo, A.P.K., Kouakou, E.-G. and Bié, G.R. (2019) Caractérisation géoélectrique du système aquifère du département de Dabakala Côte d'Ivoire, 292 p. Géostatistiques de la fracturation et des propriétés hydrauliques, Application à la région des montagnes de Côte d'Ivoire (domaine Archéen), Thèse de Doctorat de l'Université de Poitiers, 274 p.

[13] Lasm, T., Baka, D., Oga, Y.M.S. and Soro, N. (2012) Contribution hydrogéologique à la connaissance des aquifères discontinus du département de Ferké (Nord de la Côte d'Ivoire) pour une meilleure alimentation en eau potable. *Revue Ivoirienne des Sciences et Technologie*, **19**, 114-135.

[14] Organisation Internationale pour les Migrations (2023) Stratégie NORD (2023-2025). Organisation Internationale pour les Migrations, 16 p.

[15] Boucher, M. (2007) Estimation des propriétés hydrodynamiques des aquifères par Résonance magnétique des protons dans différents contextes géologiques, de l'échantillon à l'échelle hydrogéologique. Thèse de Doctorat de l'Univ. d'Orleans, 198 p.

[16] Chalikakis, K. (2006) Application de méthodes géophysiques pour la reconnaissance et la protection des ressources en eau dans les milieux karstiques. Thèse de doctorat, Université Pierre et Marie Curie-Paris 6, 211 p.

[17] INS (Institut National de la Statistique) (2021) Recensement général de la population et de l'habitat (RGPH). Données socio démographiques et économiques des localités, résultats définitifs par localités: Région du Tchologo, 28 p.

[18] Ouattara, S. (2023) Activités Agro-industrielles et problèmes environnementaux dans le département de Ferkessédougou (Nord de la Côte d'Ivoire). Mémoire de master Option: Géographie Physique et Environnement, Institut National Poly-technique Félix Houphouët-Boigny, 113 p.

[19] Bouatrin, K.S. (2016) Évaluation de la productivité des forages d'eau en milieu de socle dans la région du Tchologo. Mémoire en Sciences et Gestion de l'Environnement. Option: Géosciences et Environnement, Université Nangui Abrogoua, 61 p.

[20] Guihéneuf, N. (2014) Structure des écoulements et propriétés de transport des aquifères cristallins fracturés et altérés: Application au site de Choutuppal (Inde du Sud). Thèse de doctorat, Université Rennes 1, Géosciences-Rennes, 247 p.

[21] Wyns, R., Gourry, J.-C., Baltassat, J.-M. and Lebert, F. (1999) Caractérisation multiparamètres des horizons de subsurface (0-100 m) en contexte de socle altéré. 2*ème Colloque GEOFCAN*, Orléans, 105-110.

[22] Coulibaly, M. (2001) Hydrogéologie des milieux de socle: Hydrodynamique des réservoirs fissurés. Cas de la région de Niellé (Nord de la Côte d'Ivoire). Mémoire de DEA des Sciences de la Terre. Option Hydrogéologie, Université de Cocody, 71 p.

[23] Lachassagne, P. and Wyns, R. (2005) Aquifères de socle: Nouveaux concepts-Application à la prospection et la gestion de la ressource en eau. *Géosciences*, **2**, 32-37.

[24] Dahlin, T. and Zhou, B. (2004) A Numerical Comparison of 2D Resistivity Imaging with 10 Electrode Arrays. *Geophysical Prospecting*, **52**, 379-398. https://doi.org/10.1111/j.1365-2478.2004.00423.x

[25] Maréchal, J., Wyns, R., Lachassagne, P., Subrahmanyam, K. and Touchard, F. (2003)

Anisotropie verticale de la perméabilité de l'horizon fissuré des aquifères de socle: Concordance avec la structure géologique des profils d'altération. *Comptes Rendus. Géoscience*, **335**, 451-460. https://doi.org/10.1016/s1631-0713(03)00082-8

[26] Baltassat, J.M., Mathieu, F., Ambroise, B., Barbet, C., Béon, O., Dewandel, B., Lachassagne, P., Norie, A. and Wyns, R. (2015) Méthodologie et résultats d'application de la tomographie électrique de résistivité par courant continu pour l'exploration hydrogéologique des aquifères discontinus en domaine de socle. Aquifères de socle: Le point sur les concepts et les applications opérationnelles. La Roche-sur-Yon (France), 6 p.

[27] Blé, L.O., Soro, T.A., Gabriel, E., Ahoussi, E.K., Oga, M.S., Biémi, J. and Akossi, D. (2015) Productivité des forages d'eau en milieu cristallin et cristallophyllien dans la région de Daoukro (Centre-Est de la Côte d'Ivoire). *Synthèse*, **30**, 76-90.

[28] Koïta, M. (2005) Essai d'optimisation de la productivité des forages pour l'alimentation en eau potable des formations de socles: Cas de Dimbokro. Mémoire DEA Univ. Abobo Adjamé, 78 p.

[29] Gnamba, F.M., Oga, Y.M.S., Gnangne, T., Lasm, T., Biémi, J. and Kouakou Y.K.N. (2014) Analyse de la productivité des aquifères de fissures du socle paléoprotérozoïque de la région de Katiola (Centre Nord de la Côte d'Ivoire). *European Scientific Journal*, **10**, 79-98.

[30] Assemian, E.A., Kouamé, K.F., Saley, M.B., Affian, K., Youan, T.M., Jourda, J.P. and Biemi, J. (2014) Étude de la productivité d'un aquifère de socle et approche statistique pour la détermination des tranches de profondeurs potentiellement productives: Cas de la région de Bongouanou, Est de la Côte d'Ivoire. *Revue des sciences de l'eau*, **27**, 81-97.

[31] Djroh, S.P., Ouattara, Y., Soro, D.D., Kouamelan, K.S., N'Zi, K.A.A., Gnoleba, S.P.D. and Kouamé, L.N. (2023) Identification des aquifères de fracture en milieu cristallophyllien: Contribution de la méthode de résistivité électrique (Bouna, Nord-Est de la Côte d'Ivoire). *International Journal of Innovation and Applied Studies*, **38**, 637-648.

[32] Kouakou, E.G.K., Dosso, L., Kouamé, L.N., Sombo, A.P. and Sombo, B.C. (2015) Contribution des méthodes de résistivité électrique a la recherche d'eau en milieu cristallin: Cas de Yakassé-Attobrou et d'Abié, région de la Mé, Côte d'Ivoire. *Revue Ivoirienne des Sciences et Technologie*, **26**, 194-211.

[33] Engalenc, M. (1978) Méthodes d'étude et de recherche de l'eau souterraine des roches cristallines de l'Afrique de l'Ouest. Comité interafricain d'études hydrauliques, série hydrogéologie, Vol. 1, 318 p.; Vol. 2, 193 p.

[34] Ehoussou, K.M., Kouassi, A.M. and Kamagaté, B. (2018) Caractérisation hydrodynamique des aquifères fissurés de la région du Bélier (centre de la Cote d'Ivoire). *Larhyss Journal*, **36**, 119-143.

[35] Jourda, J.P., Saley, M.B., Djagoua, E.V., Kouamé, K.J., Biémi, J. and Razack, M. (2006) Utilisation des données ETM+ de Landsat et d'un SIG pour l'évaluation du potentiel en eau souterraine dans le milieu fissuré précambrien de la région de Korhogo (Nord de la Côté d'Ivoire): Approche par analyse multicritère et test de validation. *Télédétection*, **5**, 339-357.