Original Scientific Article • DOI: 10.2478/rmzmag-2021-0015

Received: March 05, 2022
Accepted: March 24, 2022

Identification of favourable geological formations for the determination of groundwater

Prepoznavanje geoloških formacij, ugodnih za akumulacijo podzemne vode

Moussa Diallo[1,2], Ahmed Amara Konaté[1,2,*], Mory Kourouma[1,2], Fassidy Oularé[1,2], Muhammad Zaheer[3]

[1]Laboratoire de Recherche Appliquée en Géoscience et Environnement, Institut Supérieur des Mines et Géologie de Boké, BP 84, Boké, Baralandé, Republic of Guinea

[2]Centre Emergent Africain Mines et Société, Institut Supérieur des Mines et Géologie de Boké, BP 84, Baralandé, Republic of Guinea

[3]Department of Earth & Environmental Sciences, Hazara University Mansehra 21300, Khyber Pakhtunkhwa, Republic of Pakistan

*Corresponding author: E-mail: konate77@yahoo.fr

Abstract in English

Clean drinking water supply is a major concern to the population of the urban municipality of Boké, Republic of Guinea. This study is aimed to investigate the favourable geological structure for the accumulation of groundwater in Boké. Apparent resistivity data was collected by using the Schlumberger-type vertical electrical sounding technique. The apparent resistivity values were obtained on a bi-logarithmic scale in which the distances AB/2 were plotted on the abscissa and the resistivities are on the ordinate. It found the number of terrains and their characteristics (resistivity and thickness) in the area and the behaviour of the current in the soil through a curve. The results show that the structures favourable to the accumulation of groundwater were fractured dolerites, cracked shales and cracked or crushed sandstones. The sandstones were the most important in terms of the amount of water. They are located at a depth of more than 100 metres. It was also found that dolerites and shales are located at shallower depths (less than 100 m).

Keywords: Groundwater, geo-electric method, lithological section, fracture zones, Prefecture of Boké

Abstract in Povzetek

Zagotavljanje zalog čiste pitne vode je eden ključnih izzivov za prebivalce mestne občine Boké v Republiki Gvineji. Namen članka je raziskava geoloških struktur, ki so primerne za akumulacijo podzemne vode v mestni občini Boké. S Schlumbergerjevo metodo navpičnega električnega sondiranja je bila določena navidezna upornost. Vrednosti navidezne upornosti so bile prikazane na logaritemskem diagramu z razdaljami AB/2 na abscisi in upornostjo na ordinati. Opredeljenih je bilo več območij in njihove značilnosti (upornost in debelina). Določena je bila krivulja obnašanja toka v tleh. Rezultati kažejo, da so strukture, ki so ugodne za akumulacijo podzemne vode, pretrti doleriti, pretrti skrilavi glinavci in pretrti ali zdrobljeni peščenjaki. S stališča količine podzemne vode so slednji najbolj pomembni. Ležijo na globini preko 100 m. Doleriti in skrilavi glinavci ležijo na plitvejših globinah (manj kot 100 m).

Ključne besede: podzemna **voda, geoelektrična metoda, litološki profil, razpoklinska območja, Prefektura Boké**

Introduction

The urban municipality of Boké which is the subject of this study, like the rural municipalities of Boké, benefits from significant mining investments due to the presence of several bauxite deposits in its surroundings. In recent years, a dozen mining companies have settled there. This also justified its designation as a special economic zone of Guinea through the decree of April 25, 2017. The presence of companies has led to a population growth in recent years. The population of the prefecture increased from 760,119 inhabitants in 1996 to 1,092,291 inhabitants in 2014 before reaching 1,157,540 inhabitants in 2016 [1]. This exponential population growth has had consequences on the socio-economic activities of local populations. Access to basic social services (electricity, water and health) is a real problem these days. Referring to [1], compared to previous years and to other regions of the country, the population of Boké has experienced a decline in its accessibility to drinking water. Its water accessibility rate fell from 71.3% in 2007 to 48.3% in 2012. However, the country average was 67.8% in 2012. Regarding domestic consumption in the Boké region, the rate is 8.3% against 10.6% in the country. The rate of village hydraulic boreholes in the region is 25.5% against 35.3% for the country [1].

Groundwater is found below the surface of the earth within the saturated layers of sand, gravel and pore spaces in sedimentary as well as crystalline rocks. Surface water (rivers, lakes) and superficial aquifers (perched aquifers), which constitute the current main sources of supply, are rapidly drying up due to climate change (drought), human activities (deforestation, salt extraction, charcoal production, aggregate extraction, etc.), and mining. In addition to rapidly drying up, these waters are affected by pollution in the vicinity of large cities and mining facilities [2]. Hence the need to seek out and exploit new sources of drinking water for the population, such as water from deep fractures. Being deep, sufficient in quantity, and less polluted, these waters are suitable for supplying agglomerations and industrial installations.

Several studies of different methods have been carried out in the area for the research of groundwater in order to ensure the supply of drinking water to the population. [3] conducted a study of the groundwater research project on the Boffa geological sheet and examined the characteristics of the different aquifers by using geophysical methods composed of seismic refraction, electrical sounding, profiling by the two-spaced device and resistivity logging. In the same vein, [2] carried out studies to determine the best geophysical method and stated that the most suitable were electrical methods (electrical drag and sounding), the seismic method (seismic refraction), and the magnetic method (magnetic profile). In addition, the National Water Point Development Service (SNAPE) carries out village hydraulic boreholes each year in the Boké region to fill the void of drinking water. These boreholes are carried out based on classical methods supported by the interpretation of aerial photos and geomorphological observations (talweg line, valley, slopes, etc.). As a result, it records a rate of failure or low flow boreholes of around 25% [4].

The electrical resistivity survey such as the Schlumberger configuration enables the changes of apparent resistivity with depth to identify the water-saturated bodies, which are characterized by lower resistivity zones [5]. The resistivity value is changed corresponding to water content in the geological materials. The fracture's features are usually filled with groundwater and have a lower resistivity value of the rock layer than water-bearing strata [6]. According to [7], the four-electrode quadrupole (AMNB) of Schlumberger is considered satisfactory by technicians in previous studies and remains the most widely used.

From the analysis of the aforementioned studies, it appears that they rarely use methods to decrease the failure rate and obtain high-throughput boreholes; others propose very complex and expensive methods that do not take into account certain important parameters (depth of aquifers, types of aquifers with high flow rates, the forms of the anomalies sought, lead time, etc.).

When proposing a method or a complex of methods for investigating groundwater, several factors must be taken into account, including

ease of use, reliability, speed and cost. With this logic, [8] used the geophysical method to determine the productivity of boreholes in the Toumodi region (Côte d'Ivoire). At the end of this study, it was found that the coupling of geomorphological and geophysical methods reduces the negative drilling rate and optimizes the exploitation of positive drilling. A study carried out by [9] in Burkina Faso on the optimization of the geophysical implantation of boreholes in the base area and focused on the drilling and electrical drag improved the overall success rate by more than 10%. According to [8] the geophysical investigation through the survey and electric train carried out in Côte d'Ivoire (Center-North) made it possible to identify the structures and characterize the aquifers (thicknesses of the alteration and the depth of the cracked horizon) of this region. In another study by [10] carried out in Tanda (eastern part of the Ivory Coast), the use of geophysical prospecting by electrical resistivity for the search for groundwater made it possible to determine with good precision the exact position of conductive anomalies and several fractures of a different direction.

[11] found that the geoelectric survey of Schlumberger types gives good results in the characterization of subsurface structures. Similarly, [12–15] have each in the context of their studies demonstrated the reliability of geoelectric soundings in determining the nature of geological layers and aquifers. Geophysical methods were proved to be the most active technique in the exploration of groundwater resources. With a support borehole parameter and their interpretation from the resistivity imaging method, consistent information regarding the groundwater can be produced. From the above development, it appears that geophysical methods are appropriate for the siting of boreholes to decrease the failure rate and achieve high throughput boreholes. This work, therefore, aims to precisely locate areas or structures favourable to the accumulation of groundwater in the urban municipality of Boké.

The first part of this work will focus on the overall presentation of the study area; the materials and methodology used will be described in the second part; the results obtained will be presented and interpreted in the third part, and a conclusion accompanied by perspectives will bring this work to a close.

Materials and methods

Study area

Our study area is located between 14°00' and 15°00' West longitude; 10°00' and 11°00' North latitude. Figure 1 shows the location map of the study area.

In terms of relief, soil, vegetation, climate and economy, the study area is characterized by plains, plateaus, hills and lowlands with an elevation ranging from -5 m to 217 m. The relief map is shown in Figure 2.

The soil is lateritic skeletal, hydromorphic and alluvial; the soil texture is: clay 0–45%, sand 20% approximately, silt 30% approximately; the soil is permeable and porous in places [16].

Most of the area is covered with wooded savannah. Trees characteristic of the tropical forest are located in a narrow band along the river valleys, both on the slopes and on the tops of the hills. The plateaus are characterized by herbaceous and tree vegetation [17].

The Boké area has a tropical climate with two seasons, each of which lasts six months (the dry season from May to October, and the rainy season from November to April). With 0 millimeters of precipitation, December is the driest month. With an average of 613 mm, the month of August records the heaviest rainfall. The inter-annual average of precipitation is 2,227 mm [17].

March is the hottest month of the year with an annual temperature of 33.5 ° C in 2019 and the coldest month is January with an average temperature of 22.2 ° C in 2019 [16].

The main economic activities in the study area are mining, agriculture, fishing, livestock, transport and trade.

From the hydrographic point of view, the urban municipality of Boké is watered by two main rivers. They are the Cogon River, terminated by the Rio Compony with a length of 390 km, and the Tinguilinta River, which forms from the city of Boké the Rio Nuñez. In addition to these two main rivers, many rivers water our study region such as the Kassongony, Sangui,

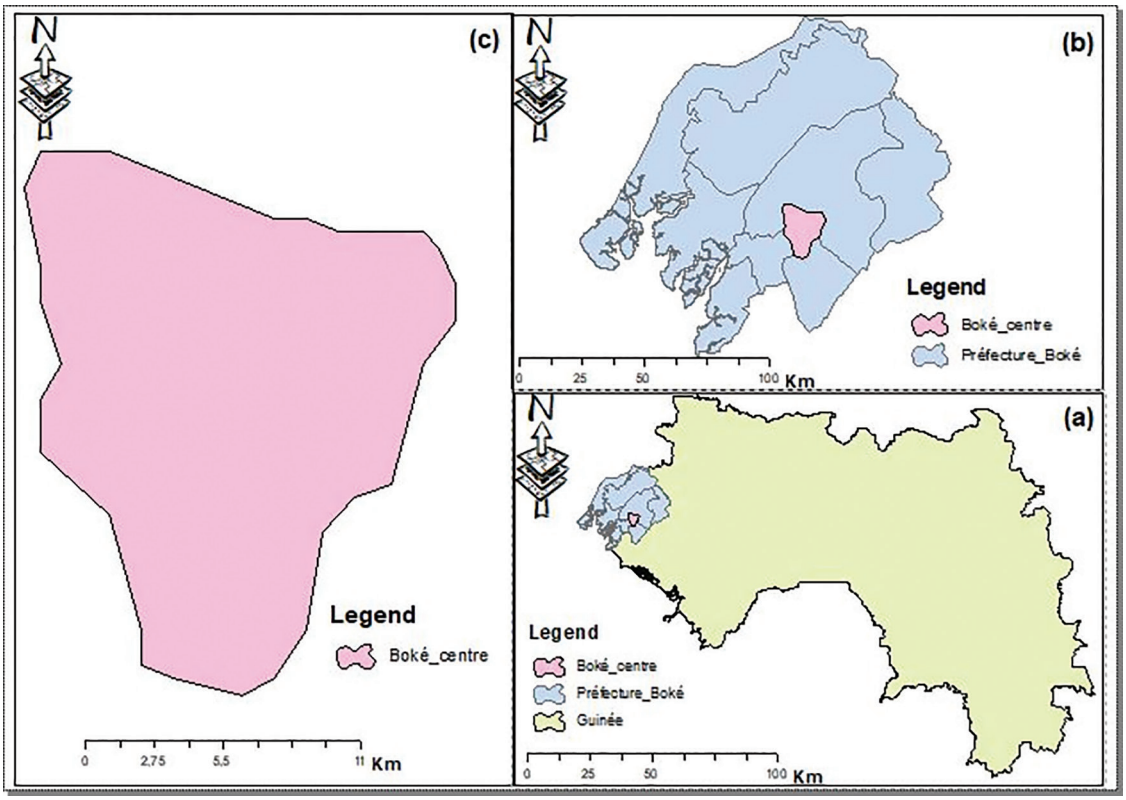

Figure 1: *Location map of urban municipality of Boké (Boké centre).*

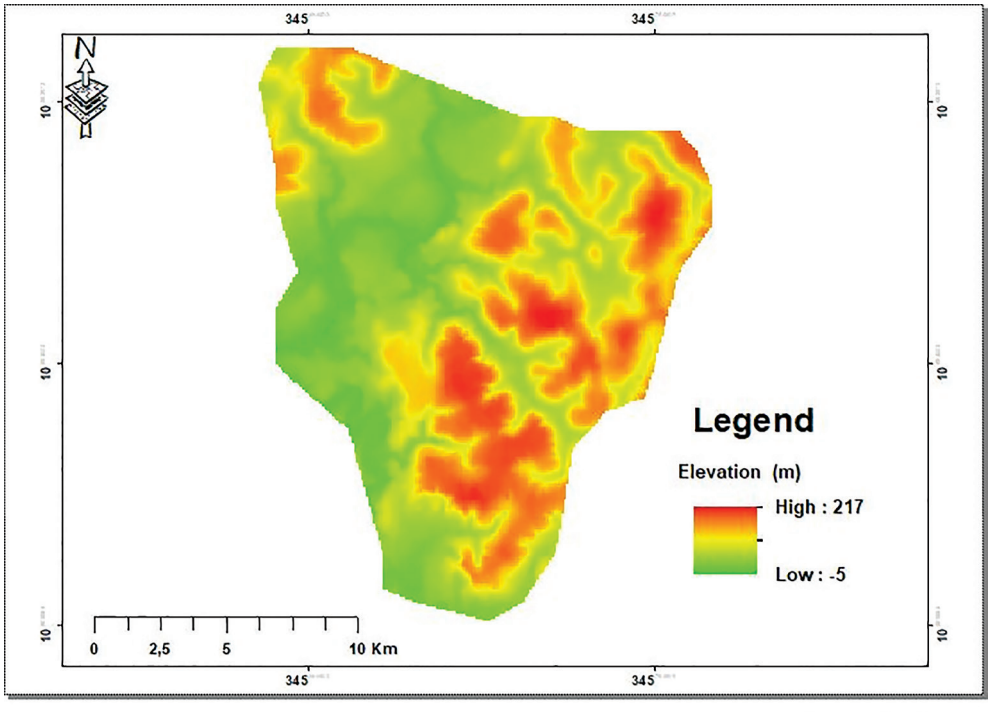

Figure 2: *Elevation map of urban municipality of Boké (Boké centre).*

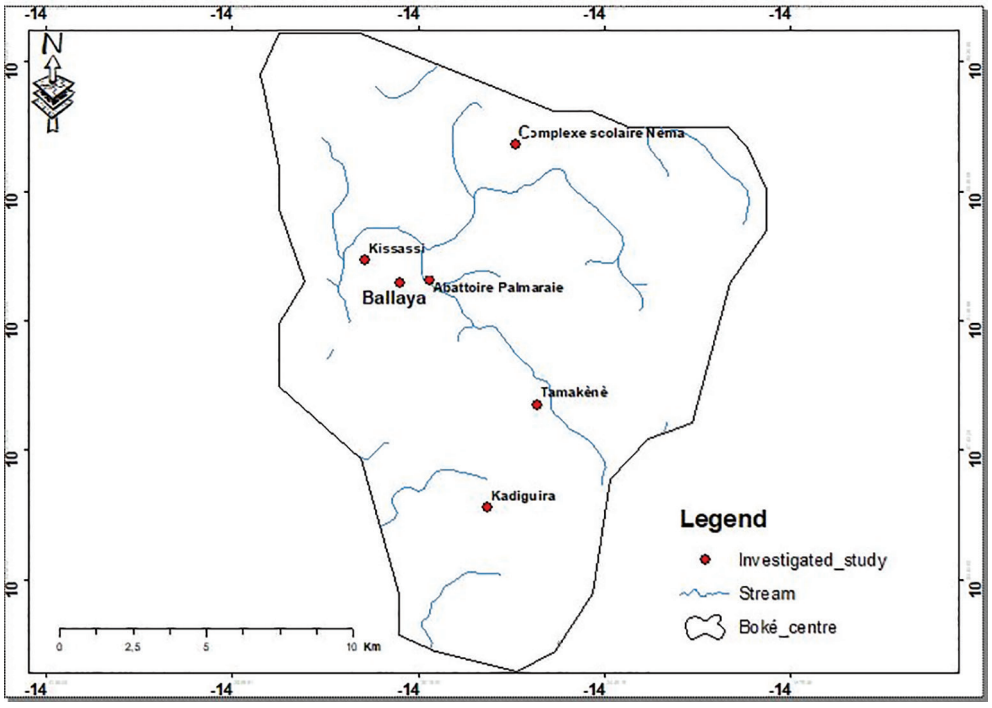

Figure 3: *Hydrographic map of urban municipality of Boké (Boké centre).*

Dolonkhi, etc. The hydrographic map is shown in Figure 3.

Several major basins are shared in the study area. In particular, the Batafon basin (7,478 hectares), the Tinguilinta basin (4,812 ha) and the Nunez basin (2,761 ha) [17]. Based on the nature of the slopes, the altitude of the sources, the nature of the terrain and the seasons, the regime of the waterways is irregular.

Geologically, our study area belongs to the sedimentary cover. It was relatively calm with great magmatic activity in the Mesozoic [18].

The terrigenous terrains of the Ordovician (argillites, aleurolites and sandstones), Silurian (quartz sandstones, schists, argillites, etc.), and Devonian (sandstones, coarse-grained aleurolites, etc.) are developed in the urban municipality of Boké. These terrains are all covered by unconsolidated deposits of marine or lacustro-fluvial origin from the Paleogene (represented in our region by clays, argillites and quartz sands) and from the Quaternary (the Quaternary formations are represented by different facies: Marine, continental, lacustro-fluvial) [3].

An intense eruptive activity dating from the Mesozoic and due to the tectonic movements of the North African platform occurred in our study area. These Mesozoic intrusions are represented by dolerites, gabbro-dolerites, Congo-diabases and gabbro-quartzes [18].

The Boké zone belongs to the West African craton and its lands occupy part of the Bowé syneclise. In Boké, the base does not outcrop [18]. The Boké area is affected by two tectonic faultts. Namely: the deep faults which served for the rise of the basic magma, and the secondary faults developed on the cover. These two faults constitute the current hydrographic network.

According to [19], the study region is located within the limits of three major morphological zones: Fouta-Djalon plateau, coastal plain and shelves.

From the hydrogeological point of view, our study area belongs to the northwestern part of Guinea which abounds in significant water reserves fed by atmospheric precipitation and by rivers [3]. The geological conditions of the region make it possible to distinguish two groundwater sampling environments: bedrock and the superficial formations that cover them. Mesozoic doleritic rocks and healthy shales constitute the bedrock. In

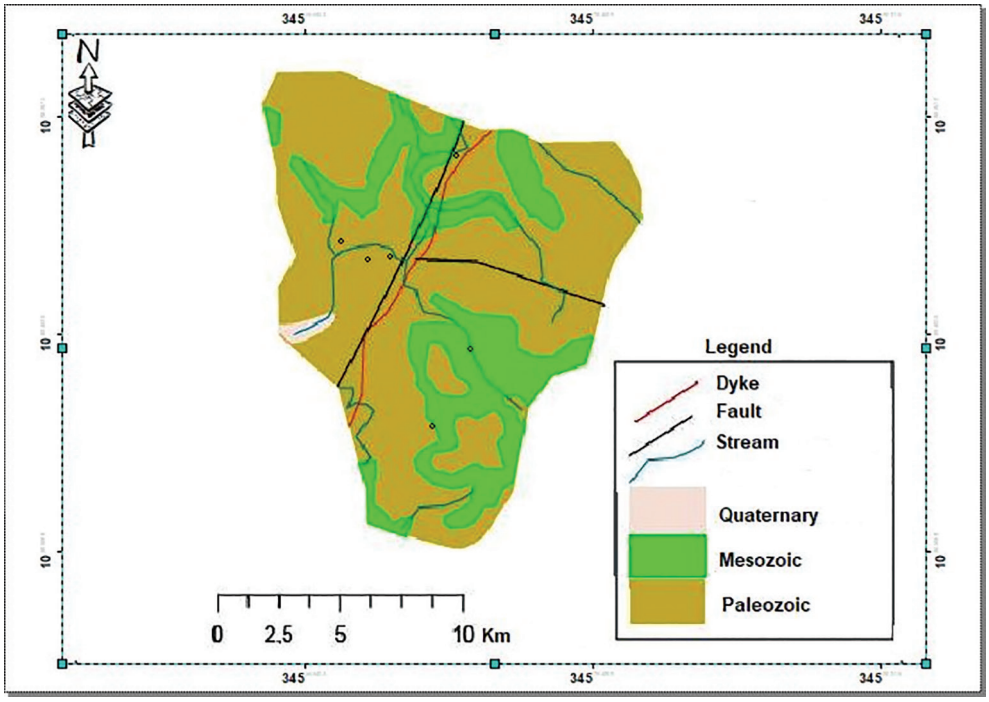

Figure 4: *Geological map of urban municipality of Boké (Boké centre).*

these formations, water is linked to cracking or crushing zones [2].

In the study area, the waters of tectonic fractures are generally attached to doleritic magmatic rocks and argillites which are fractured and crushed by tectonic movements. These areas are not well known, but they can be one of the main sources of good quality water supply. The study area contains several nappes in the weathering crust. This is evidenced by the high number of artisanal wells in all settlements and the presence of groundwater sources in the area [2]. The geological map of the urban commune of Boké is shown in Figure 4.

Materials

For the collection of geophysical data, a compact RSP6 resistivity meter of the SCINTREX Canada type and its accessories were used to determine the resistivity of the sites; a Garmin-type GPS was used as a tool for the geo-referencing of the measurement points; and WINSEV software (version 6.4) was used for data processing.

Methods

To achieve our objective, a geophysical survey was conducted on six sites (see Figure 5) which were: Kissassi; Abattoire Palmeraie; Tamakènè; Nema school complex; Kadiguira; and Ballaya.

According to [20], in practice, the choice of geophysical methods depends on:

- The nature of the sought target which must cause an anomaly sufficient to be measured;
- The quality of precision sought which must correspond to the resolving power of the method and the device used;
- The objective of prospecting work and in particular the scale at which it is undertaken, which determines the framework for implementing field measurements.

In the context of groundwater research, the parameters sought concern the reservoir: its position, its geometry and the quality of the water it contains [20].

For the present work, since it is a question of the survey for groundwater, our choice takes into account not only the capacity of a method to locate the zones of fractures or crushing considered as zones of accumulation of groundwater, but also the cost, the implementation time and the ease of use in the field. This justifies the

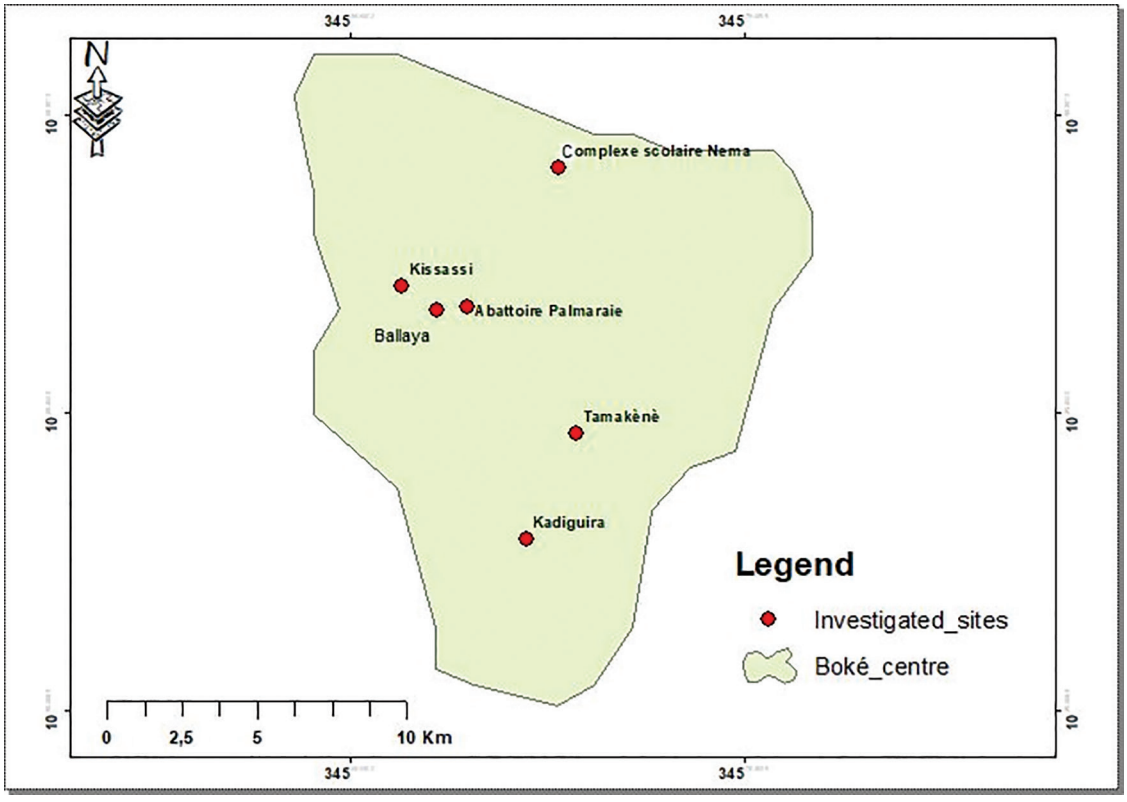

Figure 5: *Location map of study sites.*

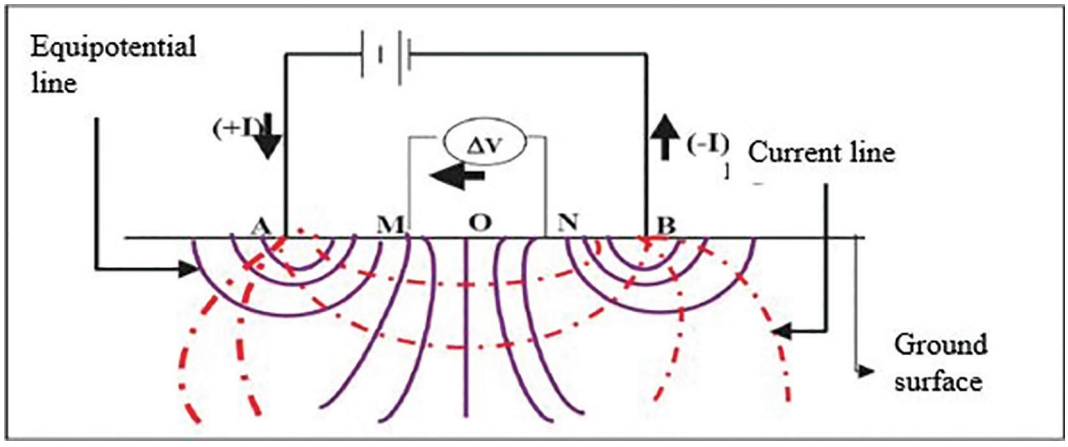

Figure 6: *Schlumberger device.*

choice of the geo-electrical method (electrical sounding) of the Schlumberger type.

- Work device: Several devices are envisaged to determine the distribution of resistivities in the subsoil. The choice of device depends on the depth of investigation. Any measuring device has in fact four electrodes, two electrodes A and B, for sending currents (transmission circuit) and two others M and N, for measuring the potential ΔV (measuring or receiving circuit). The Schlumberger configuration is shown in Figure 6.
- Measurement technique: The measurement technique consists of separating the injection circuit from the measurement circuit. Four electrodes are used for this in practice, AMNB (the measuring quadrupole). From

two electrodes, called injection electrodes A and B, an electric current of intensity I is sent into the ground and the potential difference (ΔV) is measured between two other electrodes, called measurement electrodes MN [21].

- Processing: The results of the resistivity measurements are entered into the software, and after processing, the apparent resistivity values are obtained on a bi-logarithmic scale whose distances AB/2 are reported on the abscissa and the resistivities are on the ordinate. The petro-geophysical model defining the number of terrains and their characteristics (resistivity and thickness) in the area and the physical-geological model which highlights the behavior of the current in the ground through a curve are finally obtained. Knowing the geology of the area, the nature of the terrain is defined by analogy with the resistivity values of the rocks in the region.

Results and discussion

The results and their interpretation, the coordinates of the points and the parameters of the measuring device on the sites are as follows:

A- Kissassi site

1) Curve of electrical positioning sounding 1 (SEP1): the geometric characteristics of the device at this point are: AB/2 = 40 m; MN/2 =10 m; k = 275. The geographic coordinates are:

   X = 57,448; Y = 1,208,604; and Z = 36 m.

   At this point, the petro-physical model reveals an area of three layers. Taking into account the geology and the physical properties of the rocks of the area, the lithology is presented from top to bottom as follows (Figure 7):
   - A layer of cuirass having a resistivity of 5,851 Ωm and a thickness of 1.6 m;
   - An alteration crust with a resistivity of 2,517 Ωm and a thickness of 2 m, and;
   - A formation of low resistivity (820 Ωm) compared to the first and second which is fractured clays. It is beyond 3.6m deep and this layer constitutes the superficial aquifer.

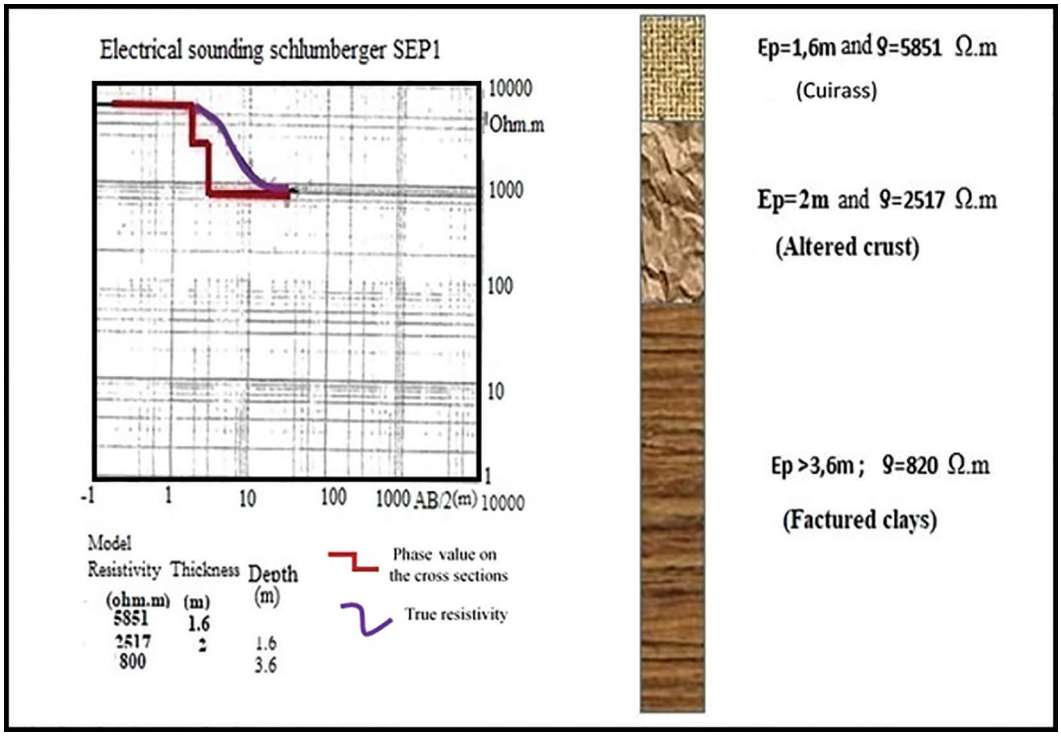

Figure 7: *Lithological section of SEP1. Ep = Thickness.*

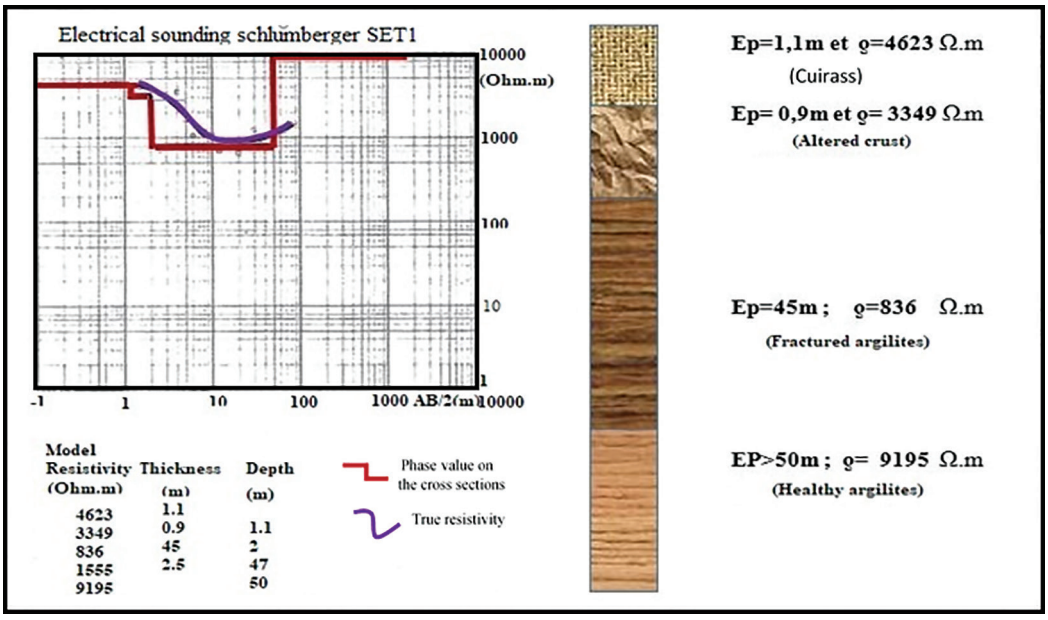

Figure 8: *Lithological section of SET1. Ep = Thickness.*

2) Electrical Test Sounding 1 (SET1): the geometric characteristics of the device at this level are: AB/2 = 30 m; MN/2 = no measurement = 10 m; and k = 275.
   Compared to the first survey, the electrical test survey specifically intersected four layers including (Figure 8):
   – A layer of cuirass having a resistivity of 4,623 Ωm and a thickness of 1.1m;
   – A layer of crust altered having a resistivity of 3,349 Ωm;
   – A thick layer of fractured argillites with an average resistivity of 836 Ωm and a thickness of 45 m;
   – A last layer having a high electrical resistivity (9,195 Ωm); it is the bedrock (healthy argillites).

B- Abattoire Palmeraie site

The geometric characteristics of the device on this site are: AB/2 = 40 m; MN/2 = 10 m. The geographic coordinates are: X = 576,652; Y = 1,207,919; Z = 7 m.

1) Curve of electrical positioning sounding 2 (SEP2).
   The petro-physical model of the survey (SEP2) presented the lithology from top to bottom as follows (Figure 9):
   – A thin surface layer having a thickness of 0.64 m and a resistivity of 543 Ωm (sandy clays soil);
   – A layer of altered crust with a thickness of 1.3 m and a resistivity of 1602 Ωm;
   – Thin layer of clay with a resistivity of 758 Ωm and a thickness of 1 m;
   – A layer of fractured shale 45m thick and a resistivity of 378 Ωm; The water table is at this level;
   – A healthy layer of shales.
   The bedrock roof was cut to a depth of 35 m.
2) Test electrical sounding 2 (SET2):
   The lithological section of this survey is as follows (Figure 10):
   – A layer of cuirass which has a thickness of 1.7 m and a resistivity of 4,410 Ωm;
   – A weakly altered layer (altered crust);
   – A layer of weakly fractured dolerites is located beyond 5.7 m depth. This zone admits an electrical resistivity of 453 Ωm.
   The top of the bedrock (fractured dolerites) of this hole was intersected at a depth of 35 m.

C- Tamakènè site

The characteristic parameters of the device are: AB/2 = 40 m; MN/2 = 10 m; k = 275. The geographic coordinates are as follows: X = 580,265; Y = 1,203,704; Z = 57 m.

1) Electrical positioning sounding curve (SEP3):

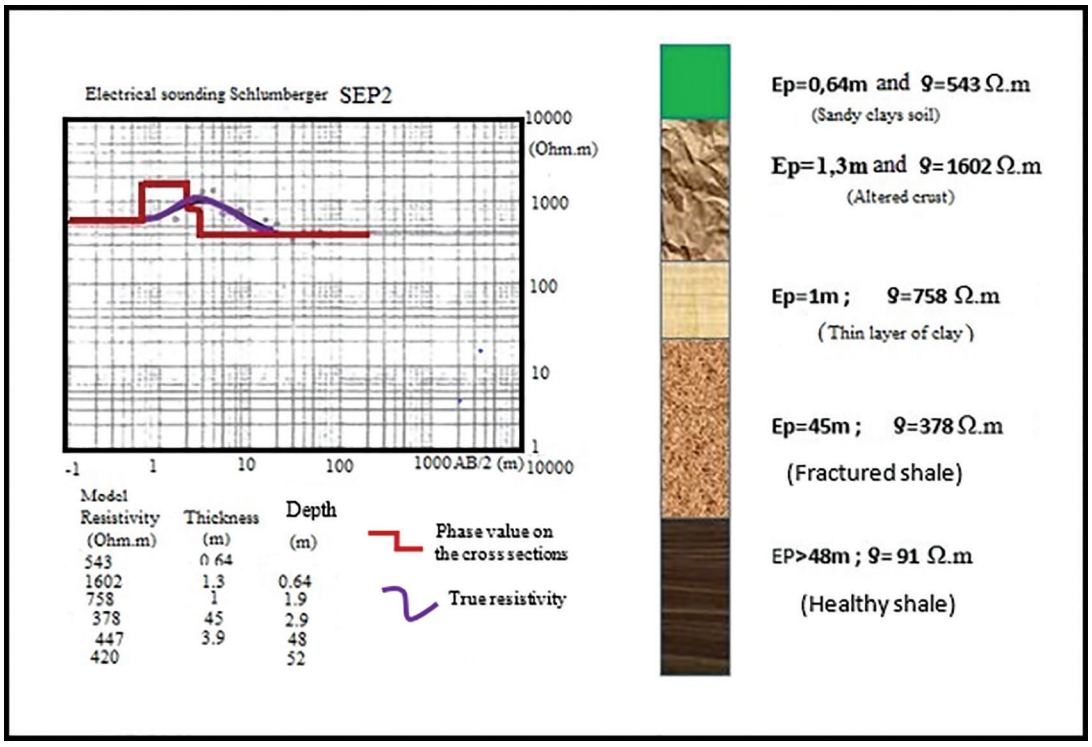

Figure 9: *Lithological section of SEP2. Ep = Thickness.*

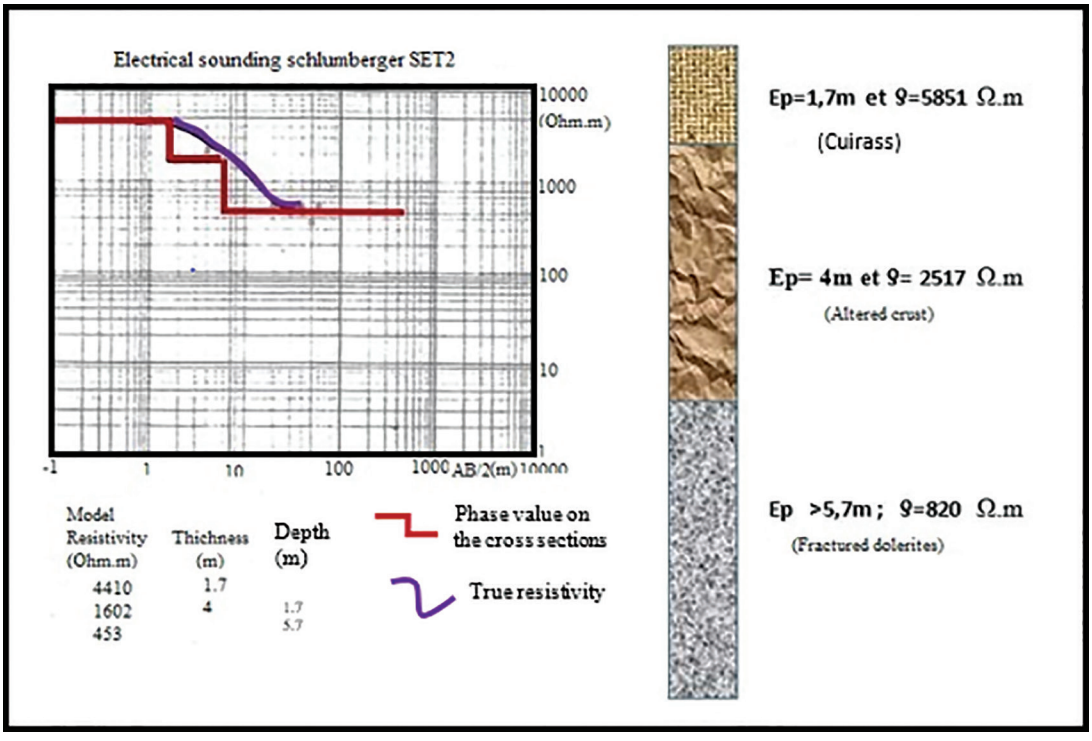

Figure 10: *Lithological section of SET2. Ep = Thickness.*

The lithological section revealed by the latter is as follows:

From top to bottom (Figure 11):

- A superficial formation having a thickness of 1.4m and a resistivity of 1,741 Ωm;
- A layer of slightly altered crust with a resistivity of 2,379 Ωm and 3.65 m thick;
- A thin layer of clay with a thickness of 1.5 m and a resistivity of 1,008 Ωm;
- A thick layer (199 m) of highly fractured shale characterized by an electrical resistivity of 261 Ωm. The aquifer is located at this level. Below this layer is bedrock (healthy shale).

2) Electrical Test Sounding 3 (SET3).

The geographical coordinates of this site are mentioned in Figure 12.

At this level (SET3), the lithology is presented from top to bottom as follows (Figure 12):

- A layer of cuirass which extends over a thickness of about 2.12 m and an average resistivity of 5,000 Ωm;
- A layer of altered crust with an average resistivity of about 1,300 Ωm and a thickness of about 6 m;
- A thick layer of sandstone beyond 21 m characterized by an electrical resistivity of 41,201 Ωm.

D- Nema school complex site

The geometric characteristics of the device on this site are: AB/2 = 40 m; MN/2 = 10 m; and K = 275.

1) Curve of electrical positioning sounding 4 (SEP4):

The lithology at this point is, from top to bottom, as follows: (Figure 13):

- A layer of cuirass which has a resistivity of 5,345 Ωm and a thickness of 1.5 m;
- A layer of altered crust with a resistivity of 1,115 Ωm is beyond 1.5 m.

2) Electrical sounding test 4 (SET4):

The electrical test sounding performed shows the following lithology (Figure 14):

- A layer of altered crust with a thickness of 5.8 m and a resistivity of 1,278 Ωm;
- A layer of wet clay located about 13 m deep with a resistivity of 829 Ωm;
- Beyond 10 m depth, there is a layer of fractured and wet clay. It has a resistivity of 121 Ωm.

E- Kadiguira site

The geometric characteristics of the device are like the previous sites (Nema school complex, Tamakènè).

1) Curve of the electrical positioning sounding (SEP5).

The lithological section of SEP5 gave us the following, from top to bottom:

- A layer of altered crust which extends over a thickness of 7.5 m and a resistivity of 908 Ωm;
- A thick layer of wet clay constituting the aquifer with a thickness of 52 m and a resistivity of 290 Ωm;
- A last layer which constitutes the bedrock (healthy clay). It is located beyond 60 m deep and has a resistivity of 3397 Ωm

2) Electrical sounding test 5 (SET5).

The lithologic section of SET5 is presented from top to bottom as follows (Figure 15):

- Altered crust with a thickness of 6.05 m and a resistivity of 814 Ωm;
- A layer of fractured clay located at a depth of 6.05m, characterized by a resistivity of 367 Ωm and a thickness of 18 m (this is the aquifer);
- Beyond 24 m, we have the upper part of the bedrock (healthy clay).

F- Ballaya site

1) Curve of electrical positioning sounding 6 (SEP6).

The lithological section of SEP6 is presented from top to bottom as follows (Figure 16):

- An altered and wet (altered crust) layer 2.3 m thick with a resistivity of 262 Ωm;
- A layer of fractured argillites, characterized by levels, with a thickness of 29.1 m and an average resistivity of 167 Ωm;
- A layer of healthy argillites located more than 31 m deep with a resistivity of 2,418 Ωm.

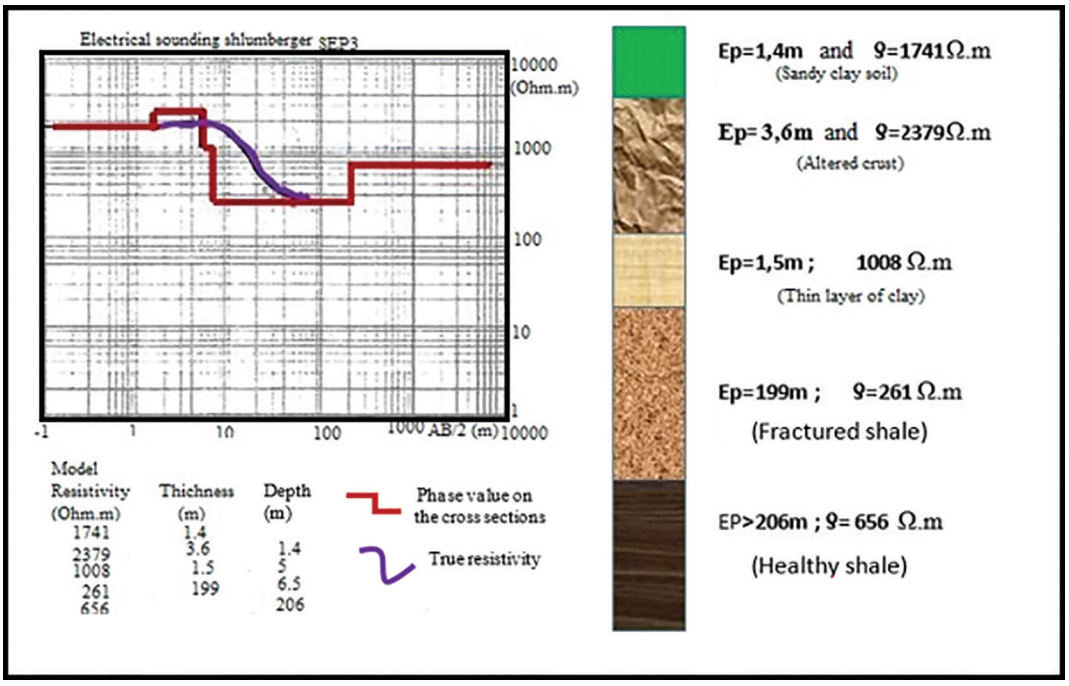

Figure 11: *Lithological section of SEP3. Ep = Thickness.*

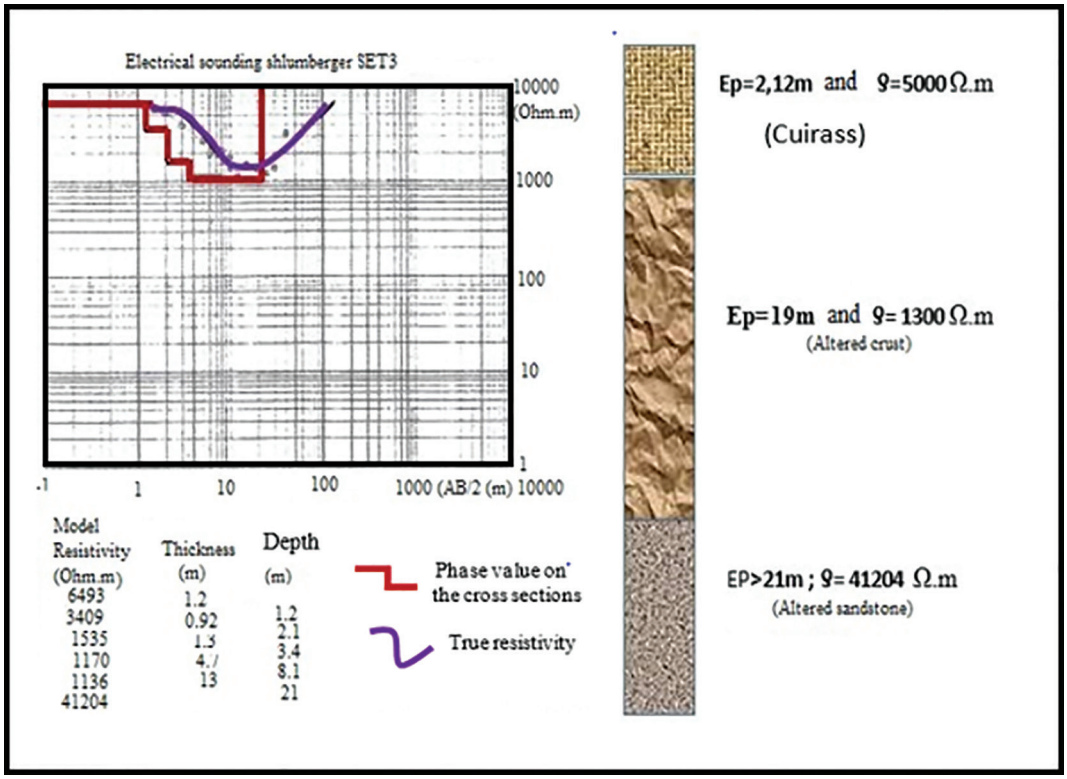

Figure 12: *Lithological section of SET3. Ep = Thickness.*

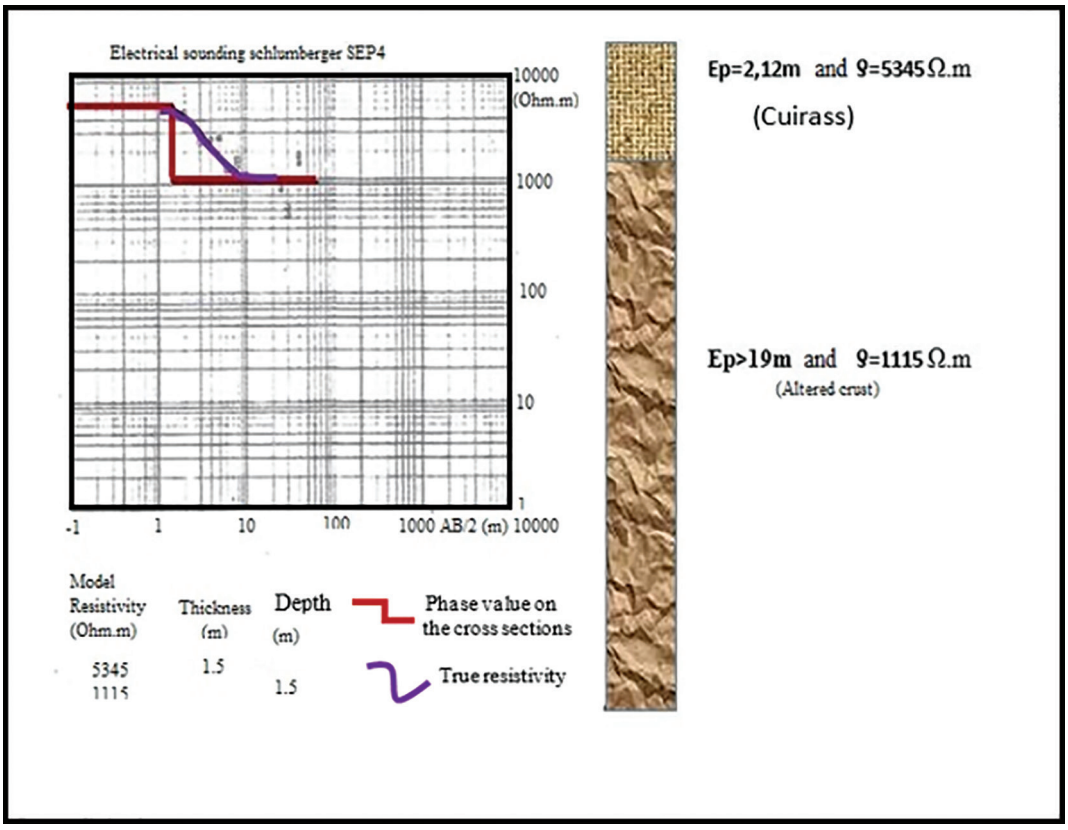

Figure 13: *Lithological section of SEP4. Ep = Thickness.*

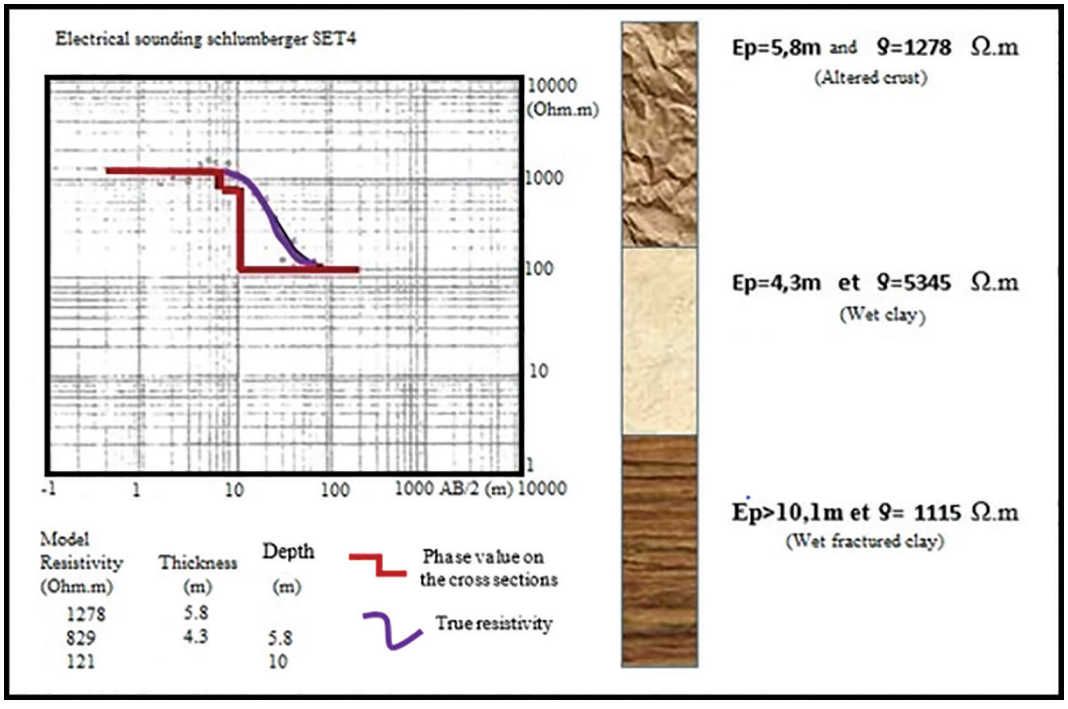

Figure 14: *Lithological section of SET4. Ep = Thickness.*

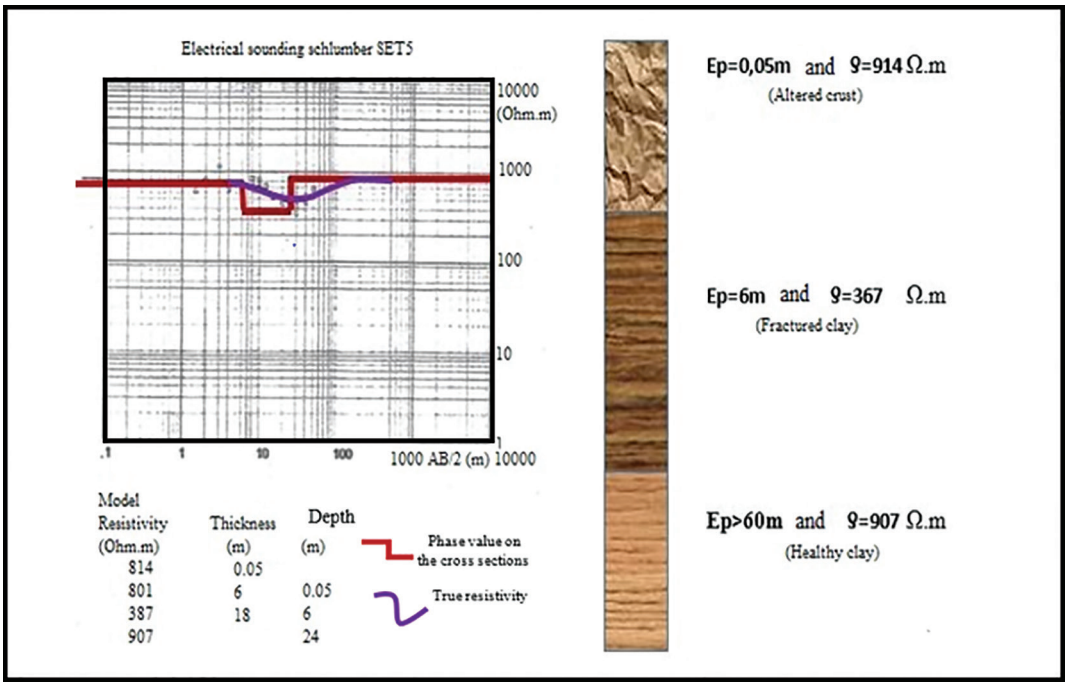

Figure 15: *Lithological section of SET5. Ep = Thickness.*

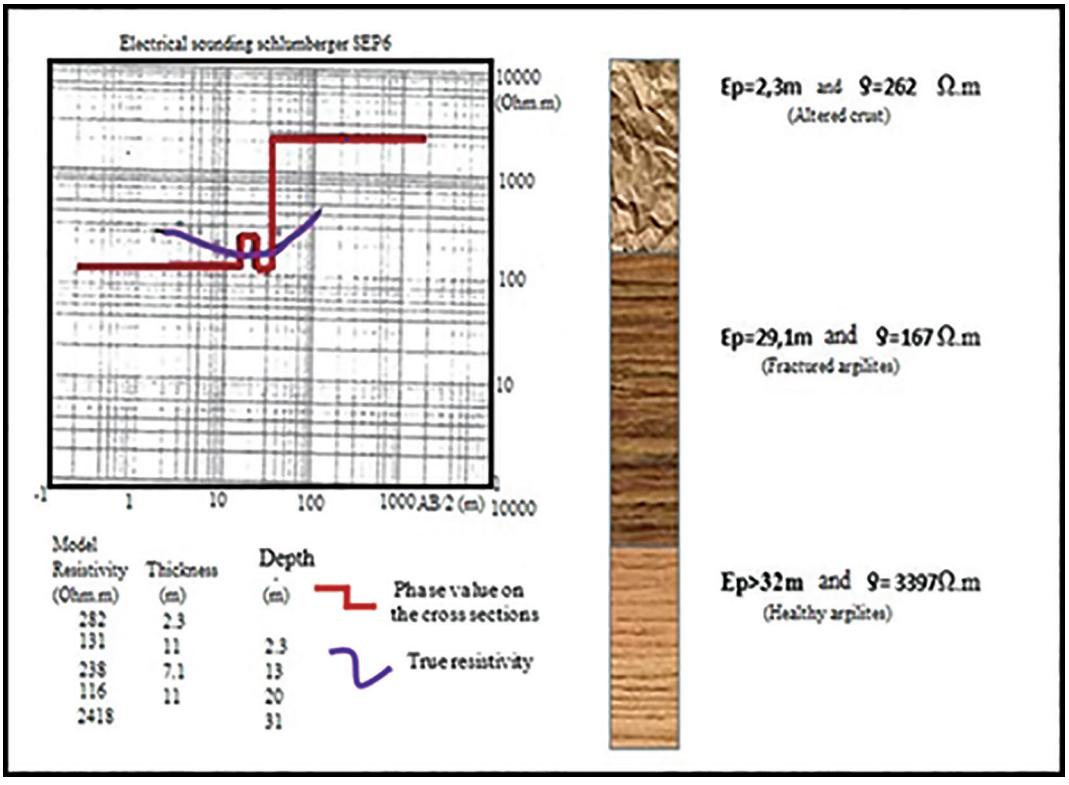

Figure 16: *Lithological section of SEP6. Ep = Thickness.*

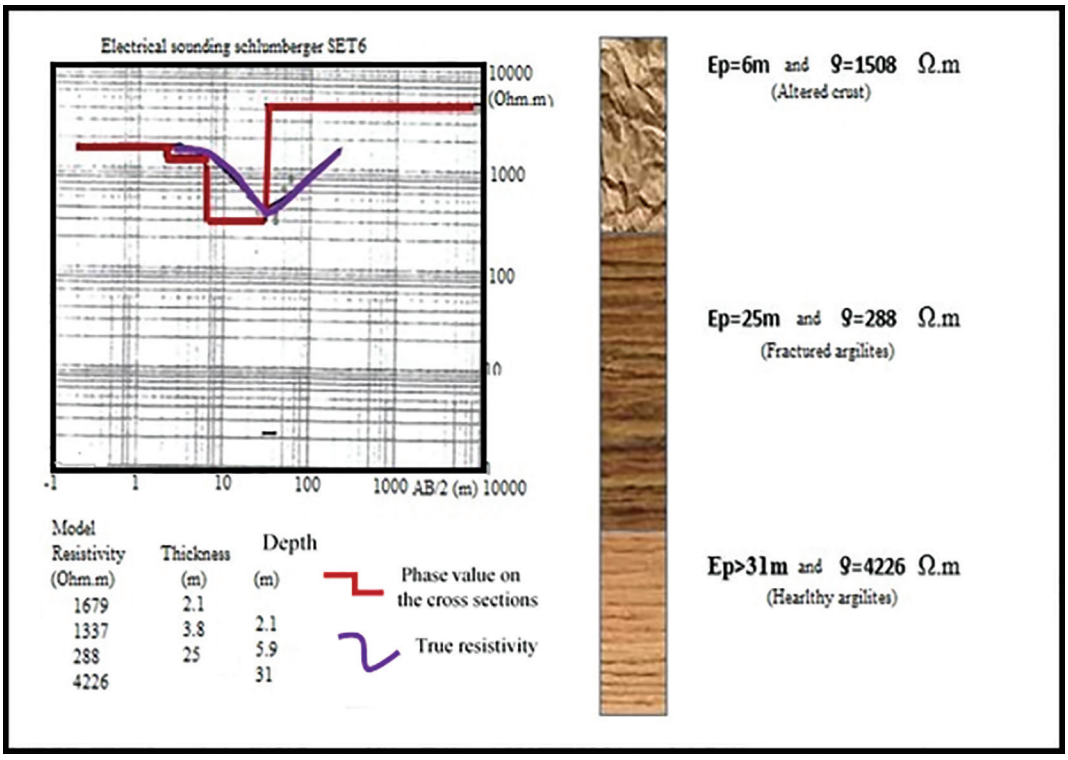

Figure 17: *Lithological section of SET6. Ep = Thickness.*

2) Electrical sounding test (SET6):
The lithologic section of SET6 is presented from top to bottom as follows (Figure 17):
   – A layer of altered crust with two levels, the upper part resistant and the lower part less resistant; it has an average resistivity of 1,508 Ωm and a thickness of about 6 m;
   – A thick layer of fractured argillites with a resistivity of 288 Ωm and a thickness of 25 m;
   – Beyond 31 m, we have healthy substratum (argillites). It has a resistivity of 4,226 Ωm.

Discussion

The analysis and interpretation of the results of the electrical soundings carried out at the six sites studied in the area enabled us to highlight three superimposed zones or layers in such a way that the comparison of the resistivities is presented as follows: $\varrho 1 > \varrho 2 < \varrho 3$.

The first layer of the study area extending over approximately 40 m corresponds to the covering of the sedimentary cover; the second constitutes an arena of low resistivity and being on a depth of surroundings 5 m; the third layer is the very resistant and fissured in places bedrock. Several authors, in the context of hydrogeological studies with different objectives, have determined the lithology of the sites using electrical soundings. This is the case of [22], [9–10] who, in their studies, succeeded in highlighting the geological structures, increasing the production of the drillings and decreasing the negative drilling rate. This supported our choice of the method and the results obtained.

Conclusions

At the end of this study, we find that our area has a lithology of several terrains arranged from top to bottom:

– A layer of weathering crust covered in places by a thin layer of the cuirass or topsoil. The average thickness of this layer is 40 m;
– A thin layer of wet clay with an average thickness of 4.5 m which is intercalated between

the weathered crust and the top of the fissured bedrock;
- A layer of cracked shales, dolerites or sandstones (roof of the substratum) follows the layer of clays. It is at this level that the most important fractures for the accumulation of groundwater are located. This zone is located at more than 40 m depending on the location;
- A healthy formation which constitutes the substratum. It consists of healthy shales, doleritic intrusions and sandstones.

Structures favourable to the accumulation of groundwater are fractured shales, fissured dolerites and fissured or crushed sandstones. The latter (sandstone) has a significant thickness and is generally located at a great depth (100 to 150 m).

Despite the efforts, it must be recognized that like any other study, this one has limitations. They are: ignorance of the direction of groundwater flow and lack of knowledge of the physicochemical properties of the waters in the area. These shortcomings are justified by the lack of material and financial resources necessary during the works.

References

[1] INS Guinée (2018): *Rapport annuel. Conakry*. Institut National de la Statistique de Guinée, 28 p.

[2] Kourouma, M. (2016): *Choix d'un complexe rationnel de méthodes géophysiques pour la recherche des eaux souterraines au Nord-Ouest de la Guinée.* Thèse. CERESCOR, Centre de Recherche Scientifique de Guinée: Guinée, 176 p.

[3] Diallo, I. (1979): *Projet de recherche des eaux souterraine sur la Boffa en vue de l'adduction de la population en eau potable*. Mémoire de fin d'étude supérieure. Boké, Institut Supérieur des Mines et Géologie de Boké (ISMGB), Guinée, 102 p.

[4] SNAPE (2018): *Rapport annuel.* Conakry, 18 p.

[5] Kim, M.K.J.K.N., Jeong, G. (2011): Surface geophysical investigations of landslide at the Wiri area in southeastern Korea. *Environmental Earth Sciences*, 63(5), pp. 999–1009, DOI: 10.1007/s12665-010-0776-z.

[6] Kadri, M., Nawawi, M.N.M. (2010): Groundwater exploration using 2D Resistivity Imaging in Pagoh, Johor, Malaysia*.* In: *AIP Conference Proceedings*, pp. 151–155.

[7] Morad, M.D. (2012): *Utilisation des dispositifs de géophysique électrique non classiques pour l'étude des couches géologiques profondes: cas des chotts el Gharbi et chergui (Algérie).* Thesis. Université d'Oran: Algérie, 198 p.

[8] Michel, K.A., Coulibaly, D., Koffi, Y.B., Biemi, J. (2013): Application de méthodes géophysiques à l'étude de la productivité des forages d'eau en milieu cristallin: cas de la région de Toumodi (Centre de la Côte d'Ivoire). *International Journal of Innovation and Applied Studies,* 2(3), pp. 324–334.

[9] Dieng, B., De Heusch, K.A., Bakyono, B. A. (2004): *Optimisation de l'implantation géophysique des forages en zone de socle au Nord du Burkina Faso*. Groupe des Ecoles EIER-ETSHER, Ouagadougou 03, Burkina Faso.

[10] Kouakou, E.G.K. (2012): Utilisation de la prospection géophysique par résistivité électrique pour la recherche d'eau souterraine dans le département de Tanda (Est de la Côte d'Ivoire). *European Journal of Scientific Research,* 83(2).

[11] Falco, P. (2013): *Sondages géoélectriques "Null-Arrays" pour la caractérisation des structures de subsurface*. Thesis. Université Neuchatel.

[12] Njueya A.K., Kengni, L., Fonteh, M.F., Dongmo, A.K., Ntankouo., R.N., Nkouathio, D.G., Tazo, C. (2016): Apport des Sondages Électriques Verticaux à la Localisation et la Caractérisation des Aquifères en zone Volcanique au Cameroun: Cas d'Ebone et ses Environs. *European Journal of Scientific Research*, pp. 54–65.

[13] Kouakou, E.G.K., Dosso, L., Kouame, L.N., Sombo, A.P., 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. *La Revue Ivoirienne des Sciences et Technologie,* 26, pp. 194–211.

[14] Koussoubé, Y., Nakolendoussé, S., Bazié, P., Sawadogo, A.N. (2003): Typologie des courbes de sondages électriques verticaux pour la reconnaissance des formations superficielles et leur incidence en hydrogéologie de socle cristallin du Burkina Fasso. *Pangea infos, Société Géologique de France,* 1999, 31/32, pp. 33–36.

[15] Bernardi, A., Detay, M., De Gramont, H.M. (1988): Recherche d'eau dans le socle africain. Corrélation entre les paramètres géoélectriques

et les caractéristiques hydrodynamiques des forages en zone de socle. *Hydrogeology Journal,* 4, pp. 245–253.

[16] INS Guinée (2020): *Annuaire des statistiques de l'environnement,* 256 p.

[17] Dansoko, K. (2019): *La mise en œuvre d'un protocole suivi-évaluation environnementale et sociale du permis Alliance Minière Responsable (AMR).* Rapport de fin d'études supérieures, Institut Supérieur des Mines et Géologie de Boké (ISMGB), Guinée, 68 p.

[18] Mamedov, V.I., Bouféév, Y.V., Nikitine, Y.A. (2010): *Géologie de la République de Guinée.* Geoprospects Ltd: Université d'état de Moscou, 166 p.

[19] Nabé, L. (2017): *Géologie et étude des faciès bauxite de la feuille Boffa*. Rapport de fin de d'étude supérieur, Institut Supérieur des Mines et Géologie de Boké (ISMGB), Guinée, 97 p.

[20] 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)*. PhD Thesis. Université Pierre et Marie Curie-Paris VI, Institut international, 303 p.

[21] Cissé, O., Kourouma, A. (2006): *Utilisation des méthodes géophysiques pour la recherche des eaux souterraines à Lambanyi dans la commune de Ratoma*. Rapport de fin d'études supérieures. Institut Supérieur des Mines et Géologie de Boké (ISMGB), Guinée, 51 p.

[22] Lavoie, A.C. (1998): *Application de la méthode des sondages électriques à la caractérisation des aquifères et des dépôts meubles, Basses-Terres du St-Laurent, région Nord de Montréal*. Mémoire de maitrise, 210 p.