ISSN 2229-5518

Electrical resistivity and geomorphology For Groundwater Exploration In Hard Rock Areas: Application to Kongoti (South-East of Côte d'Ivoire)

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Abstract— In the area of Kongoti, the satisfaction of drinking potable water needs has become a major issue. To overcome these difficulties, people make use of groundwater through the construction of boreholes. Thus, a geophysical survey (electrical profiling; electrical sounding) coupled with geomorphology, was undertaken, with the aim of localising and characterizing cracks aquifers, a potential target for water supply. The interpretation of the geoelectrical cross-sections allowed identification of several fractures (N 50, N 135, N140) including the oriented one N145 seem very productive. A drilling has been made with a rate of 10.8 m3 per hour.
Findings of this study are important and watch interest of such a approach in the exploration of crack aquifer.

Index Terms— Geophysical survey, Geomorphology, Fracture, Crack aquifer, Drilling, Kongoti.

1 Introduction

A prospecting method has been done for water search in Kongoti's location in the department of Daoukro. This study from the desire of the Ivoirian government to satisfy a need in water for populations. To do it, two types of electrical measure have been made. It is about eschaustive and nearly continued electrique mesasures by electrical profiling according to a permanent spread of electrodes (10 m) and specific electric measures, according to a variable electrodes, in order to explore much more deep layers and thus to analyse vertical discontinuities. The aim of geophysical survey is to identify cracks aquifers in order to propose drilling sites, to obtain at least a rate of 10m3/h of water at Kongoti.

2 Geological and geographical context of department of department Daoukro

Located in the Centre-east of Côte d'Ivoire, the studied location is situated in the department of Daoukro between the longitude 3°29′ and 4°33′ West and the latitude 6°57′ and 7°31′ North, Fig.1. The yearly middle rainfall from 1940 to 2005 is 1174.5 mm [1]. The department is drained by comoé, its tributaries and small streams are derived from N'ZI. Daoukro's department geological formations are essentially schistous with some granitic intrusions somewhere else. In the Daoukro schistous basement, the granitoid consists essentially of biotite granites, two micas granite and intrusive granites [2], [3]. The location submitted to our study is essentially located in schists zone.

On the structurally level, the photogeological interpretation displays that the predominating fractures direction is SE to ESE, the direction NE is less regular. Some fractures NS are observed in a sporadic way [3]. Schists and grauwackes present a dense fracturation with a more marked schistosity.

On the hydrogeolocal level, one re-finds the classical superposing of a superficial and porous reservoir (alluvium, colluvium and otherness) and an aquifer discontinuous hosted by fractures of the base (crack aquifer). At Kongoti, from the four (04) existing drillings, on notices that the alteration thickness varies between 35 and 61 m with rates from 1.3 to 11.3 m^3/h. The static level gets found at depths between 27and 48 m. The variability extreme obtained rates, for sometimes neighboring drillings, underline the very discontinued character of aquifers. These aquifers get developped with fracturations, begot by relationship between intrusive materials, or following faults. The study of aquifers system in environment of cristallophyllien base is so fundamental and essential for the determination of areas and pick up underground waters, the transfer of solute is conditioned by the organization of geometry of the aquifer reservoirs [4].

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ISSN 2229-5518

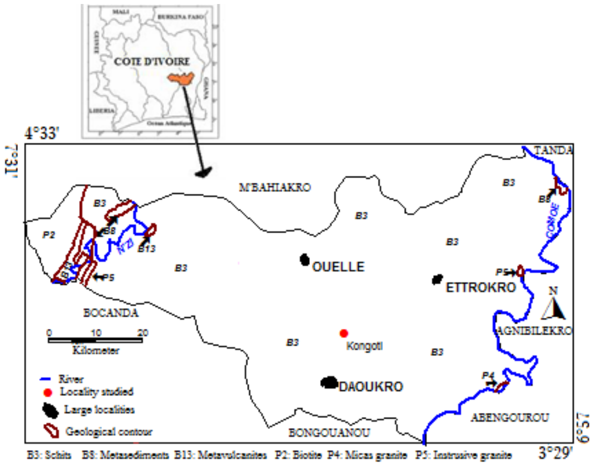

Fig. 1. Geological map of Daoukro's [3], [4].

3 Materials and Methods

This study has required the use of several data types including apparent resistivity data and geological and topographic maps of square degrees of M'Bahiakro and Agnibilekrou (Kouame-N'dori) to scale 1/200000 respectively realized by the hydraulic central direction [2], [3] and by the of Center for Cartography and Remote Sensing of Côte d'Ivoire (CCT) the measure appliance, used to get appearing resistivity data is the Syscal junior.

In the study area taking into account of the geology, the conductive layers constituted by area porous formations and /or split inter-connected are favorable places to the presence of water. The electrical resistivity methods according to electrical profiling and vertical electrical sounding (VES) surveys have been used to determine these areas.

In order to study lateral variability of materials, the applied technique is an electrical profiling. The electrical profiling method is based on the same four-electrode principle as the conductivity cell. The electrical field is distributed in a soil volume, which size can be estimated from the distance among AMNB electrodes. The electrode array is moved along a surveyed line and the electrical measurements result in a horizontal profile of apparent resistivity. The final results include subsurface apparent resistivity values from the measured locations. Results may be plotted as profile lines or contour maps (isopleth resistivity map). A particular attention will be put on the shape, the width or power, the fullness of observed anomalies upon electric profile lines, thus the clue of fracturation (IF). The shape of anomaly this essential in the position of survey points and drilling in the base area [4], [5]. Three sites have been studied witch six (6) electrical profiling made according to the schlumberger array with the following geometric characteristics: AB=200, MN=20 m. Vertical electrical sounding allow to know the succession of unlike layers on resistivity base and thicknesses (Dabas and al., 1989). The VES array consists of a series of the electrode combinations AMNB with gradually increasing distances among the electrodes for consequent combinations. The depth of sounding increases with the distance between A and B electrodes. The result of VES measurements with central-symmetric arrays is apparent electrical resistivity as a function of half of the distance between the current electrodes (ER = f (AB/2). The relationship between ER and AB/2 can be converted into a relationship between electrical resistivity and actual soil depth through a computer interpretation. For our study, for mine VES have been done as well according to the schlumberger array with a length of maximum line of 200 m.

4 Results

The network analysis of draining and the gratefulness of grounds enable to define four fully favorable areas geophysical surveys upon unlike study sites have given many outcomes which will be analyzed later on, Fig. 2.

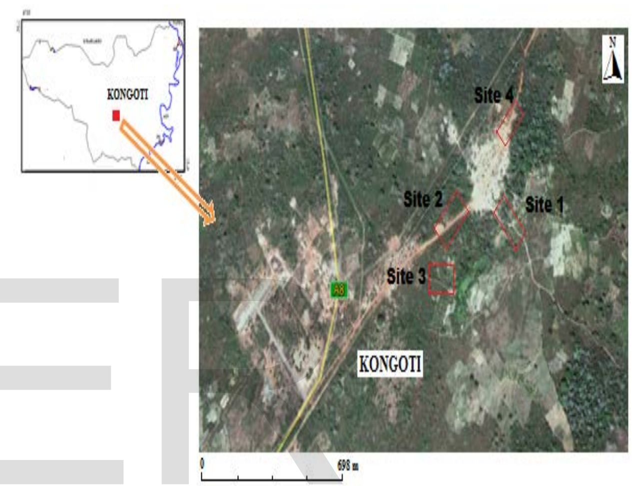

Fig. 2 Located geophysics sites of Kongoti

4.1 Identification and characterization of discontinuity zones

The profiles of resistivity presente weak value landing of resistivity according to the average. These levels corresponding to some conductive anomaly areas would be associated to some conductive anomaly areas (contact area, faults, and fractures). The conductive anomalies seen are directed following the directions N50°; N135° and N140° (figure 3, Tableau I). They presente variable shapes (V, K, U), weak averages in widths and fullnesses. The fracturation cluse is weak (IF< 0.43) for anomalies "K" and "U" and good (IF = 1.7) for anomaly "V". VES have been done on these different anomalies.

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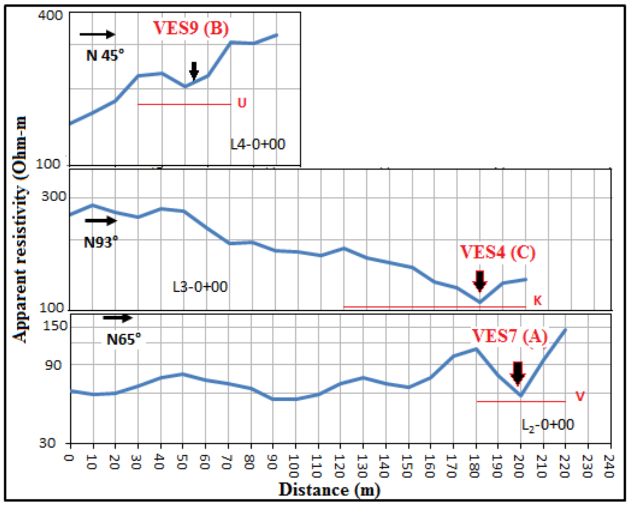

Fig. 3 Some profiles lines of Kongoti

TABLE 1
CHARACTERISTIC OF ELECTRIC ANOMALIES OF KONGOTI

Sites		1	2	3
Profile		L2-0+00	L3-0+00	L4-0+00
Direction of fracture (°)		N145	N 50	N135
anomaly	Width (m)	40	80	40
	Forme	V	K	U
	Amplitude (Ω.m)	87	75	101
	IF (%)	1.7	0.41	0.42

4.2 Interpretation of outcomes of electrical surveys

The interpretation of results of the nine (9) VES performed on different sites give three (3) to five (5) grounds. They get gathered in four (4) types following their speed.

The first type presents three grounds it gathers VES4, VES5 and VES6 performed on the same site. It is characterized by a first conductive level (120 to 200 Ω.m) of weak thickness (0.4 m) corresponding to the arable land. This level goes beyond a gravelly horizon of a maximum thickness of 8 m and resistivity varying between 1500 and 3000 Ω.m. Below is a clayey-sandy level of low resistivity (77 to 110 Ω.m), Fig. 4a. These three levels are the saprolite, the wall of the underlying horizon corresponding to the cracked bedrock is poorly known. However, this type of curve characterizes zones with strong alteration.

The second type presents five (5) grounds, it gathers VES2 and VES7. It contains, under identified grounds in the first type, another clayey-sandy level of weak resistivity (24 to 50 Ω.m) so more damp or clayey and the holy bedrock relatively fissured, Fig. 4b. This kind of curve has a strong thickness of the saprolites and the roof of the substratum fissured to approximately to 66 m of depth.

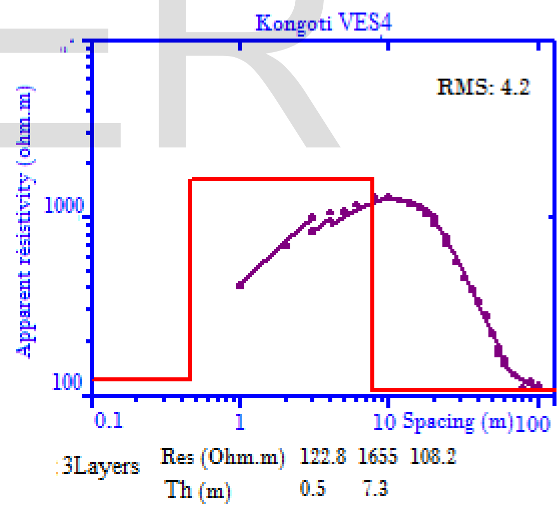

Fig. 4a Obtained model for VES4 of Kongoti

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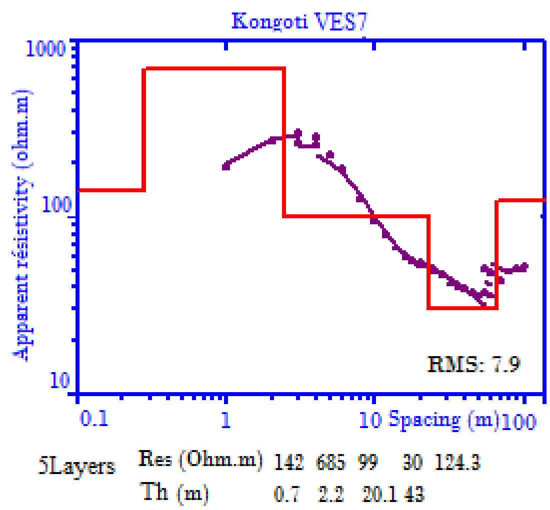

Fig. 4b Obtained model for VES7 of Kongoti

Th tuted of VES1, VES3 and VES8, Fig. 5a. It displays a first ground of weak thickness (0.8 m maximum) corresponding to arable land under which, follow two clay-sandy horizons with a maximum thickness around the 60 m on some VES. The cracked substratum is at 25 m of depth for VES1.

The last type is only made of VES9 perfomed next to a former drilling debiting 11.3 m3/h. This VES is composed of three (3) horizons. Differently to the previous type, this one contains a second resisting level (2662 Ω.m) corresponding to a nasty dried level and clayey-sandy thick overcoming a horizon altered and cracked whose roof would be 41 m depth, Fig. 5b.

The aim of this study is to fulfill a need in water of the said location, three drilling points have been chosen. These choices depend on the combination of geomorphological, hydrogeological and geophysical parameters.

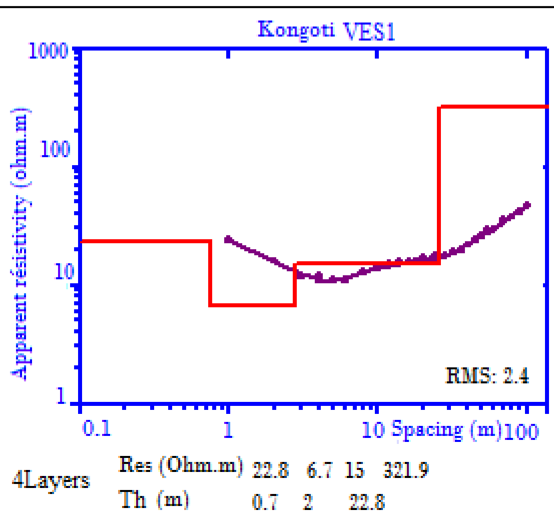

Fig. 5a Obtained model for VES1 of Kongoti

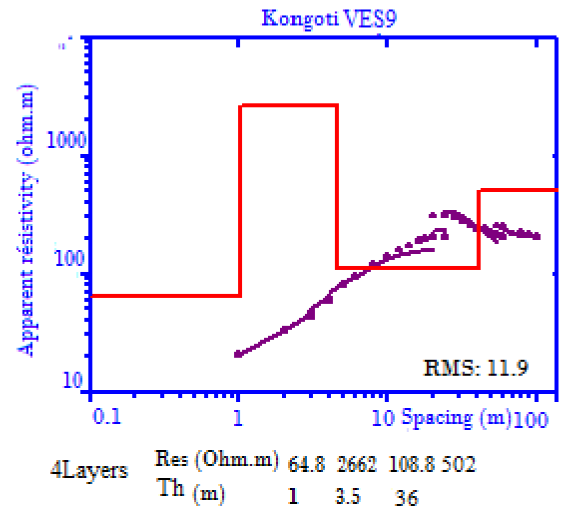

Fig. 5b Obtained model for VES9 of Kongoti

- **Implantation point A**

The profiles resulting from the electric trail have revealed various structures, including a fracture substantially oriented N145 ° on the anomaly "V". The facturation clue (IF = 1.7) is the highest of the study location. This anomaly is situated in the convergence location of the hydrographic network and underlined by very condensed vegetation. All these factors are indicators of the presence of groundwater. VES7 carried out on this anomaly, presents a great alteration thickness (63 m) and a weak level of resistivity (124 Ω.m) located at 66 m of depth corresponding to the fissured horizon, Fig. 6.

- **Implantation point B**

L4-0+00 profile helped to identify a fracture of direction N135° on the anomaly "U" which is located in an area dotted with veins of quartz oriented N110° and N60°. In addition, there are in this area an abandoned drilling of 11.3 m^3/h. The perfomed VES9 upon this anomaly shows up a thick level on the re-climbing up indicating a large complex conductive. This type of VES presents factures in the contact base-saprolite Fig.7.

ISSN 2229-5518

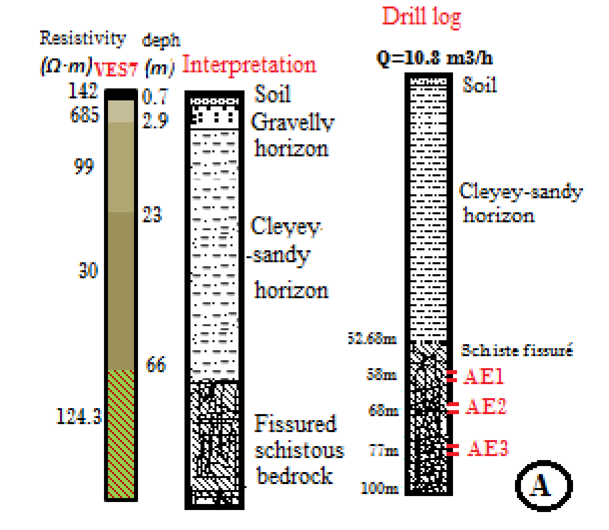

Fig. 6 Interpretation VES7 (A) of Kongoti and drill log

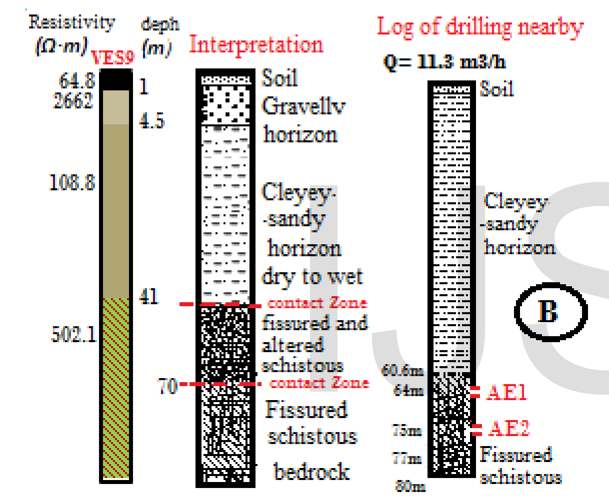

Fig. 7 Interpretation VES9 (B) of Kongoti and drill log

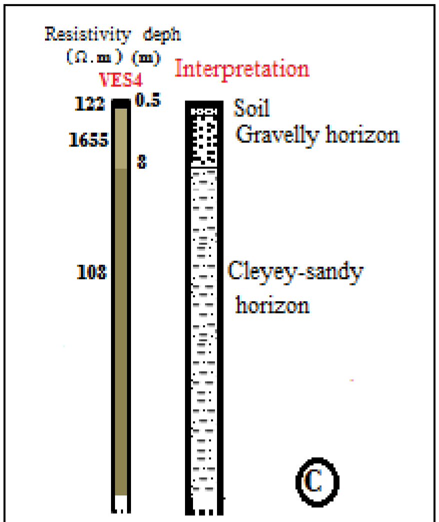

Fig. 8 Interpretation VES4 (C) of Kongoti

- **Implantation point C**

At Kongoti, the third point choice following the order of realization drilling has been based on the anomaly "K", of facturation clue 0.4, identified by the profiling located half slope. It has shown up a fracture of direction N50°, underlined by a lining up hydrophilic trees. The VES4, performed at this place displays a great alteration thickness whose the wall is unknown on the type of got curve, Fig.8.

The realized drilling on the point A has given water arrivals at 58, 68 and 77 m with a rate of 10.8 m^3/h. The alteration thickness is 52. 68 m.

5 Discussion

The choice of a productive fracture is function of its lengthening direction, of its length, of its width, of its inter-connection. With other fractures and by the presence of veins, dykes etc [6]. Indeed, the lengthened fractures following the structural direction are generally shut. These are often long fractures and entering. Parallel fractures to the compelling direction (perpendicular to previous ones) are generally short, entering and widely open [7], [8]. In addition, opening of a fracture is function of the size of the stitch. In the study area, electrical profiling allowed to discover several fractures of orientation N50°, N135° and N145°. VES conducted on these are clues of horizontal fracturing presences [4], [9], [10], [11], [12], [13 such as the trailing ascent (VES7) the strong thickness of complex conductive (VES4) and the change of inflexion on the final ascent (VES9). The intensity of fracturation is expressed by the parameter clue of fracturation for, according to Dieng [5], it informs about the degree of fracture of a rock and it is dominating when its value is over two. The productivity of a work is function of power draining of the main fracture induced by the drilling. One has to choose the fracture or the split system able to drain the greatest volume ground. It is at that time that, the geomorphological potential (depressions, sides and marshes, vegetation linings, flowing areas) coupled at the facturation is so important and has directed our site choices to drill. The perfomed drilling on the first choice (point A) with a flow rate of 10.8 m^3/h emphasize this thesis. The results show that the N145 ° fracture is hydraulically active.

6 Conclusion

The use of geomorphology combined to the resistivity method (electrical profiling and vertical electrical sounding) in the search and prospecting of groundwater in kongoti's location has permitted to know with a good precision the accurate position of conductive anomalies and several fractures oriented around the directions N50°, N130°, N145°. In addition, it has enabled an estimation of the thickness of the saprolites and the location of the altered levels and cracked in bedrock following implantation of a drilling of hourly flow 10.8 m^3. Geophysics, more precisely electrical resistivity methods constitute a very efficient method to carry out hydrogeological studies in order to locate and characterize aquifers from base.

ACKNOWLEDGMENT

Authors would like to thank National office of drinkable water of Cote d'Ivoire and GEOEXPERTISE, without them this study would not take place. They also thank all the anonymous instructors for their remarks and criticisms which made it possible to improve this present article.

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