International Journal of Geosciences, 2025, 16(5), 287-301
https://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

Aquifers Characterization for the Location of Drinking Water Supply Points in Gbangbégouiné-Yati, in the Department of Man (West of Côte d'Ivoire)

Ismael Sylla[1], Moussa Ouedraogo[1*], Donissongou Dimitri Soro[2], Abou Junior Diaby[1], Soungari Jean-Paul Yeo[1], Cheik Abdoul Karim Bamba[1], Marc Pessel[3], Bamory Kamagate[4]

[1]Geology Laboratory, Geophysics Department, University of Man, Man, Côte d'Ivoire
[2]Applied Geophysics Laboratory, Félix Houphouët-Boigny University, Abidjan, Côte d'Ivoire
[3]Paris-Saclay Geosciences Laboratory (GEOPS), Paris Saclay University, Orsay, France
[4]Geosciences and Environment Laboratory, Nangui Abrogoua University, Abidjan, Côte d'Ivoire
Email: *moussa.ouedraogo@univ-man.edu.ci

How to cite this paper: Sylla, I., Ouedraogo, M., Soro, D.D., Diaby, A.J., Yeo, S.J.-P., Bamba, C.A.K., Pessel, M. and Kamagate, B. (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

Received: April 18, 2025
Accepted: May 25, 2025
Published: May 28, 2025

Abstract

This study aims to identify from geo-electrics the areas favorable to the installation of drinking water supply (AEP) drilling in the sub-prefecture of Gbangbégouiné-Yati in order to contribute to a better distribution and management of water tables in the Department of Man. To achieve these objectives, piezometric maps and electrical resistivity maps were produced to understand the functioning of groundwater and to have the imaging of the subsoil. The piezometric maps revealed a regressive trend in the water level in the period from February 2024 to April 2024 and flow towards the lowlands in the north and, more mainly, in the east. Electrical resistivity imaging reveals three types of formations: conductive formations (resistivities between 100 and 1000 Ohm.m), medium resistivity formations (1000 to 3200 Ohm.m), and resistive formations (3200 to 6000 Ohm.m). Low resistivity formations likely to contain water in this locality are located between depths of 40 m and 50 m.

Keywords

Geoelectric, Piezometry, Electrical Resistivity, Water Table, Côte d'Ivoire

1. Introduction

The Earth's surface is covered with 71% water, making it the only planet that contains water in all its states (gaseous, liquid, solid). About 2.5% of this water is fresh, the rest being ocean water. Water is an essential element for both human food and plant and animal production [1].

In Côte d'Ivoire, access to drinking water remains a major challenge despite the significant surface water resources available. These surface waters, due to their exposure to the atmosphere, are particularly vulnerable to the effects of climate change and pollution, requiring costly treatment before consumption.

In this context, groundwater appears to be a preferred source of supply, being naturally protected from some pollution and less sensitive to climatic variations. The supply of drinking water to populations is therefore oriented towards the exploitation of groundwater [2], whose bacteriological and physicochemical quality generally meets the international standards of the WHO [3] [4].

However, water supply problems remain a global reality, affecting all types of countries and economies for various reasons. This situation is aggravated by increasing population pressure [5]. Water supply is thus one of the major concerns of human societies and is among the priority objectives of development projects throughout the world.

In Côte d'Ivoire, many efforts have been made since 1973 to supply the population with quality water [6]. However, these efforts have encountered significant difficulties, particularly related to the nature of the geological formations, 97.5% of which are occupied by crystallophyllian and crystalline terrains [7] [8].

Prospecting these aquifers from the surface is complex, leading to a high failure rate of drilling. This difficulty is mainly due to the discontinuity of the geological formations [6] [9].

In crystalline and crystallophyllian basement environments, the physical characteristics of aquifers are documented. These characteristics mainly concern the state of alteration of the rocks and the presence of fractures. The typical profile of the basement presents three main layers arranged parallel to the paleosurface [10]-[12]. From the surface to depth, we observe: i) a lateritic layer rich in clayey materials, ii) an underlying fissured layer characterized by dense horizontal cracking in the first few meters, and iii) a deep unfissured layer, permeable only in deep fracture zones.

From a hydrogeological point of view, these three layers form a single aquifer where the alterites provide the storage function and the fissured zones the conductive function [11] [13]. The groundwater concentration zones are located at the intersections of tectonic accidents.

Many researchers in the subregion have worked on the characterization of these aquifers to facilitate the exploitation of groundwater resources. In the mountainous western region of Côte d'Ivoire, several studies [14]-[16] have used passive remote sensing to identify lineaments associated with fracturing. [4] notably demonstrated the correlations between remote sensing data and groundwater resources in basement rocks. However, the interpretation of aerial photographs remains complex due to the dense vegetation and the thick alteration layer covering the sound rock.

In this context, the application of geoelectrics for the identification of favorable areas for the installation of drinking water supply (DWS) boreholes is of crucial importance. This geophysical method allows a thorough evaluation of the characteristics of the subsoil, thus contributing to effectively locating groundwater resources and improving the quality of life of communities.

This study proposes the use of innovative methods of hydro-geophysical prospecting, in particular, the method of Induced Polarization coupled resistivity (PP/R). This technique, which is similar to Electrical Resistivity Tomography (ERT), makes it possible to obtain pseudo-sections of apparent resistivity, which are then analyzed. It offers the advantage of identifying probable aquifers by specifying the geometry and its position in the subsoil in order to facilitate exploitation.

The main objective of this study is to detect hydrogeological targets likely to supply the population of Gbangbégouiné-Yati. More specifically, it is about understanding the behavior of groundwater through a piezometric study and characterizing the hydrogeological targets by imaging using the PP/R method.

2. Study Area: Geological and Hydrogeological Contexts

The Department of Man, located in the west of Côte d'Ivoire in the Tonkpi region (between 07˚20' and 07˚60' West longitudes and 07˚00' and 07˚40' North latitudes), includes ten sub-prefectures, including Gbangbegouiné-Yati. The latter, located between 7˚16'00" and 7˚30'00" North latitude and 7˚36'00" and 7˚48'00" West longitude, has 32,854 inhabitants [17]. The region benefits from a transitional equatorial climate, known as a mountain climate [16], characterized by abundant rainfall (more than 1587 mm on average per year from 1983 to 2019) and two distinct seasons: a long rainy season from March to October and a dry season from November to February. The vegetation is diverse, ranging from dense semi-deciduous forests to savannahs, including grassy mountain forests [18]. The hydrographic network, mainly influenced by the Sassandra Basin (75,000 km^2, 650 km long), is composed of tributaries originating in the Toura and Dan massifs (**Figure 1**). The structure of these rivers is shaped by geological fracturing and external factors such as climate and geomorphology, with a strong correlation between the hydrographic network and regional accidents [18] [19]. In the sub-prefecture of Gbangbégouiné-Yati, there are permanent rivers, such as the Kô, as well as temporary rivers, forming a complex and vital hydrographic network for the region.

From a geological point of view, Gbangbégouiné-Yati is located in the Liberian domain of the Man Ridge. This ridge is delimited to the east by the Sassandra fault, which marks the border between the Liberian and Eburnean domains. The region can be divided into two large groups separated by the Man-Danané fault, oriented N70˚ [20]. From a lithological point of view, the Gbangbégouiné-Yati sub-prefecture presents a compartment of granulitic nature, composed mainly of intrusions of charnockites and charnockitic orthogneiss, with some intrusions of norite and enderbite. Structural analysis reveals that the Gbangbégouiné-Yati charnockites are affected by a schistosity oriented N70˚ (**Figure 2**), a direction identical to that of the Man-Danané fault described by [20]. This concordance underlines the importance of this geological structure in the configuration of the region's subsoil.

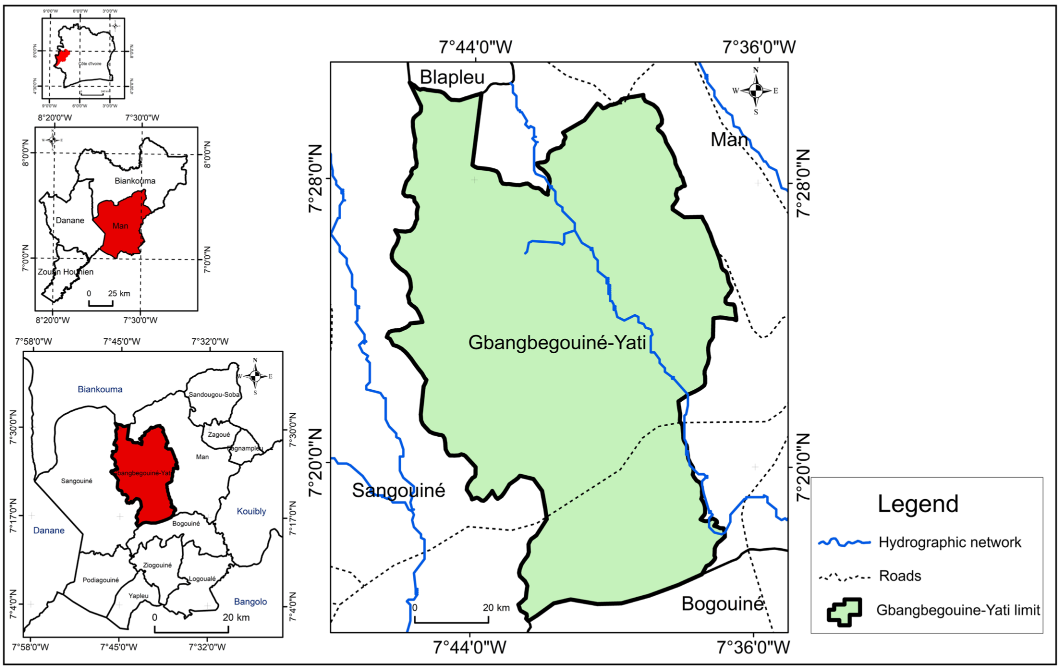

Figure 1. Map of the hydrographic network of the locality of Gbangbégouiné-Yati.

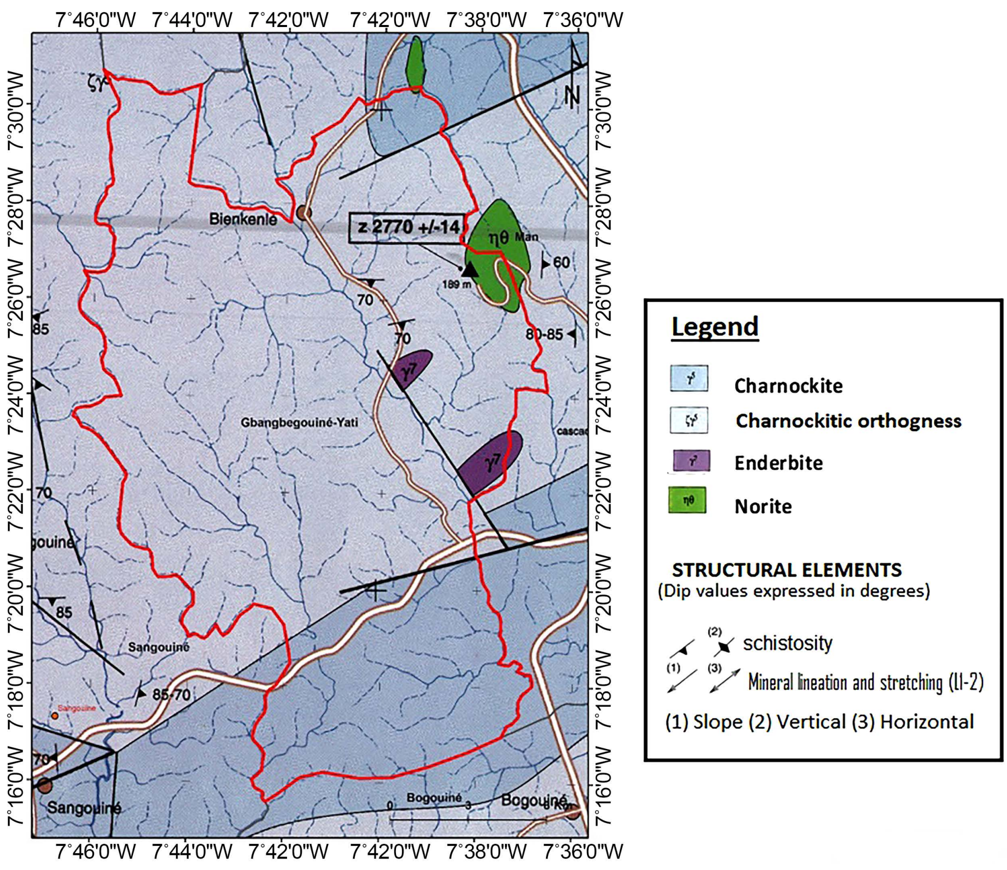

Figure 2. Geological map of Gbangbégouiné-Yati.

3. Materials and Methods

This study used two main methods: piezometry to determine the direction of groundwater flow in Gangbégouiné-Yati and the TRE geoelectric prospecting technique.

A preliminary study was conducted in the sub-prefecture to identify the different types of structures and determine the area suitable for geophysical prospecting by TRE. Piezometrics was carried out using a manual piezometric probe. With a monthly frequency starting from the dry season (February, 2024) to the beginning of the rainy season (April, 2024), piezometric measurements were carried out on catchment structures (traditional wells) in the locality.

The piezometric measurements, obtained by subtracting the graduated tape measurements from the altitude values, were used to create piezometric maps representing the surface of the water table by isopiezoid curves.

The TRE technique, on the other hand, measures the potential difference due to conduction currents in the subsoil layers. Particularly useful in hydrogeology, it provides information on geological structures and sometimes on the hydraulic parameters of reservoirs. Resistivity, the main parameter measured, is influenced by the nature of the rocks and the quantity and quality of the imbibition water [21]. The circulation of the electric current is mainly by volume conduction through the imbibition of water, except in the case of clays, where surface conduction can occur.

Several electrode devices exist for TRE, each with its advantages and disadvantages. The most common are the Wenner (alpha and beta), Schlumberger, dipole-dipole, pole-dipole, pole-pole, and gradient devices. The choice of device depends on the target studied and the objectives of the study. The apparent resistivity values obtained are represented in a pseudo-section or pseudo-section of apparent resistivity, allowing an interpretation of the different sections of the subsurface (**Figure 2**).

In this study, the dipole-dipole device was used for electrical resistivity tomography (ERT). Analysis of geological and piezometric maps allowed the eastern part of the study area to be targeted for investigations. Four profiles were established: profiles 1 and 3 oriented N85˚, profile 2 oriented N65˚, all three with a length of 360 m, and profile 4 oriented N155˚ over 260 m, intersecting the first three. The measurement process begins with the current generator powering the TxII, which transmits the current to the electrodes via 4 mm diameter cables. The potential difference is then measured between the receiving electrodes connected to the GRx 8-32 by 2 mm diameter cables. The signals received by the GRx 8-32 allow us to visualize the appearance of the pseudo-sections on the personal digital assistant (PDA) screen in situ, offering the possibility to identify and correct measurement errors before data processing on the 'IP Post-process' software. This methodological approach ensures the accurate acquisition of electrical resistivity data, which is crucial for understanding the structure of the subsoil in the studied area.

The measurements are carried out using a translation process, with a step of 20 meters, until the entire profile is covered. In concrete terms, after each measurement, the device is moved: the first transmission electrode (A) is abandoned, and each element of the device takes the place of the next one. Thus, the cable initially connected to A moves to position B, B takes the place of M, M that of N, and N advances to the position of the next electrode. This sequence is repeated until reaching the end of the profile and is reproduced identically on each profile studied. This procedure requires maximum concentration and effective communication between operators. Indeed, any handling error can not only distort the results but also damage the equipment or even present a risk of electrocution in the event of careless contact with the electrodes or transmission cables. Rigor in the execution of these operations is therefore crucial to guarantee the reliability of the data collected and the safety of personnel (**Figure 3**).

This combined methodology allows an in-depth analysis of the hydrogeological characteristics of the Gangbégouiné-Yati region, providing crucial information on the structure and behavior of local aquifers.

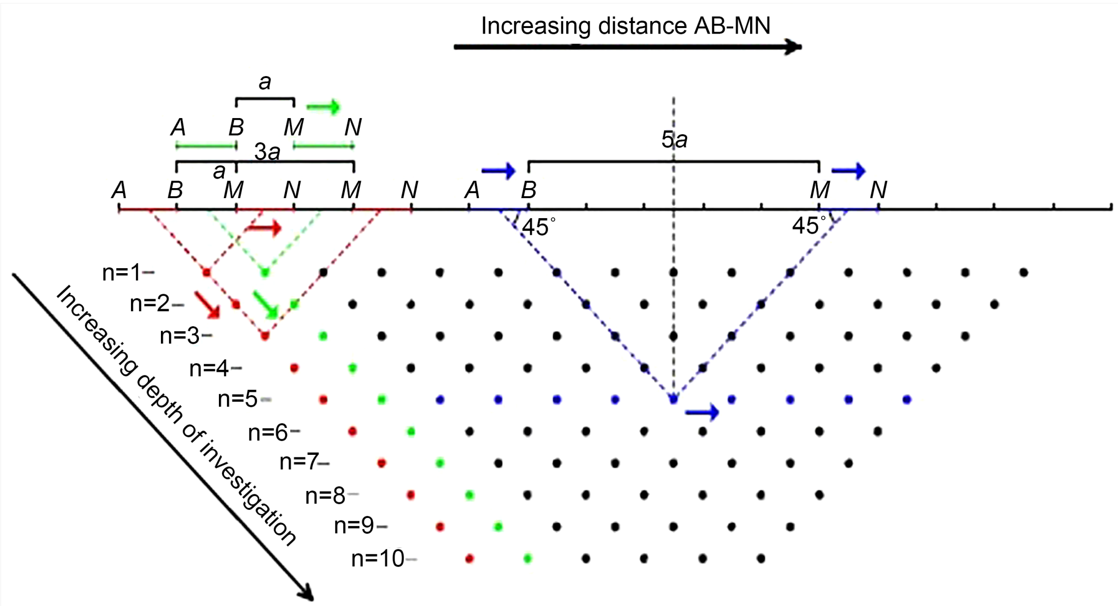

Figure 3. Diagram of the acquisition of an electrical panel and a pseudo-section or pseudo-cut. Case of a dipole-dipole device [22]. Each level makes it possible to identify the depth associated with it according to the chosen geometry.

4. Results and Discussion

4.1. Results

4.1.1. Behavior of Groundwater Resources

The field reconnaissance in Gbangbégouiné-Yati made it possible to identify around forty catchment structures with varied characteristics, mainly traditional wells, a few modern wells, and a water tower. Analysis of the piezometric maps from February to April 2024 (**Figure 4**) reveals the evolution of the water level of the aquifer and the direction of underground flow. In February, the piezometric level varies from 369 m upstream to 341 m downstream. March shows a significant drop, with levels ranging from 361 m upstream to 339 m downstream, a trend that stabilizes in April with levels between 361 m upstream and 341 m downstream. The three maps indicate an overall flow direction from west to east, with some secondary flows from west to north. These observations guided the choice of the study site, located east of Gbangbégouiné-Yati, where the flow trend is most marked. This piezometric analysis, combined with the inventory of existing works, provided an important basis for understanding the local hydrogeology and guided the geophysical investigations.

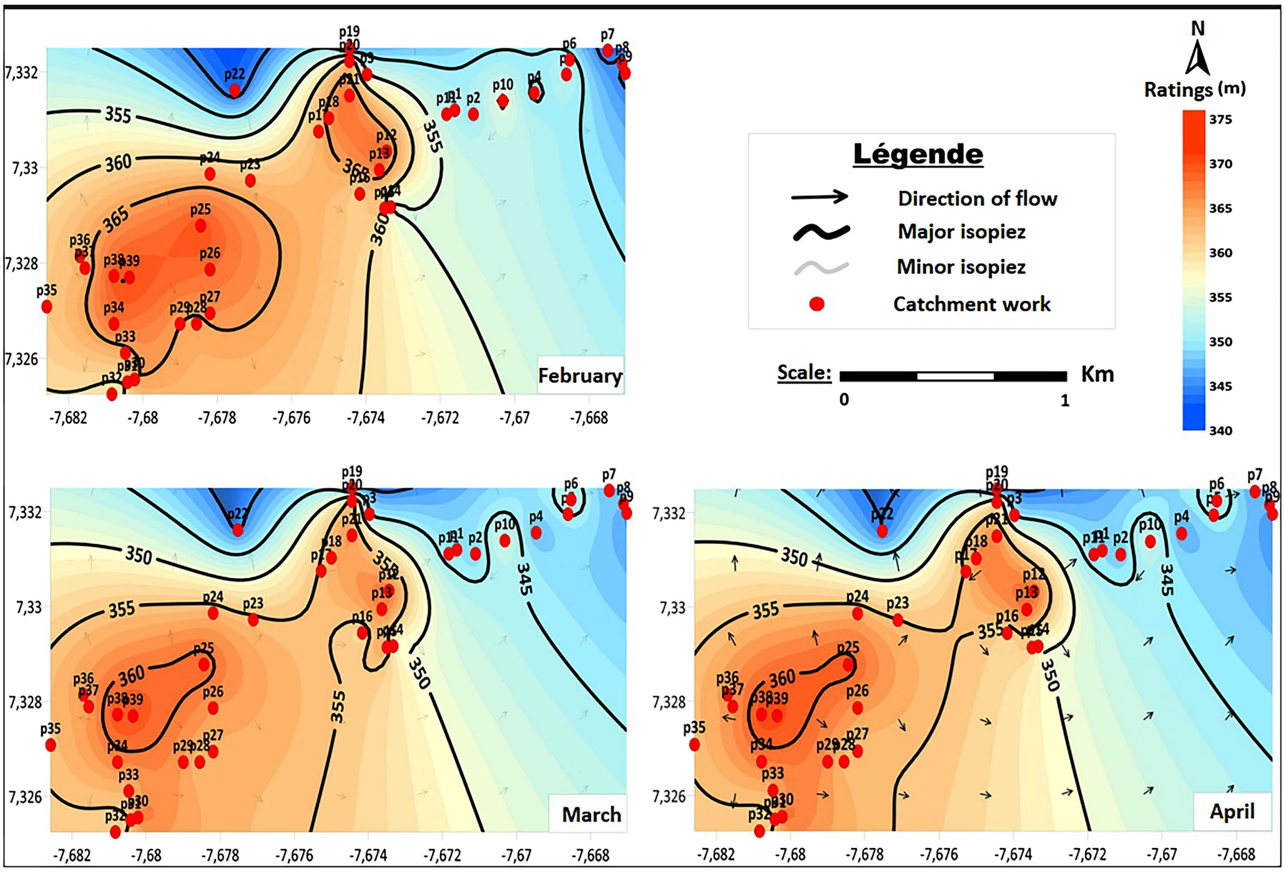

Figure 4. Piezometric maps from February 2024 to April 2024. The three (3) maps show the piezometry over three months, including February, which marks the end of the long dry season and the beginning of the long rainy season (March and April). The black arrows indicate the direction of water flow from west to east and north.

4.1.2. Characterization of the Subsoil by Geoelectric Imaging

The color contrast observed on the pseudo-sections (**Figure 5**) corresponds to the apparent resistivities of the different layers or formations between 20 m and 120 m below the surface. For a better understanding of the pseudo-sections, this contrast can be divided into 3 groups according to the most resistive formation to the least resistive. Thus, the formations of low resistivity (very conductive) with resistivities between 200 and 1000 Ohm.m are represented by the colors (blue and green). Then, those of average resistivities (less conductive compared to the previous ones) with resistivities between 1000 and 3200 Ohm.m by the colors orange and yellow. Finally, the formations of very high resistivities (non-conductive) with resistivities above 3200 Ohm.m whose colors are red and violet. In general, we can observe on the profiles a heterogeneity as much vertical as lateral of the formations.

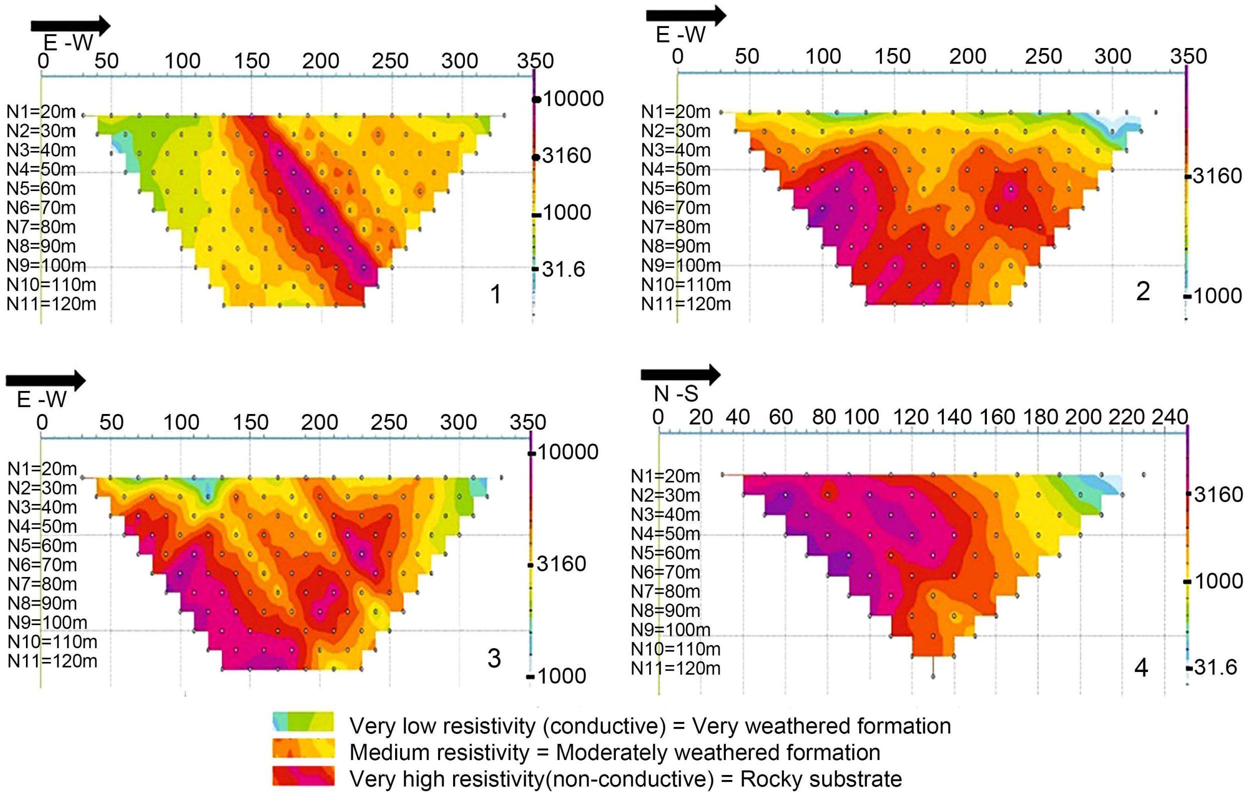

Figure 5. Pseudo sections showing the four investigated profiles. The depth in meters (m) is located on the left of each pseudo section, the distance from the profile above, and the scale of apparent resistivities on the right. The distance gives information on the thickness of the underlying formations, while the scale of apparent electrical resistivities provides information on the resistive nature of the formations.

On the pseudo-section of profile 1 (**Figure 6**), we find, from the beginning of the profile, a zone of low resistivity (conductive) which is presented in an almost triangular shape. This zone is 120 m long (0 to 120 m) compared to the horizontal. These conductive formations have a depth of up to 100 m from the surface. Practically, the same type of formations are observed from 270 m to the end of the profile, but this time, they are at a relatively shallow depth (between 20 m and 30 m deep) compared to the first formations observed. A terrain of very high resistivity oriented towards the southeast (oblique) is observed in a rectangular shape and extends over a distance between the distances 130 m and 160 m. This terrain plunges over the entire depth taking into account the surface of the profile. The rest of the profile is dotted with formations of average resistivities. This profile is marked by a domination of terrains of intermediate resistivity.

As previously, profile 2 (**Figure 5**) displays at the beginning and end of the profile semi-circular formations of low resistivity, respectively, 160 m long with a depth reaching 30 m, 160 m (190 to 360 m) long, and 20 to 40 m below the surface. Between distances 60 and 140 m, at depths 40 and beyond 120 m, formations of high resistivity emerge with shapes almost similar to those of the previous profile but with rounded edges and oriented in the same direction (southeast). This same type of formation is observed a little further away, but this time, it is almost triangular in shape with a smaller extent (50 to 100 m depth below distances 210 and 270 m). Formations of medium resistivity cover the largest remaining area of the profile and are included between formations of high and low resistivity.

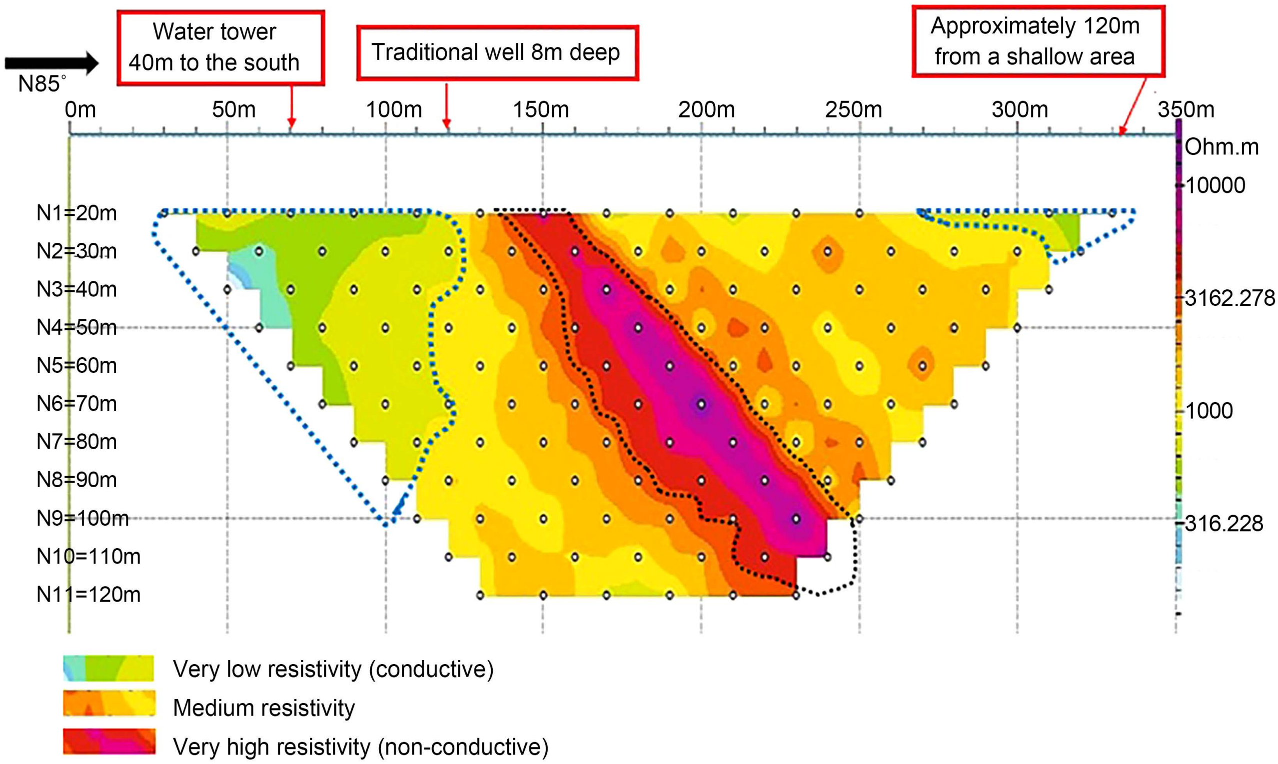

Figure 6. Detailed apparent electrical resistivity imaging of the subsoil at profile 1.

Concerning the third profile, we can observe in the first depths up to 70 m semi-circular formations with rounded edges of low resistivities at the beginning and end of the profile (**Figure 5**). Those at the beginning are between 50 and 140 m along the horizontal and then are limited to 40 m below the surface, and those at the end of the profiles are limited to distances 290 and 360 m, then plunge to 70 m in depth. In addition to the formations of low resistivity, we note the formations of high resistivity in the first 40 meters of depth with directions identical to the previous ones at the beginning of the profile (50 to 90 m along the horizontal) and others at depths of 40 and 70 m in the middle of the profile (170 to 250 m along the horizontal). We can observe around the formations of high resistivity and below those of low resistivity formations of average resistivity. As in the previous profile, we observe a covering of the formations of high resistivity by formations of medium resistivity.

On the last profile (Figure 7), we can identify the same formations as on the previous profiles, but this time, we find from the beginning of the profile up to 140 m and in the first meters of depth up to 110 m quasi-rectangular formations with rounded edges of high resistivities. Then, between 180 m and 240 m along the horizontal, we find quasi-triangular formations of low resistivities that go 50 m below the ground surface. Finally, the formations of average resistivities occupy the space between the formations of high and low resistivities. As in the previous profiles, we observe an overlap between the formations of high resistivities and the formations of average resistivities.

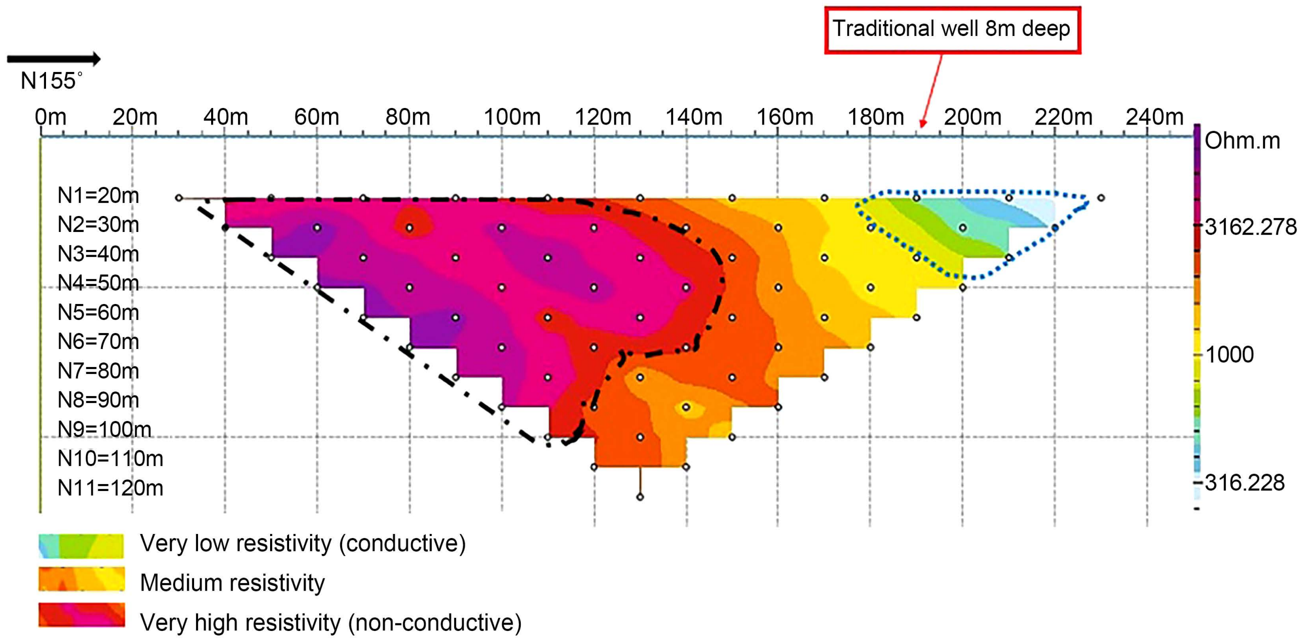

Figure 7. Detailed apparent electrical resistivity imaging of the subsoil at profile 4.

4.1.3. Lithological Identification

This model, obtained during drilling a few meters from profile 1, identified 5 layers superimposed on the fractured bedrock.

From the surface, a layer of lateritic armour (0 - 3 m) precedes that of lateritic clay (3 - 10 m). Just below these, a thick layer of clay is followed by another, thicker layer of clay arena, almost 24 m deep. These layers, which are probably conducive given their position relative to profile 1, could represent a perched aquifer. A final layer of gravelly arena, a formation that was probably altered before coming into contact with the fissured resistive rock, forms the final part of this lithology.

This lithology of 3.5 m^3/h and 67 m depth is in line with the geoelectric imagery of profile 1, which passes right next to the borehole. The bedrock only appears at a depth of 51 m (Figure 8). The site of the structure is on the side of a mountain.

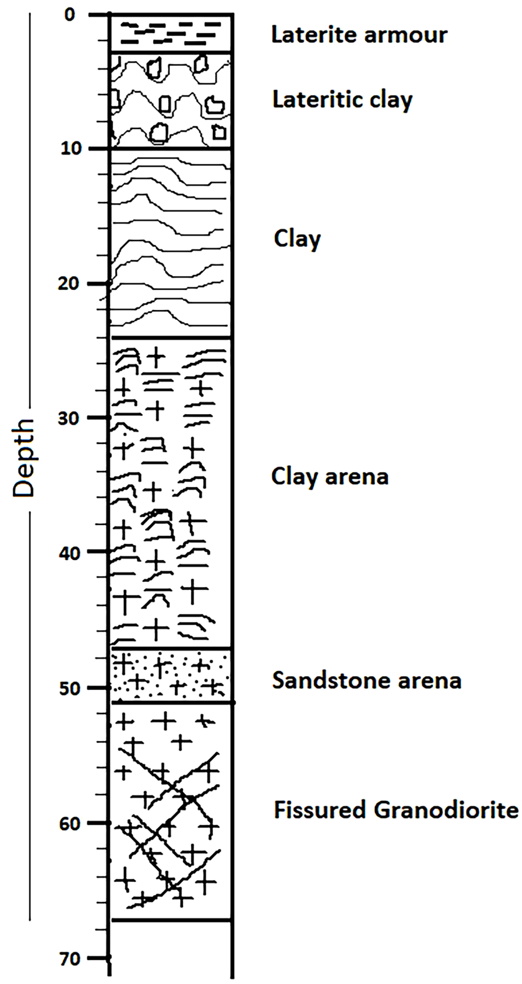

Figure 8. Field model of the borehole drilled at Gbangbégouiné-Yati.

4.2. Discussion

The piezometric study carried out to understand the behavior of groundwater highlighted, through the piezometric maps, a drop in the water level in the water table and a general flow-oriented West-East and West-North. The overall decrease in the piezometric level observed between February and April 2024 can be explained by several factors:

- recharge of the water table;
- the absence of precipitation during this period;
- overexploitation of groundwater by the population due to incomplete coverage of the SODECI national supply network in the sub-prefecture.

The direction of groundwater flow, from West to East and North, corresponds to the topography of the study area, with the highest altitudes in the West and decreasing towards the lowlands in the East and North. Similar phenomena have been observed in other regions, notably in Korhogo (Côte d'Ivoire), where flow occurs from the peaks towards the White Bandama River, with a drop in water level attributed to the absence of rain and pumping [23]. Similarly, the study of

Oualidia (Morocco) confirms flow from the peaks towards the Atlantic Ocean and fluctuations in the water table level linked to climate cycles [24] [25]. These observations suggest that the eastern part of the sub-prefecture presents the best hydrogeological targets.

Analysis of the four pseudo-sections of the eastern part reveals a continuity of geological formations. The conductive formations observed at the beginning of profiles 1, 2, and 3 have variable thicknesses (90 m, 30 m, and 40 m, respectively). Profile 4, whose end joins the beginning of profile 1, confirms this continuity with conductive formations with a thickness of 50 m. This continuity is also observed for the conductive formations at the end of profiles, with depths varying from 30 m (profile 1) to 60 m (profile 3), as well as for formations of medium and high resistivity.

Field observations allow us to attribute the areas of very high resistivity to the outcropping bedrock. The arrangement of the formations, from the most conductive on the surface to the most resistive at depth, suggests that the low resistivity formations result from the alteration of the moderately resistive formations, themselves resulting from the high resistivity formations. This hypothesis explains the variation in thickness of the different formations observed on the profiles.

Low-resistivity formations, more exposed to atmospheric agents, present a more pronounced alteration. These altered formations, characterized by high permeability and porosity, constitute privileged zones for the accumulation of water and, therefore, for the installation of drinking water wells. This profile corresponds to the recent models proposed by [11] [12] [26], who attribute the hydraulic conductivity of basement aquifers to the alteration process rather than to tectonic fracturing.

These results are consistent with other studies conducted on basement formations. [27] recommends focusing on areas where the thickness of the Weathered Zone (ZA) and the first few meters of the Stratiform Fractured Zone (ZFS) are the greatest, with resistivities between 150 - 400 Ohm.m and 800 - 2000 Ohm.m. A study in Katiola (Côte d'Ivoire) confirms these observations, identifying the best flow rates between 20 and 50 m depth in the weathered zone [28]-[30].

5. Conclusions

The main objective of this study was to identify areas favorable to the installation of drinking water drilling in the sub-prefecture of Gbangbégouiné-Yati in order to contribute to better distribution and management of groundwater resources in the department.

Analysis of piezometric maps revealed that the water resources of Gbangbégouiné-Yati fluctuate over time. The flow is mainly towards the lowlands located in the North and, more particularly, in the East, making the latter area a privileged sector for the search for groundwater. This hypothesis was confirmed by the PP/R carried out in the Eastern part. Subsoil imaging made it possible to identify the alteration zones characterized by low resistivities (between 200 and 1000 Ohm.m) and thicknesses varying from 40 to 100 m as hydrogeological targets.

These results demonstrate that the sub-prefecture has sufficient groundwater resources to justify the installation of boreholes. To optimize the productivity of these works, it is recommended that they be carried out at depths of between 40 and 50 m. However, the realization of one or more test boreholes would be necessary to validate the conclusions of this study.

In order to improve knowledge of the environment for better management of the locality's water resources, it would be interesting to take measurements using the magnetic method to obtain more precision on the geometry of the aquifer and even vertical surveys of 50 m depth to describe the different lithologies and hydrodynamic parameters of the lithologies present. In addition, piezometric studies should be extended over a longer period with the work of the Man department as piezometers.

Conflicts of Interest

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

References

[1] Baali, F. (2001) Eude hydrogéologique hydrochimique de la région karstique de Chéria N-E Algérien. Master, Université d'Annaba Algérie, 100 p.

[2] Buvat, S. (2012) Caractérisation de l'organisation spatiale de la couverture pédologique par mesure de la résistivité électrique: Application à la cartographie des sols en contexte agricole. Thèse de Doctorat, Université Pierre et Marie Curie-Paris 6.

[3] Faillat, J.P. (1986) Aquifères de fissures en zones tropicales humides; Structure, hydrodynamique et hydrochimique (Afrique de l'Ouest). Thèse de Doctorat d'État, Université des Sciences et Techniques du Languedoc, 536 p.

[4] 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.

[5] Boé, J. (2007) Changement global et cycle hydrologique: Une étude de régionalisation sur la France. Thèse de Doctorat Climatologie, Université Paul Sabatier, Toulouse III, 253 p.

[6] Youan, T.M. (2008) Contribution de la télédétection et des systèmes d'information géographiques à la prospection hydrogéologique du socle précambrien d'Afrique de l'Ouest: Cas de la région de Bondoukou Nord Est de la Côte d'Ivoire. Thèse Unique, Université de Cocody, 236 p.

[7] Jourda, J.P. (2005) Méthodologies 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 de la zone test de Korhogo (Côte d'Ivoire). Thèse de Doctorat d'État, Université de Cocody, 402 p.

[8] Ouedraogo, 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

[9] Ouédraogo, M., Ouattara, I., Babine, A., Sylla, I., Kamagaté, B. and Savané, I. (2021) Geoelectrical Application to Drilling for Groundwater Exploration in the Bandama Blanc Catchment Area in the Crystalline Zone of the Korhogo Region (Ivory Coast). *Journal of Scientific & Engineering Research*, **12**, 196-204

[10] Wyns, R., Baltassat, J., Lachassagne, P., Legchenko, A., Vairon, J. and Mathieu, F. (2004) Application of Proton Magnetic Resonance Soundings to Groundwater Reserve Mapping in Weathered Basement Rocks (Brittany, France). *Bulletin de la Société Géologique de France*, **175**, 21-34. https://doi.org/10.2113/175.1.21

[11] 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

[12] 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

[13] Lachassagne, P., Wyns, R., Bérard, P., Bruel, T., Chéry, L., Coutand, T., *et al*. (2001) Exploitation of High-Yields in Hard-Rock Aquifers: Downscaling Methodology Combining GIS and Multicriteria Analysis to Delineate Field Prospecting Zones. *Groundwater*, **39**, 568-581. https://doi.org/10.1111/j.1745-6584.2001.tb02345.x

[14] Kouamé, F., Gion, P., Biémi, J. and Kouadio, A. (1999) Méthode de cartographie des discontinuités-images extraites d'images satellitales: Exemple de la région semi-montagneuse à l'Ouest de la Côte d'Ivoire. *Télédétection*, **1**, 139-156.

[15] Lasm, T., Kouamé, K.F., Oga, M.S., Jourda, J.R.P., Soro, N. and Kouadio, H.B. (2004) Étude de la productivité des réservoirs fracturés des zones de socle. Cas du noyau archéen de Man-Danané (Ouest de la Côte d'Ivoire). *Revue Ivoirienne des Sciences et Technologie*, **5**, 1-15.

[16] Saley, M.B. (2003) Cartographie thématique des aquifères de fissures pour l'évaluation des ressources en eau. Mise en place d'une nouvelle méthode d'extraction des discontinuités images et d'un SIHRS pour la région semi-montagneuse de Man (Nord-Ouest de la Côte d'Ivoire). Thèse de Doctorat, d'Université de Cocody-Abidjan, 209 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 Tonkpi, 37 p.

[18] 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 Poitier, 274 p.

[19] Kouamé, K.F. (1999) Influences de la variabilité climatique et de la dégradation environnementale sur le fonctionnement de l'hydrosystème du N'Zo dans la région guinéenne humide et semi-montagneuse de la Côte d'Ivoire. Contribution de la télédétection, des systèmes d'informations géographiques et du modèle hydrologique HYDROTEL. Thèse d'État ès Sciences Naturelles, Université de Cocody, 379 p.

[20] Koumelan, A.N. (1996) Géochronologie et géochimie des formations archéennes et protérozoïques de la dorsale de Man en Côte d'Ivoire. Implication pour la transition archéen-protérozoïque. Thèse de doctorat, de l'Université de Rennes 1, 290 p.

[21] 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, France, 211p.

[22] 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' Université d'Orleans, 198 p.

[23] 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, Université Paris Saclay, 241 p.

[24] Gilli, E., Mangan, C. and Mudry, J. (2008) Hydrogéologie. Objets, méthodes et applications. 2è édition, Dunod, 291 p.

[25] Fadili, A. (2014) Étude hydrogéologique et géophysique de l'extension de l'intrusion marine dans le sahel de l'Oualidia (Maroc): Analyse statistique, hydrochimie et prospection électrique. Thèse de Doctorat, Univérsité de Chouaïb Doukkali, 175 p.

[26] 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

[27] 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, Université d'Abomey-Calavi, 178 p.

[28] 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.

[29] Dibi, B., Inza, D., Goula, BTA., Savané, I. and Biémi, J. (2004) Analyse statistique des paramètres influençant la productivité des forages d'eau en milieu cristallin et cristallophyllien dans la région d'Aboisso (Sud Est de la Côte d'Ivoire). *Sud Sciences & technologies*, No. 13, 25-27.

[30] Soro, D.D. (2017) Caractérisation et modélisation hydrogéologique d'un aquifère en milieu de socle fracturé: Cas du site expérimental de Sanon (région du plateau central au Burkina Faso). Thèse de doctorat, Université Pierre et Marie-Curie 6, France et Institut International d'Ingénierie de l'Eau et de l'Environnement, 303 p.