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Deep Aquifers Study Using Geo-Electrical Imaging for Drinking Water Borehole Installation in Nioronigué (Department of Ouangolodougou, Northern Côte d'Ivoire)

Moussa Ouedraogo[1*], Ouattara Ismaïla[1], Yao Kouadio Assémien François[1], Coulibaly Lérèyaha[1], Ismael Sylla[1], Traoré Issa[1], Marc Pessel[2], Bamory Kamagate[1,3]

[1]UFR Sciences Géologiques et Minières, Université de Man, Man, Côte d'Ivoire
[2]GEOPS Laboratory, Université Paris-Saclay, CNRS, Orsay Cedex, France
[3]Laboratoire de Géosciences et Environnement, Université Nangui Abrogoua, Abidjan, Côte d'Ivoire
Email: *moussa.ouedraogo@univ-man.edu.ci

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Abstract

Access to groundwater in bedrock areas, such as the locality of Nioronigué with a high human density, is often hindered by the discontinuous nature of aquifers and the geological complexity of the crystalline substrate. In response to the pressing demand for sustainable drinking water in Nioronigué, Northern Côte d'Ivoire, this study employs Electrical Resistivity Tomography (ERT) with a dipole-dipole array to map deep aquifers within an intricate crystalline basement. Four geophysical sections, 290 meters long and to depths of 105 meters, generated two dominant subsurface facies: conductive facies (<100 Ω·m) and resistive facies (>100 Ω·m). Of specific interest is profile 4, which included an extremely conductive anomaly at 60 - 200 m lateral distance and 90 m depth, coinciding with fig tree (*Ficus gnaphalocarpa*) markers and crossing anomalies in the other profiles—a good sign of a strong, water-filled zone. The best hydrogeological conditions, including high aquifer thickness and good geometry, are found at the suggested site for drilling at X = 150 m with a target depth of 50 - 75 m. Comparison with regional studies affirms the existence of productive aquifers commonly at depths between 40 - 70 m. This marks the efficiency of ERT in the delineation of fractured and altered areas, supporting precise borehole siting in basement rocks. The study provides a replicable geophysical procedure for groundwater exploration in impoverished regions facing demographic and climatic pressures.

Keywords

Deep Aquifers, Geoelectrics, Electrical Resistivity Tomography, Côte d'Ivoire

1. Introduction

In Côte d'Ivoire, access to drinking water is a major challenge, particularly in the rural areas of the north where hydraulic infrastructure is insufficient. The locality of Nioronigué, in particular, is situated in a context characterized by rainfall influenced by climate change, coupled with demographic pressure due to the presence of a camp for displaced populations and refugees in significant numbers from Mali and Burkina Faso. Located in the sub-prefecture of Ouangolodougou, this locality faces vital needs for water. Unlike surface water, groundwater is considered one of the most important sources of drinking water supply due to its high storage capacity and low exposure to pollutants [1] [2]. Indeed, these aquifers, located at great depths under a cover of more or less thick laterites, are generally protected from seasonal fluctuations and any pollution [3]-[5]. In such circumstances, it is reasonable to search the drinking water supply towards deep aquifers whose water quality generally meets WHO standards [3]. Thus, this alternative aims to capture the water trapped in these pockets of rock formations using innovative and improved methods. Despite numerous drilling projects, Ouangolodougou faces a persistent water supply problem, especially during the dry season. In the Nioronigué basement, groundwater is mostly the only reliable source of sustainable drinking water intended for consumption. This lack of water is due to poor management of pumps, which are often damaged, a lack of knowledge about discontinuous aquifers, and the methods used to search for these aquifers, resulting in low drilling yields [6]-[8]. Consequently, villagers must travel long distances to access drinking water, often of unsatisfactory quality [9]. The hydrogeological database in this region is almost nonexistent. The only known works are those of [10] [11], which are unfortunately very fragmentary.

Several geophysical methods allow for refining the characterization of complex aquifers to install sustainable boreholes. Among these different methods, we have the electrical method, which is the most commonly used for the installation of water boreholes [12]. It is in this context that the electrical resistivity tomography imaging method was initiated to characterize the aquifers of Nioronigué. The general objective of this study is to locate deep aquifers and identify sites for the installation of drinking water boreholes in Nioronigué. Specifically, it involved:

- Studying the lateral and vertical variation of the electrical resistivity of the underlying formations using geophysical imaging;
- Identifying the areas with promising aquifer potential for groundwater exploitation.

2. Study Area

2.1. Geographic Context of the Study Area

The department of Ouangolodougou, to which Nioronigué locality belongs, is located in the north of Côte d'Ivoire, in the Tchologo region. This department has 5 sub-prefectures and is part of the border area with Mali and Burkina Faso to the north. It is bordered to the southeast by the department of Ferkessédougou, to the south by that of Sinématiali and Korhogo, and to the west by the department of M'Bengué (**Figure 1**). It is located between 9˚40'00" and 10˚30'00" North latitude and 6˚00'00" and 4˚50'00" West longitude. The department of Ouangolodougou is the capital of the municipality, sub-prefecture, and department with an area of 17,728 km² [13].

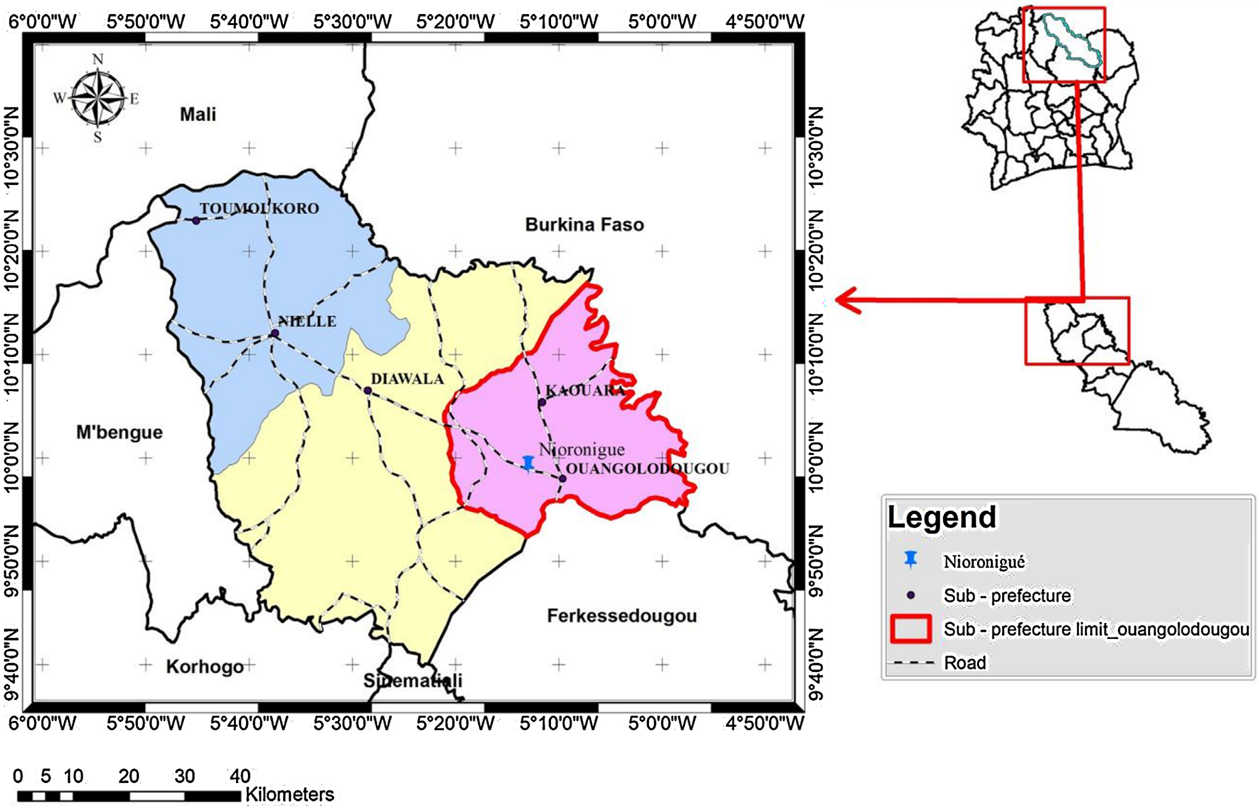

Figure 1. Geographic situation of the study area.

2.2. Geological Overview of the Study Area

In terms of petrography, the rocks that characterize the Ouangolodougou sub-prefecture are biotite granitoids, granites, schists, and grauwackes. Thus, there are magmatic and metamorphic assemblages [10] [11]. From a structural point of view, a main NE direction characterizes the contact zones between the lithologies (**Figure 2**). The volcanic-sedimentary formations show well-developed schistosity.

Regarding the study area, the alteration profile varies according to the lithological nature of the protolith [14]. During fieldwork, we identified the presence of formations such as lateritic crust, pink sand, and biotite granodiorite.

2.3. Hydrogeological Context of the Study Area

The department of Ouangolodougou is traversed by the Comoé River and its tributaries (**Figure 3**). These form vast floodable areas that can reach between 500 m and approximately 1 km in some places [15]. Outside of the Comoé, the rivers are intermittent and dry up during the dry season, while during the rainy season,

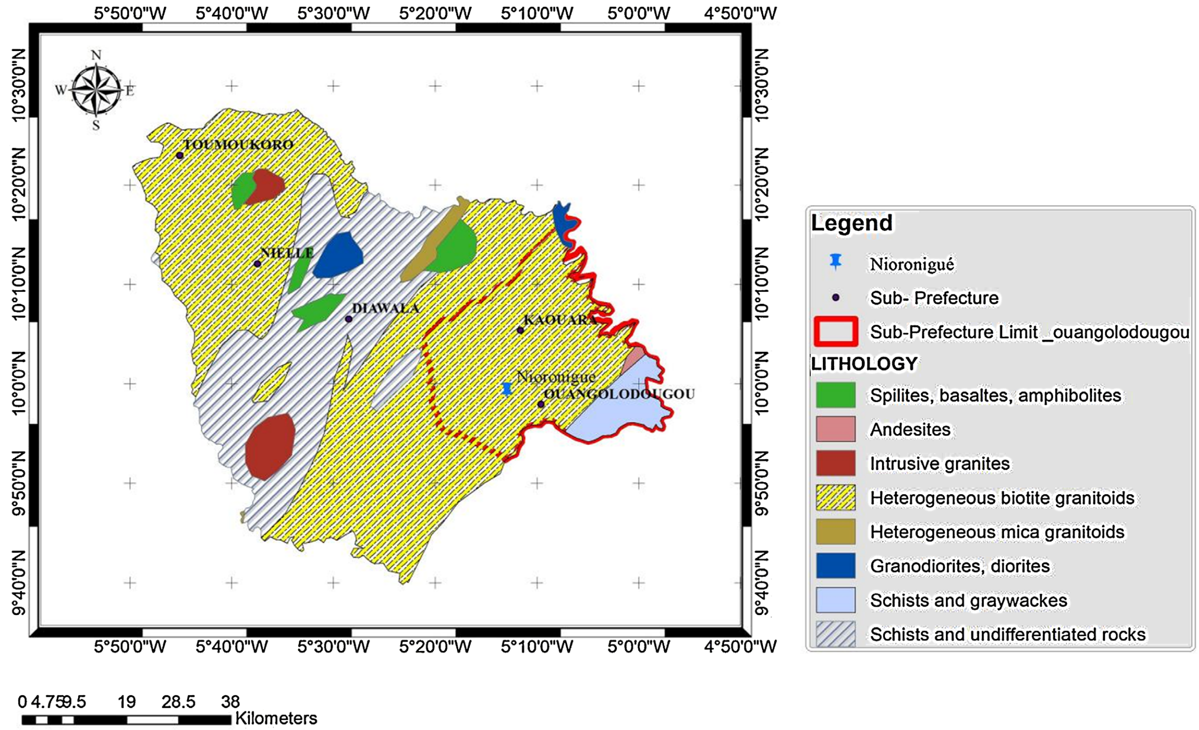

Figure 2. Geological map of the study area.

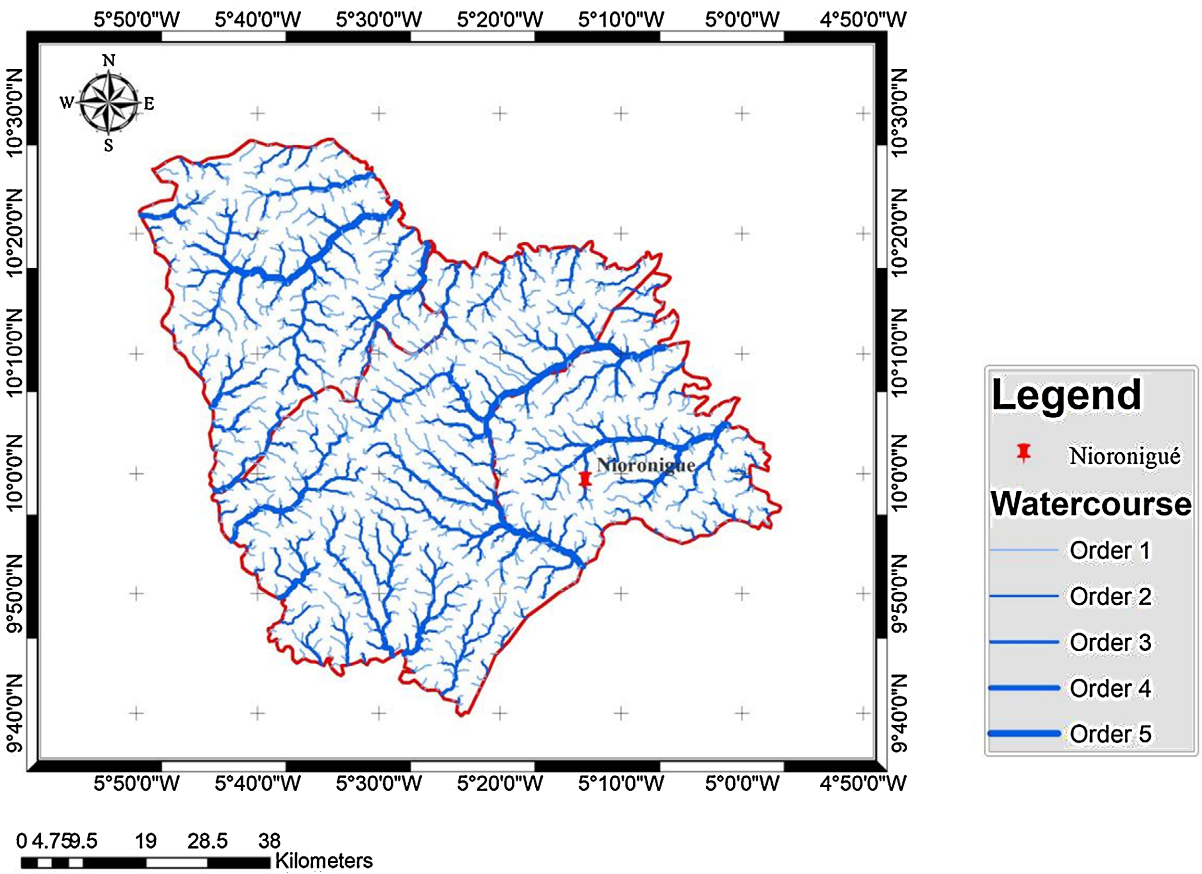

Figure 3. Map of the hydrographic network of the study area.

floods occur in certain waterways, causing damage to crops and homes [16].

The crystalline and metamorphic basement can sometimes be affected by tectonic events such as cracks and fractures. The presence of an aquifer in this basement depends on the existence of cracks and/or alterations. The fractured environment is heterogeneous, and its hydraulic characteristics are determined by the geometry and density of the fractures. The hydraulic continuity of this hydrogeological system relies on the interconnection of the cracks [17]. In addition to lateritic aquifers, these fractured aquifers are generally exploited through drilling. Fractured aquifers have an irregular shape and are located at varying depths depending on the region. They exhibit much higher permeability than laterites, but with low usable porosity.

3. Material and Methods

3.1. Material and Equipment Used

The main equipment used for the geophysical surveys consists of a TX II transmitter for transmitting current into the ground, a GRX 8-32 receiver for measuring resistivity, chargeability, and other parameters, and a personal digital assistant (PDA) associated with the receiver to program and generate all field measurement operations. In addition to this heavy equipment, a generator (power source for the TX II transmitter), cables for transmitting and receiving the electrical signal, as well as large diameter electrodes, were used.

3.2. Electrical Resistivity Tomography (ERT) Method

Electrical resistivity tomography (ERT) allows for measurements of ground resistivity according to a vertical plane (2D) or within a volume of ground (3D) [18]. The measurements are presented using a pseudo-section of apparent resistivity as a function of position along the profile and the pseudo-depth used. It should be noted that within the same section, the measurements of apparent resistivity can undergo variations even among themselves.

3.3. Implementation of ERT on the Nioronigué site

To create an electrical panel, a set of electrodes is arranged along a straight profile with regular spacing "a". The voltage is measured for different combinations of the transmitter (AB) and the receiver (MN) (**Figure 4**). By convention, the measurements are presented in the form of sections where the x-axis corresponds to the position along the profile, and the y-axis corresponds to the rank "n", which characterizes the distance between the emitting and receiving parts of the device. The rank is a function of depth (pseudo-depth), and the sections obtained are called pseudo-sections of apparent resistivity.

Different configurations of emitting and receiving electrodes can be used: pole-pole, pole-dipole, dipole-dipole, Wenner, and Schlumberger. The choice of configuration is made based on the depth of investigation and the desired resolution. For this study, we chose the dipole-dipole device due to its relatively low signal-to-noise ratio and its uneven coverage, but its spatial resolution is quite good and its depth of investigation is high. This device is suitable for imaging vertical and 3D structures.

On the Nioronigué site, the implementation of electrical resistivity tomography (ERT) was carried out using the dipole-dipole device. For each profile (Figure 5),

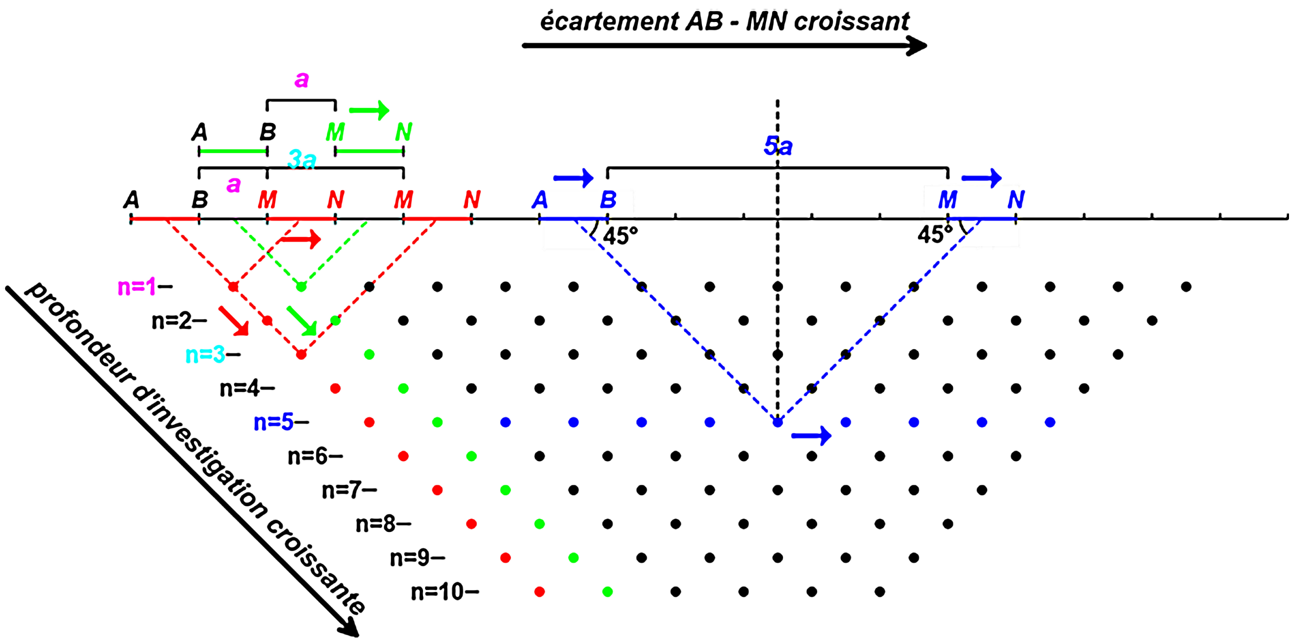

Figure 4. Acquisition diagram of an electrical panel and a pseudo-section. Case of a dipole-dipole device [19].

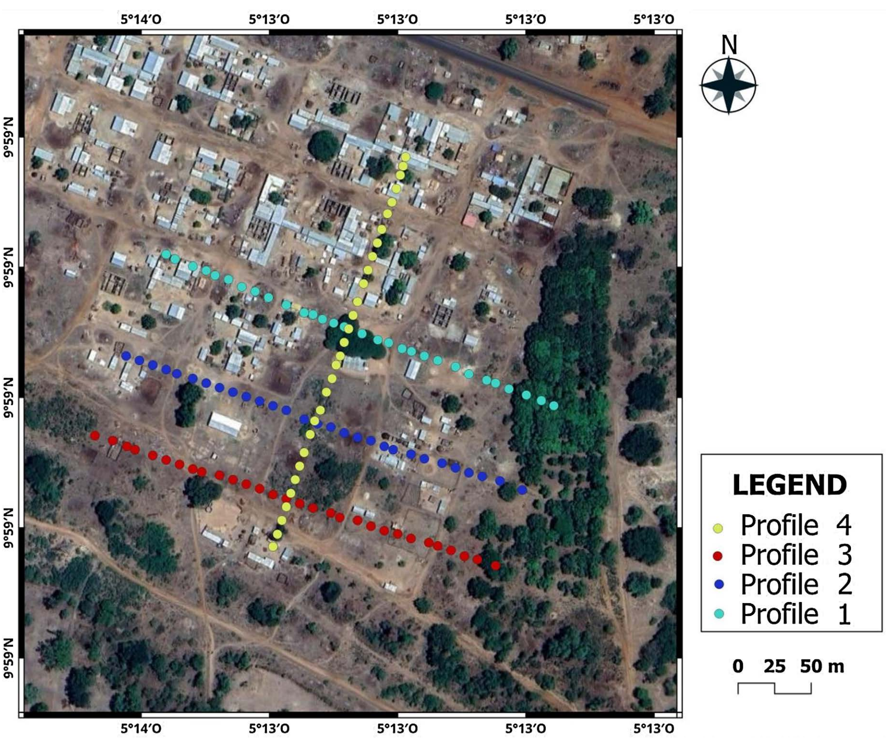

Figure 5. Location map of geophysical profiles.

30 electrodes, including 28 receivers and 2 for transmission in stainless steel, were implanted in the ground with regular spacing of 10 meters. This results in a line length of 290 m for each profile. These electrodes were connected to a receiver (GRx 8 - 32) by multi-conductor cables, while two current injection electrodes (A and B) were connected to the transmitter (TxII). The first three profiles follow the same direction, N290˚. Meanwhile, the fourth is oriented at N200˚. This direction allows the first three to intersect at a right angle. The process begins with the injection of current via TxII to the injection electrodes, while the signal is captured by the GRx 8 - 32 and displayed on the PDA as it progresses. Data acquisition was performed on 20 channels; then the channels were gradually removed to form a symmetrical panel. This approach allows for a maximum investigation depth of 105 meters. After each measurement, a translation (movement) of 10 meters is performed, corresponding to the spacing between two measurement points. This process is repeated until the last acquisition, ensuring homogeneous coverage of the terrain. All these operations allow for the production of 2D or 3D maps. In the context of this study, the obtained geo-electrical imaging is in 2D, providing a smoother and more detailed interpretation of underground structures.

3.4. Processing Equipment

The data processing equipment used consists essentially of computer tools and software such as IP-Post process for generating the measurement sequence, their analysis, and the pseudo-section processing and display.

4. Results and Discussion

4.1. Results

The data from geophysical resistivity surveys allow for results in the form of sections called pseudo-sections of apparent resistivity of the subsurface. The analysis of these pseudo-sections helps characterize geological structures and understand their significant influence on geomorphology, particularly the location of aquifers, impermeable formations, and porous environments. The results of this study highlight the clear imaging of the subsurface in the investigated area of Nioronigué. Thus, to better understand the different pseudo-sections, a color ramp is defined by the scale of apparent resistivity, with the obtained section characterized by conductive zones (light color) and resistive zones (bright color); hence, the presence of two main facies, namely a conductive facies with resistivity values below 100 Ω·m and a resistive facies with resistivity values above 100 Ω·m.

4.1.1. Identification, Variability, and Geometry of the Underlying Formations

The pseudo-section of profile 1 (**Figure 6**) is 290 m long with a maximum depth of 105 m. It is characterized by a variation of low resistivity layers from the beginning of the profile up to a distance of 180 m. The rest of the profile is marked by a slight deterioration of the resistive layers with depth. The conductive layers observed on the pseudo-section are found between depths of 10 and 75 m in a triangular shape. Meanwhile, the resistive formations generally have a rectangular shape and a dip of 45˚ following the direction of the profile. The resistive zone tends to fragment in light of the observed resistivity values. The conductive formations of the profile, considering their positioning, could be associated with the presence of an aquifer. A second zone, which is a zone of low resistivity values, appears at the beginning of the pseudo-section. This information is located just before the first 40 meters of distance. This zone could correspond to a conductive formation that extends from the first few meters of depth. This conductive formation would constitute a recharge area for the probable underlying aquifer.

Profile 2 (**Figure 7**), which is roughly identical to profile 1, also shows variations

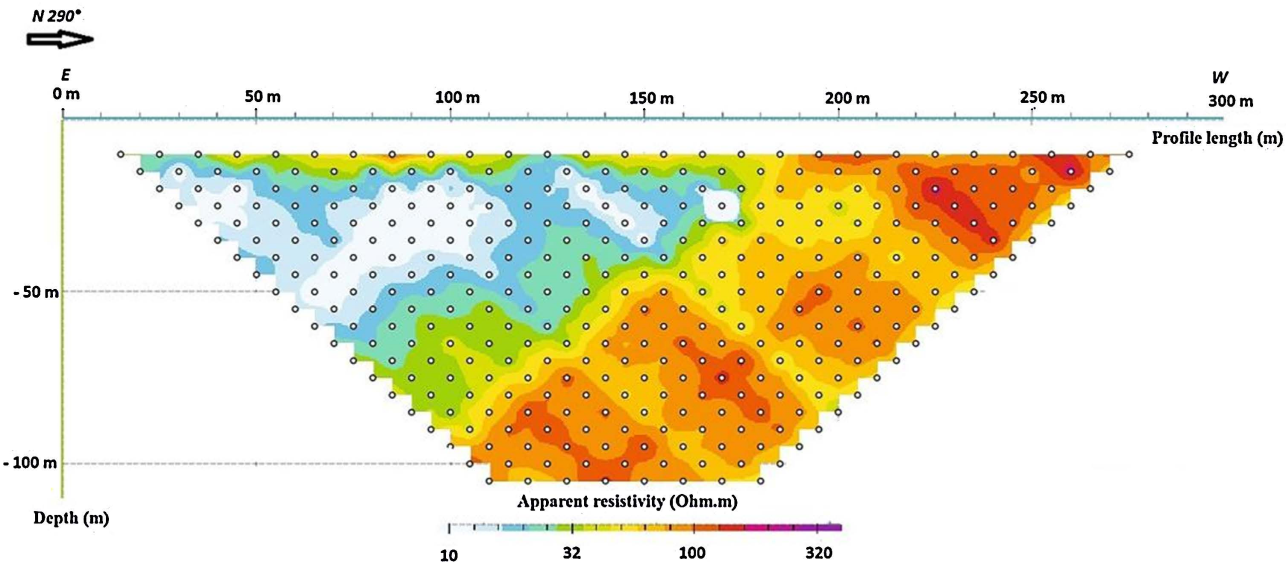

Figure 6. Pseudo-section of profile 1.

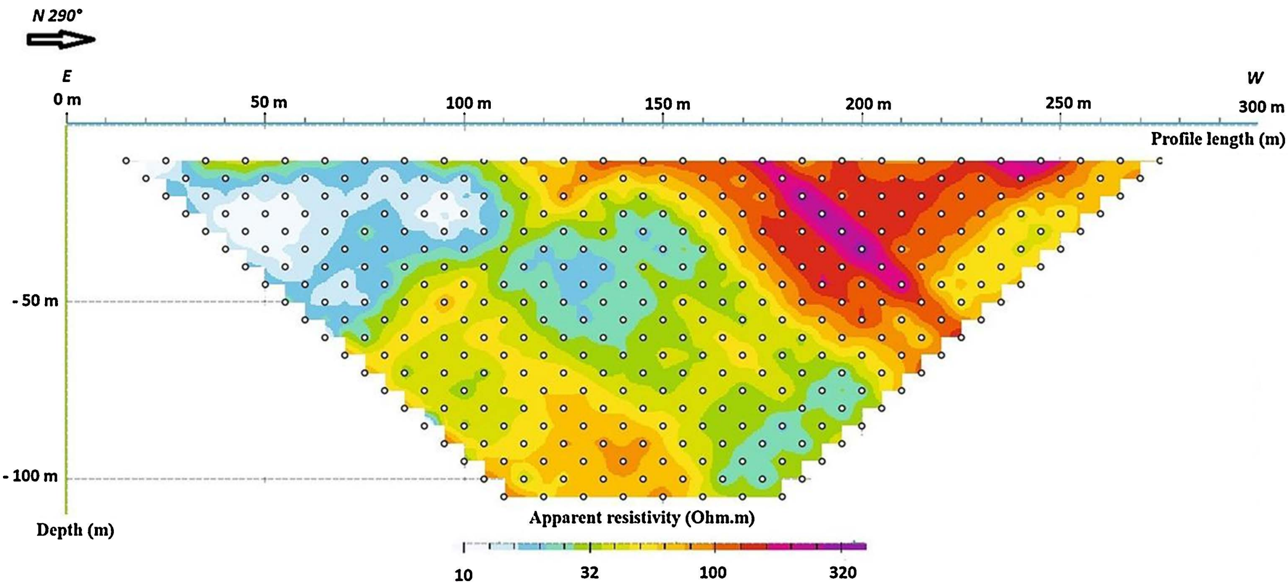

Figure 7. Pseudo-section of profile 2.

in layers of low resistivity from the beginning of the profile up to 170 m. This area has a triangular shape extending from the initial depths to 65 m. A second rectangular area is located in the heart of the pseudo-section between depths of 20 m and 105 m. It is 80 m long. The rest of the profile, which extends from 160 m to 260 m, is marked by a degradation of very resistive layers observed over the first 70 meters of depth. These resistive formations have a triangular shape. This profile also presents a very conductive zone at the beginning of the profile. In addition to these two areas in the heart of the pseudo-section and at the end, this profile also shows at the beginning a triangular low resistivity zone that extends over a distance from 10 m to 110 m with a depth of 70 m. This low-resistivity zone, located at the beginning of the profile, is a conductive area that could be a surface aquifer containing a free water table and possibly a recharge zone. These areas of high conductivity, located in the heart of the profile, could also be an aquifer, considering the environment.

Profile 3 (**Figure 8**) is practically representative of the low resistivity areas from the beginning to the end. A high-resistivity zone is also identified in the first 15 meters of maximum depth. This zone is 140 m long (35-175 m) and less expressive. As we can see, three zones are distinctly conductive due to the low resistivity values observed. Almost at the beginning of the profile, the first zone is observed over a distance of 100 m and plunges to a depth of 65 m with an irregular shape. Then, a second zone is located between distances of 120 and 185 m with a more or less rectangular shape. It is located just below the first 20 meters down to an 80 m depth (60 m thick). Finally, we observe a last zone, also rectangular in shape, from a distance of 185 m to the end of the profile. This one has a thickness of 30 m (10 - 40 m depth). The first two zones could be recharge zones. This zone is less significant due to its geometry, but due to the topography, it is a hydrologically important point. We are probably dealing with an aquifer.

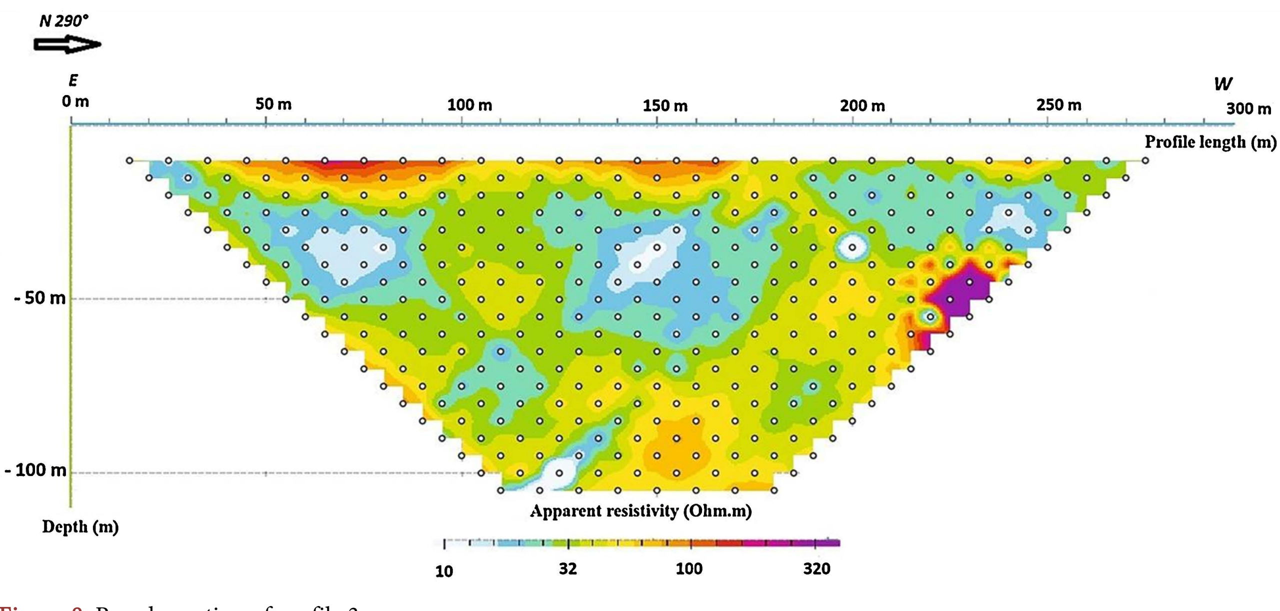

Figure 8. Pseudo-section of profile 3.

Like the previous profiles, profile 4 (**Figure 9**) presents low- and high-resistivity facies from start to finish. A first resistant facies is observed at the beginning of the profile and dips at 45˚ in the direction of the profile, from the surface to depth. It is recognizable up to 50 m, depending on the length of the profile. Another, more resistant facies is 85 m long (from 135 to 220 m) over the first 30 meters of maximum depth. It has a circular shape and could extend to the end of the profile. Furthermore, a highly conductive facies is found between these two observed resistant facies. Indeed, it could be subdivided into two zones, one horizontal and the other oblique relative to the orientation of the profile. Overall, this conductive facies is 140 m long (from 60 to 200 m) and 90 m deep. This conductive zone, located at the heart of the pseudo-section, could be a water-bearing aquifer that would recharge from the second overlying zone to the left of the profile. The position of the conductive facies on the pseudo-section suggests that the resistive facies tend to alter. This information is supported by the presence of the fig tree (*Ficus gnaphalocarpa*), which is a water indicator observed at this location in the field.

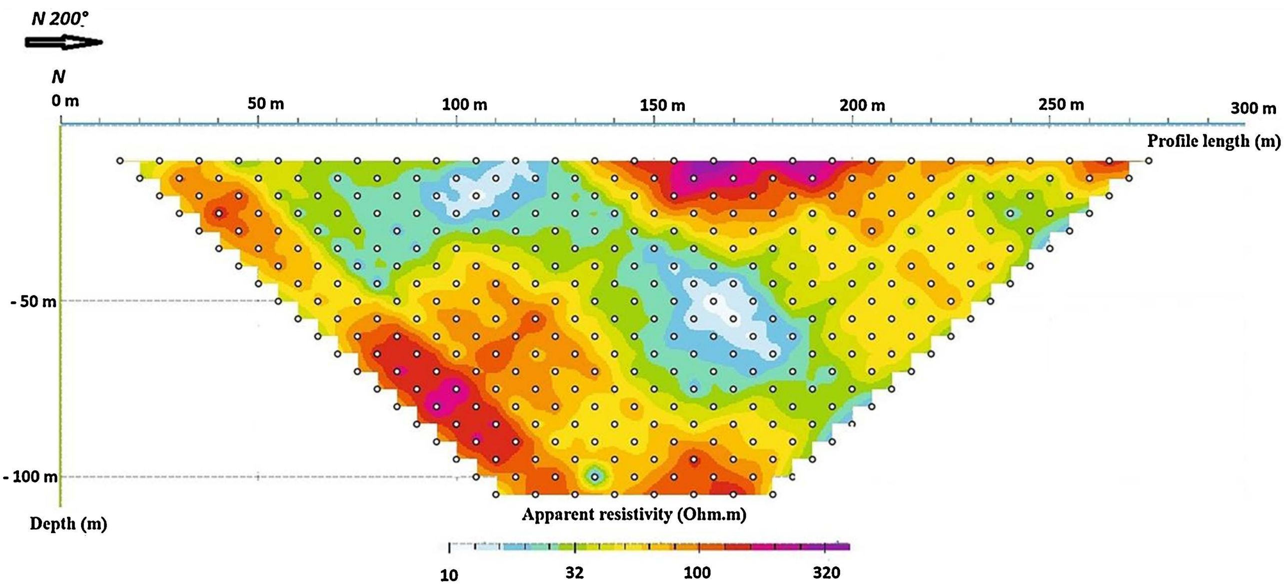

Figure 9. Pseudo-section of profile 4.

4.1.2. Proposal of Drilling Points

Following the preliminary investigations and geophysical surveys, our attention was drawn to a set of points of interest, selected based on the resistivity values of the geological formations, their geometry, and the immediate environment of potential aquifers. The point X150 m (altitude 325 m, target depth 50 to 75 m) on the profile P4 (drilling F1) was prioritized. This point indeed presents the most favorable geophysical and hydrogeological conditions for sustainable exploitation, notably a significant thickness of the saturated zone, a typical resistivity of altered and/or fractured aquifer formations, as well as an accessible depth compatible with production drilling.

4.2. Discussion

The analysis of the pseudo-sections highlighted two types of formations, namely conductive formations and resistive formations. These highly resistive zones were observed. On the pseudo-sections, there are very compact geological formations that could be the healthy rock (substratum rock). This information is also confirmed by [20], which states that formations with high resistivities correspond to healthy rocks at the experimental site of Sanon in Burkina Faso. The conductive facies of profiles 1, 2, and 3 are located practically at the same distance on each of the pseudo-sections. In addition to the fact that these three profiles are parallel, they all start at the same position and have the same length and maximum depth of investigation. Indeed, the compilation of all this information could justify the continuity of formations from one profile to another. Furthermore, the continuity of conductive facies in the profiles allows us to cautiously affirm that there is the presence of an aquifer that could be recharged by an overlying unconfined aquifer, as we observe in the relevant pseudo-sections (**Figures 6-8**). Indeed, these results are demonstrated by some authors who argue that the aquifers of laterites and fractures are often superimposed and are closely linked by a drainage phenomenon [14]. Watercourses tend to follow areas of least resistance (crushed, faulted, fractured, jointed, weathered areas, etc.); according to [10] [11] [21] [22], the type of aquifer observed on the pseudo-sections is rather related to weathered areas and/or fractures. As for profile 4 (**Figure 9**), which intersects the first three perpendicularly, it presents a zone of high conductivity at the heart of the profile.

This conductivity zone coincides with the conductive zones of the previous profiles that it intersects at the same point X = 150 m. Moreover, the presence of fig trees (*Ficus gnaphalocarpa*), an indicator tree of water presence, along the paths of profiles 1 and 4 at positions X = 150 m and X = 130 m, respectively, confirms the conductive zone (likely to contain water) at these different positions. This conductive zone could be a recharge pole for the aquifer. Overall, this conductive zone likely to be an aquifer is located between depths of 20 and 70 m. These results are similar and consistent with the works done in Côte d'Ivoire by [3] [14] [23] [24], and [25], establishing the existence of open fractures between 50 and 70 m deep. In the same context of the basement, [24] suggests depths between 40 and 70 m as optimal depths. Furthermore, [26] argues that the most productive zones are located between 40 and 60 m.

In this case, it emerges from these analyses and interpretations that the different profiles 1, 2, 3, and 4 are traversed by a continuity of conductive and altered formations. These results also show that the use of the electrical resistivity tomography technique allows for the detection of altered areas, crack zones, etc. In general, it allows for the detection of all events likely to have fragmented the sound rock by giving it sufficient permeability to be the site of underground flows. Consequently, the aquifers detected in Nioronigué are likely related to alteration, due to the fact that the detected zones do not reflect a shape likely to be oriented structures. These results are in accordance with those proposed in recent years by [27]-

[31], which support that the hydraulic conductivity of bedrock aquifers is due to the alteration process and not to tectonic fracturing.

5. Conclusions

As part of the studies conducted in Nironigué aimed at locating deep aquifers and identifying areas suitable for the installation of drinking water wells, there was a discussion about imaging the subsurface through the application of electrical resistivity tomography to identify the aquifers at the site. Different aquifers were observed, such as deep aquifers and unconfined aquifers (sub-surface). These aquifers present characteristics favorable for sustainable groundwater exploitation. This method allowed us to highlight conductive areas that could be suitable for the installation of water wells in this area. After analysis, a suitable drilling point on profile 4 could provide a high borehole yield at the position X150 m.

The proposed point was selected as the priority site due to several favorable criteria, including its location on a conductive anomaly indicative of high water saturation; the position of the aquifer, which is more protected compared to the others, also has good thickness.

As a recommendation, we suggest the next steps, such as proposed drilling for validation, borehole logging, and pumping tests to confirm the geophysical results and to quantify the hydraulic properties of the aquifer.

Acknowledgements

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Availability of Data and Material

Further study on the study area and the data is ongoing. The data cannot be released to the public until the study is completed. The data can be released to the reviewers for verification purposes.

Conflicts of Interest

To the best of the author's knowledge, there is no known conflict of interest in this study and the information provided.

References

[1] Guergazi, S. and Achour, S. (2005) Caractéristiques physico-chimiques des eaux d'alimentation de la ville de Biskra. Pratique de la chloration. *Larhyss Journal*, **4**, 119-127.

[2] Ehoussou, K.M., Kouassi, A.M. and Kamagaté, B. (2018) Hydrodynamic Characterization of the Fissured Aquifers of the "Bélier" Area (Center of Ivory Coast). *Larhyss Journal*, **36**, 119-143.

[3] Biémi, J. (1992) Contribution à l'étude géologique, hydrogéologique, et par télédétection des bassins versants subsaheliens du socle précambrien d'Afrique de l'Ouest: hydrostructural, hydrodynamique et isotopie des aquifères discontinus de sillons et

aires granitiques de la Marahoué (Côte d'Ivoire). Thèse de Doctorat d'État ès Sciences Naturelles, Université de Cocody, 479 p.

[4] Omeiza, O.A. and Dogara, M.D. (2018) Aquifer Vulnerability to Surface Contamination: A Case of the New Millennium City, Kaduna, Kaduna State Nigeria. *World Journal of Applied Physics*, **3**, 1-12. https://doi.org/10.11648/j.wjap.20180301.11

[5] Alao, J.O., Yusuf, M.A., Nur, M.S., Nuruddeen, A.M., Ahmad, M.S. and Jaiyeoba, E. (2023) Delineation of Aquifer Promising Zones and Protective Capacity for Regional Groundwater Development and Sustainability. *SN Applied Sciences*, **5**, Article No. 149. https://doi.org/10.1007/s42452-023-05371-2

[6] Sombo, A.P., Kouakou, K.E. and Bié, G.R. (2019) Caractérisation géoélectrique du système aquifère du département de Dabakala, Côte d'Ivoire. Rapport d'étude, 292 p.

[7] Dogara, M.D., Aboh, H.O., Alao, J.O. and Kogi, K.A. (2017) The Aquifer Overlying the Basement Complex in Some Parts of Dan-Hono, Kaduna, Nigeria. *KADA Journal*, **2**, 45-52.

[8] Alao, J.O. (2024) Determination of the Geophysical Signature of Soft-Clay and Hard Lateritic Soils and the Implications on Geotechnical Works Using Electrical Resistivity Imaging. *Results in Earth Sciences*, **2**, Article ID: 100025. https://doi.org/10.1016/j.rines.2024.100025

[9] Fossou, N.M.R. (2010) Contribution hydrogéologique à l'étude des aquifères discontinus du département de Ferkessédougou pour une meilleure alimentation en eau potable. Mémoire de DEA, Université de Cocody, 75 p.

[10] GEOMINE (1982) Inventaire hydrogéologique appliqué à l'hydraulique villageoise. Carte de Niellé, cahier n°3. Rapport technique, 20 p.

[11] GEOMINE (1982) Inventaire hydrogéologique appliqué à l'hydraulique villageoise. Carte de Kong, cahier n°7. Rapport technique, 19 p.

[12] Alao, J.O., Lawal, K.M., Dewu, B.B.M. and Raimi, J. (2024) Depth Estimation of Buried Targets Using Integrated Geophysical Methods: Comparative Studies at Ahmadu Bello University Geophysics Test Site. *Environmental Challenges*, **15**, Article ID: 100910. https://doi.org/10.1016/j.envc.2024.100910

[13] Kone, T. (2021) Variabilité climatique et stratégies d'adaptation des paysans dans le département de Ouangolodougou, Nord de la Côte d'Ivoire. Mémoire de Master Biodiversité et Gestion Durable des Ecosystèmes Option: Écologie et Gestion Durable des Ecosystèmes, Université Jean Lorougnon Guede, 45 p.

[14] Lasm, T. (2000) Hydrogéologie des réservoirs fracturés de socle: Analyses statistiques et 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, 223 p.

[15] Yao, T. (2009) Contribution à la gestion durable des eaux pluviales dans un contexte de changement climatique: Cas de la ville de Korhogo Mémoire de fin d'études, Master Spécialisé en Génie Sanitaire et Environnement. 2iE, 52 p.

[16] Savey, P. (2020) Étude d'Impact Environnemental et Social (EIES)—Rapport sur l'aménagement hydro-agricole-Tome 10-Ferké, Bamory-Vogo. Ferkessédougou, 2PAI-Nord CI 372 p.

[17] 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, Université de Cocody, 71 p.

[18] Ouédraogo, M., Sylla, I., Ouattara, Z., Diaby, A.J., Yeo, S.J.P. and Kamagate, B. (2024) Apport de l'imagerie géophysique à l'identification des aquifères en zone de montagne: Cas des aquifères perchés de Koyampleu à Danané. *E3S Web of Conferences*,

504, Article No. 05001. https://doi.org/10.1051/e3sconf/202450405001

[19] 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.

[20] Soro, D.D. (2017) Caractérisation et modélisation hydrogéologique d'un aquifère en milieu de socle fracturé: Cas du site expérimental de Sanon (Burkina Faso). Thèse de doctorat, Université Pierre et Marie Curie-Paris 6 and Institut 2iE, 303 p.

[21] Camil, J. (1984) Pétrographie, chronologie des ensembles granulitiques archéens et formations associées de la région de Man (Côte d'Ivoire). Implications pour l'histoire géologique du craton Ouest Africain. Thèse de Doctorat ès Sciences, Université d'Abidjan, 306 p.

[22] 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.

[23] Jourda J.P. (2005). Méthodologie d'application des techniques de télédétection et des systèmes d'information géographique à l'étude des aquifères fissurés d'Afrique de l'Ouest. Concept de l'hydrotechnique spatiale: Cas des zones tests de la Côte d'Ivoire. Thèse de Doctorat d'État, Université de Cocody-Abidjan, 430 p.

[24] N'Go, Y., Goné, D., Savané, I. and Goblé, M. (2005) Potentialités en eaux souterraines des aquifères fissurés de la région d'Agboville (Sud Ouest de la Côte d'Ivoire): Caractérisation hydroclimatique et physique. *Afrique SCIENCE*, **1**, 127-144. https://doi.org/10.4314/afsci.v1i1.35401

[25] Youan, T.A.M. (2008) Contribution de la télédétection et des systèmes d'informations géographiques à la prospection hydrogéologique du socle précam-brien d'Afrique de l'Ouest: Cas de la région de Bondoukou (Nord-Est de la Côte d'Ivoire). Thèse de doctorat, Université de Cocody-Abidjan, 237 p.

[26] Dibi, B., Inza, D., Goula, B.T.A., Savané, I. and Biémi, J. (2004) Analyse statistique des paramètres influençant la productivité des forages d'eau en milieu cristallin et cris-tallophyllien dans la région d'Aboisso (Sud-Est de la Côte d'Ivoire). *Sud Sciences and Technologies*, **13**, 25-27.

[27] Dewandel, B., Lachassagne, P., Wyns, R., Maréchal, J.C. and Krishnamurthy, N.S. (2006) A Generalized 3-D Geological and Hydrogeological Conceptual Model of Granite Aquifers Controlled by Single or Multiphase Weathering. *Journal of Hydrology*, **330**, 260-284. https://doi.org/10.1016/j.jhydrol.2006.03.026

[28] Courtois, N., Lachassagne, P., Wyns, R., Blanchin, R., Bougaïré, F.D., Somé, S., *et al.* (2010) Large-Scale Mapping of Hard-Rock Aquifer Properties Applied to Burkina Faso. *Groundwater*, **48**, 269-283. https://doi.org/10.1111/j.1745-6584.2009.00620.x

[29] Lachassagne, P., Wyns, R. and Dewandel, B. (2011) The Fracture Permeability of Hard Rock Aquifers Is Due Neither to Tectonics, Nor to Unloading, but to Weathering Processes. *Terra Nova*, **23**, 145-161. https://doi.org/10.1111/j.1365-3121.2011.00998.x

[30] Koita, M., Jourde, H., Koffi, K.J.P., Da Silveira, K.S. and Biaou, A. (2013) Characterization of Weathering Profile in Granites and Volcanosedimentary Rocks in West Africa under Humid Tropical Climate Conditions. Case of the Dimbokro Catchment (Ivory Coast). *Journal of Earth System Science*, **122**, 841-854. https://doi.org/10.1007/s12040-013-0290-2

[31] Langman, J.B., Blowes, D.W., Sinclair, S.A., Krentz, A., Amos, R.T., Smith, L.J.D., *et al.* (2015) Early Evolution of Weathering and Sulfide Depletion of a Low-Sulfur, Granitic, Waste Rock in an Arctic Climate: A Laboratory and Field Site Comparison. *Journal of Geochemical Exploration*, **156**, 61-71. https://doi.org/10.1016/j.gexplo.2015.05.004