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Research Article

CONTRIBUTION OF REMOTE SENSING AND ELECTRICAL RESISTIVITY TO IDENTIFY FISSURED AQUIFERS OF BASEMENT AREA AT KONG LOCALITY (NORTH-EASTERN OF CÔTE D'IVOIRE)

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ABSTRACT

This present study aims to improve supply of drinking water for people living at Kong inside semi-arid area. Methodology approach used for this study consisted to mix remote sensing and electrical resistivity methods to identify opened fissures those contained great groundwater quantity. Treatment of satellite images through remote sensing led to obtain lineament map which served as a searching guideline for developing geophysical activities such as two-dimensional electrical resistivity imaging techniques. According lineament map, major fractures occurred following three families principals directions: N130-140, N50-60 and N30-40. Investigations about electrical resistivity operations allowed identifying hydraulically fracturing directions: N30°, N55°, N110°, N120°, N140° and N170°. Following fracture N140° direction drilling characterized with fracturing index reached to 2.59 and 3 meters of weathered materials thickness. This drilling delivered groundwater air-lift yield up to 20 m3/h at depth 70, 102 and 110 meters. Drinking water supply improved by drillings established on fractures identified through synthesis of remote sensing and geophysical approaches.

INTRODUCTION

Groundwater is one of natural resource used for satisfying human drinking water needs. The locality of Kong, which is the subject of this study, particularly characterized with difficult accessibility to groundwater resources; based on little drillings and boreholes not delivering yield superior of 10 m3/h at this area. Indeed, it is fundamental for groundwater searching at crystalline basement areas to exactly know that groundwater moves through fractures and fissures created by weathering of rock, by the tectonic movement of rock masses, or-in the case of the chemical sedimentary rocks—by dissolution of rock minerals (CIEH, 1979, Lasm 2000, Youan Ta *et al*, 2008, Yao *et al,* 2012; De Lasme*et al*, 2012). This work aims to increase the drinking water supply at Kong locality through exactly positioning drillings on cross of opening fractures or fissures. For joining this specific objective, it seems necessary to combine using of remote sensing and geo-electrical resistivity methods. These approaches were considered reliable for mapping and identifying fractures. Electrical approach completes treatment of satellite image for localizing better position of tectonic discontinuity and areas with hydrogeological interests.

MATERIALS AND METHODS

Study location

The study area is located in the North-eastern part of Côte d'Ivoire territory, near the national parcComoé, and falls within latitudes 9°4'-9°12'N and longitude 4°33'- 4°40' W (see Fig 1). The vegetation can be described as a savannah area dominated by bush and relative taller trees. This locality is drained by principal river Comoe and its affluents where Gbene stream. The relief is built by dissected sloping area with heights not exceed 300 meters (Géomines, 1982). Annual rainfalls varied from 800 to 1500 meters during last three decades (Lasm*et al*., 2012). The basement of study area consists of crystalline rocks such as granodiorite for igneous family rocks and migmatites for metamorphic family rocks. Borders of geological units highlighted NNE-SSW as a

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structural direction and WNW-ESE as an orientation for major fractures. The occurence of groundwater aquifer is based on degree of weathering and/or fracturing system with discontinuous areas. Indeed, groundwater storage can be reality if tectonic events occurred rocks after their genesis.

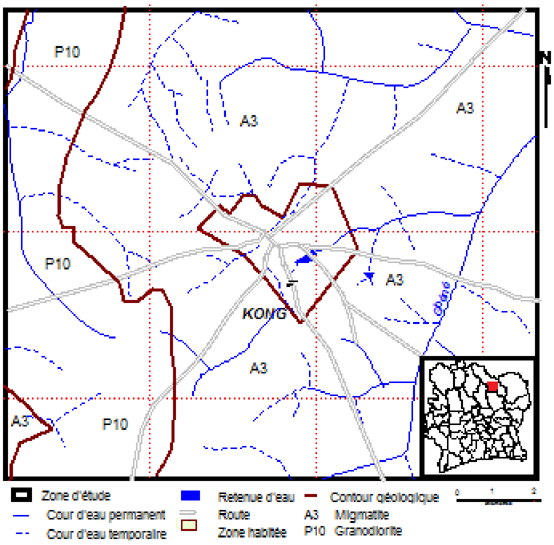

Figure 1 Geographical and geological settings map of Kong

Materials

In this study, topographical and geological maps with the same scale (1 : 200 000) were used for positioning many structural objects. In addition, digitally enhanced products of satellite Landsat-7 ETM+ image downloaded in January 2002 were required. Also, Electrical resistivity data were acquired through geophysical investigations at Kong locality from January to February 2014. The field measurements of resistivity profiles were made by using Resistivity-meter SYSCAL JUNIOR with its accessories elements such as multi-Electrodes system and Global Positioning System. The treatment of database required specific softwares such as Mapinfo Professional version 7.5 for mapping activities, ENVI version 4.1 for remote sensing, GEOrient version 9.5.1 for statistically defining of lineaments orientations, and IXID version 2 for geophysical data analyzing.

Methodology

Remote sensing and geophysical (electrical resistivity) techniques are considered rapid in the field of groundwater exploration because they precisely contribute to determine thickness of weathering zones, the faults and structural anomalies those are suitable areas for groundwater aquifer occurrence. Exploring investigation resumes two principal steps: mapping of lineaments to select potential areas confirmed by geomorphologic observation, and occurring of electrical resistivity methods at selected potential areas to choose drilling points.

Mapping of lineaments through remote sensing method

This method consisted to apply enhancement techniques such as Principal Component Analysis and directional filter (SOBEL 7X7) for distinguishing lineaments in satellite image. Lineaments were manually extracted and validated after removing other rectilinear objects such as roads and electrical lines.

Geoelectrical resistivity method

Electrical resistivity is one of preliminary method used to determine the electrical resistivity of geological layers and its results allow investigations with other geo-electrical methods. Electrical resistivity profiles allow lateral investigation that can help to localize, detect and validate lineaments or shallow fractures and discontinuous geological features. These anomalies zones graphically were revealed by downfall of electrical resistivity values indicating suitable groundwater storage areas. Morphology of downfall is fundamental for positioning of electrical soundings points and drillings at basement areas (Dienget *al,* 2004; Kouakouet *al,* 2015). Electrical resistivity data highlighted interface of fracture and weathered material with presumed depths. Then, drillers can know the expected digging depth where groundwater can meet. For this research, six (6) sites were studied due to previous exploring findings, drainage network and crossing of lineaments. At these sites, ten (10) profiles of horizontal electrical resistivity with various directions and seventeen (19) vertical geoelectrical soundings were used to get quantitative data about depth resistivity variations at different points. Horizontal electrical resistivity readings of the area surveyed are collected through a Schlumberger disposal that injects direct current through two current producing electrodes (AB =200m) and measures the difference in voltage received by two potential electrode pairs (MN=20m). Vertical geoelectrical soundings also were performed by applying Schlumberger electrodes array with a maximum length line reached 200m. Measurements were taken with a Syscal (V11.4) IRIS instrument and the inversion was performed using IPI2WIN software (Bobachevet *al,* 2011). Particularly, Index of Fracturing (IF) was manually calculated by equation below (Dienget *al,* 2014):

$$IF = \frac{\frac{H}{L}*100}{\rho_{aMin}} \quad ; H = (\rho_a Max)h - \rho_a Min \qquad (1)$$

where: ρa Max : maximum apparent resistivity; H : harmonic amplitude ; L : anomaly width

Due to objective of this study which is to satisfy the drinking water needs of the people living at Kong locality, several criteria oriented our choice for positioning of drillings. These criteria were: the convergence of drainage network, existence of thalwegs, alignment of hydrophilic trees, proximity of fractures determined by geophysical investigations and Fracturing Index value.

RESULTS

Lineaments analysis

The treatment of digitally enhanced products of satellite image allowed mapping many lineaments with various directions and sizes. The circular histogram of these lineaments highlighted an heterogeneous statistical distribution (Fig 2). Many lineaments oriented directions below: N130-140 (14,6%), N50-60 (12,4%) N30-40, (12,4%) and N140-150 (10,1%). It can also distinguished little lineaments with directions N20-30 (7,8%)

and N40-50 (7,8%). This statistical distribution of lineaments directions served as basis of geophysical investigations realized on the ground of study area.

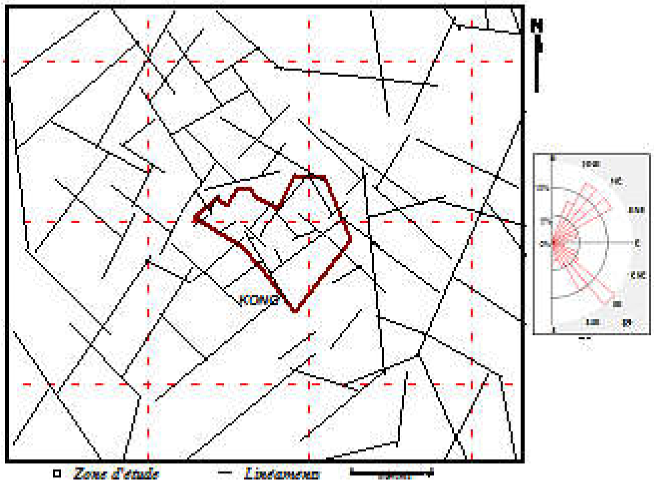

Figure 2 Map of lineaments with associated circular histogram at Kong locality

Analysis and interpretation of electrical resistivity data

Geophysical investigations concerned six (6) favourable sites where electrical resistivity data were acquired (Fig 3).

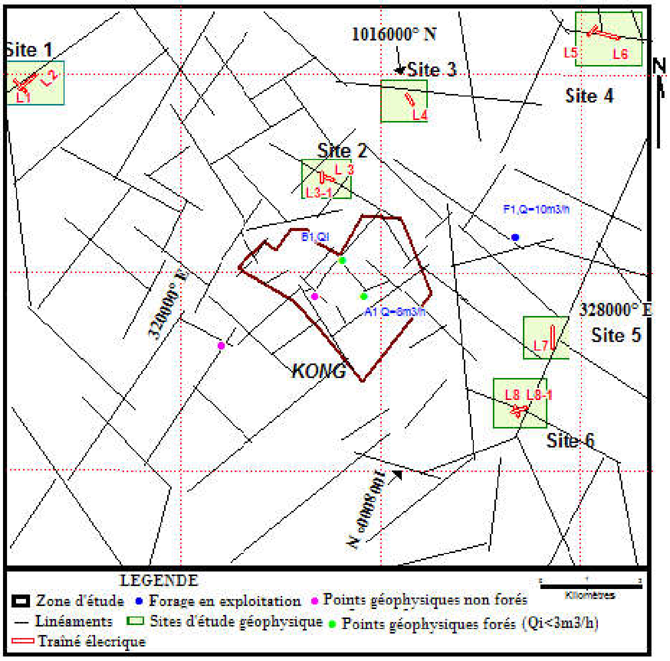

Figure 3 Localization of prospected sites

Site1: proximity of river Lakpohô (at 6 km distance of road Kong-N'golodougou)

At this site, apparent resistivity values vary from 456 to 2263 Ohm.m. They allowed profiles showing many discontinuous with various directions, morphologic images, widths (L), amplitudes (A) and Fracturing Index (IF) values (see Fig 4 and Table 1). Experiment anomalies highlighted shorter width (L<40 m) to medium ones (40m < L ≤ 80m) and high amplitudes (A > 524Ω.m) with good fracturing index value (IF>1.7).The profile L1-0+00 highlighted morphologic anomaly "K " which corresponds to geological contact of conducting element that can be existence proof of lineament with direction N55° confirmed by thalweg there. The profile L2-0+00 highlighted various morphologic picture anomalies (H, W and K) and value of Fracturing Index up to 1.5. That value reflects great opening level of ground which is suitable for groundwater infiltration and flowing.

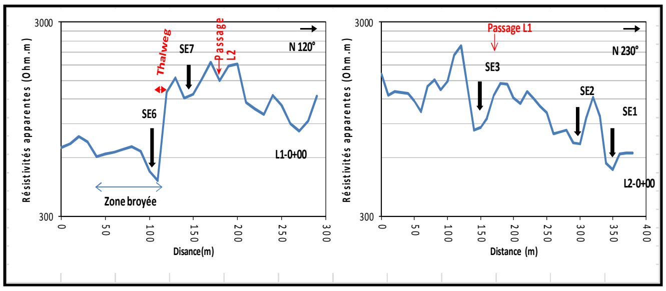

Figure 4 Electrical profiles at site 1

Table 1 Characteristics of graphical anomalies at site 1

Localité	Traîné électrique						Sondages électriques
	Identification	Direction de fracture (°)	Anomalie: Largeur (m)	Forme (m)	Amplitude (Ω.m)	IF (%)	
KONG SITE1	L1-0+00	N 55°	30	K	845	5,32	SE6
			40	U	657	3,07	SE7
	L2-0+00	N 140°	60	H	1432	2,59	SE3
			70	W	524	1,79	SE2
			40	K	713	7,77	SE1

Vertical electrical soundings occurred at site 1 gave morphological anomaly like to alphabetical letter ‘’ H’’. This kind of morphology image characterized a curve of three (3) different geological structures: the superficial covered layer such as lateritic carapace with a little thickness (1 m), characterized by resistivity between 503 and 1127 Ω.m, followed by layer of clay and sand mixed with resistivity value varying from 18 to 63 Ω.m, thickness reached 8m and overcoming fresh fissured bedrock (ρ > 1200 Ω.m) (Fig 5).

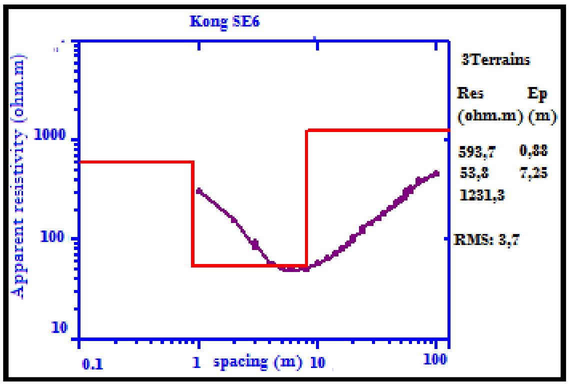

Figure 5 Curve of electrical soundings showing morphologic anomaly ‘’ H’’

It was distinguished on other soundings curves (SE2 and SE3) more than three geological layers due to intermediate resistivity layer located between conducting weathered materials and not fissured fresh bedrock with thickness reached 64m at SE2 (Fig 6). That additional layer can be considered as the fissured layer researched by prospectors.

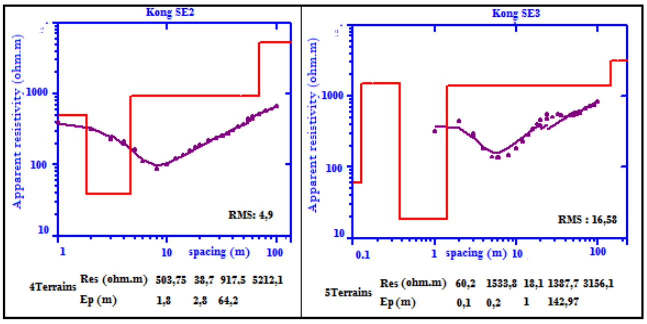

Figure 6 Curves of vertical soundings SE2 and SE3

Site 3: Proximity of hostelry of Kong** (at 4km from the road)* ***and site 5: River N'gbinnin

Electrical resistivity values of site 3 and site 5 respectively varied from 328 to 853 Ohm.m and from 309 to 504 Ohm.m (Fig 7). Profile L4-0+00 is the layout of site 3 that highlighted anomaly likely alphabetical letters "W" and "K". Anomaly "W" indicated great depth (100 m) with mean amplitude and fracturing index reached 1,5. Anomaly "K" reflects two geological conducting structures at neighbourhood. That contact obviously materialized by moisture zone testifying existence of lineament oriented N110°. This anomaly characterized by large amplitude, fair thickness and quite fracturing index (IF > 1.5) (Table 2).

Profile L7-0+00 of site 5 highlighted three types of anomalies likely "W", "H" and "U". Their characteristics indicated quite fracturing index, tolerable to high depth, but only short amplitude for anomaly "H". Anomaly ''W' corresponds to lineament with direction N140° identified by shear or crushed zone.

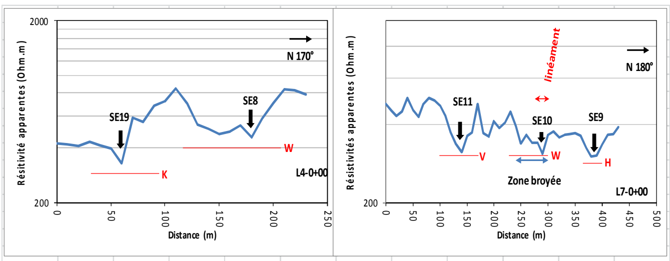

Figure 7 Electrical profiles of site 3 and 5

Table 2 Characteristics of anomalies at sites 3 and 5

Localité	Traîné électrique						Sondages électriques
	Identification	Direction de fracture (°)	Anomalie				
			Largeur (m)	Forme (m)	Amplitude (Ω.m)	IF (%)	
KONG SITE2	L4-0+00	N110°	70	K	525	2.47	SE19
			100	W	383	1,33	SE8
KONG SITE5	L7-0+00		100	V	192	2.53	SE11
		N140°	70	W	138	1,67	SE10
			40	H	63	3,37	SE9

Vertical electrical soundings occurred at anomalies of these sites were similar to those realized at site 2 (behind residence of local deputy) with same values of real resistivity. Depth of bedrock was estimated to 10 m at site 3 and 22 m at site 5 (Fig 8).

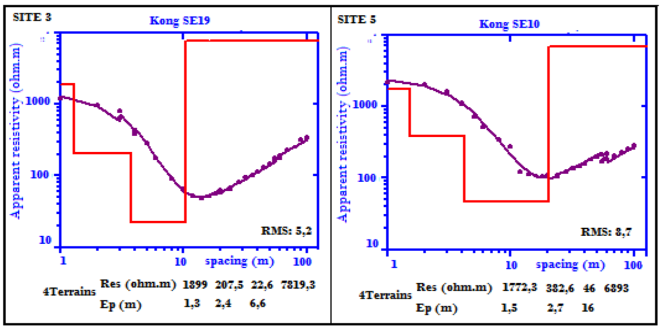

Figure 8 Curves of soundings SE19 and SE10

Site 4: near River Kotokouho*(5 km of road Kong-Manogota)*
On this site, apparent resistivity values are ranged into interval 502 to 5056 Ohm.m. The profile L5-0+00 evidenced one shattered fault zone with a thalweg direction N120°on the soil. That fault zone is characterized by anomalie describing alphabetical letter "W" with smal fracturing index (see Fig 9 and Table 3).

The profile L6-0+00 evidenced various anomalies forms (V, H and U) with great amplitude (> 500) and fracturing index up to 1. T

he lineament with direction N170° was identified through horizontal sounding by high contrasted anomaly with conducting structure and resistivity on distance axis from 220 to 270 m.

Soundings realized at this site showed three different morphological aspects. The sounding SE14 seems alphabetical letter "A'' (ρ1 < ρ2 < ρ3). It is identified by superficial layer with low resistivity (287 Ω.m) on 6 meters thickness, followed by intermediate resistivity (752 Ω.m) on small layer (0,2 m), and the last level is fissured basement (Figure 12). The soundings SE12, SE13, SE15, SE16 and SE17 gave double alphabetical letter "QH'' (ρ1 > ρ2 > ρ3 < ρ4) as occured on sites 2 and 3. Particularly, SE13, SE15 and SE17 showed a sudden variation of conducting structure which evidenced fractured zones with active fault (Fig 10).

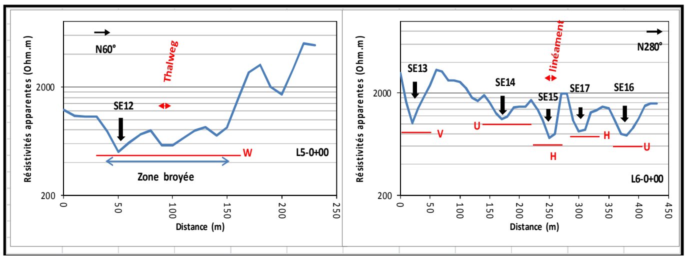

Figure 9 Electrical profiles at site 4

Table 3 Characteristics of electrical anomalies at site 4

Localité	Traîné électrique						Sondages électriques
	Identification	Direction de fracture (°)	Anomalie				
			Largeur (m)	Forme (m)	Amplitude (Ω	IF (%)	
KONG SITE 4	L5-0+00	N120°	130	W	1058	1,33	SE12
	L6-0+00		60	V	2391	1,6	SE13
			80	U	603	1,65	SE14
		N170°	50	H	1239	3,5	SE15
			60	U	1121	2,5	SE17
			60	U	731	2,35	SE16

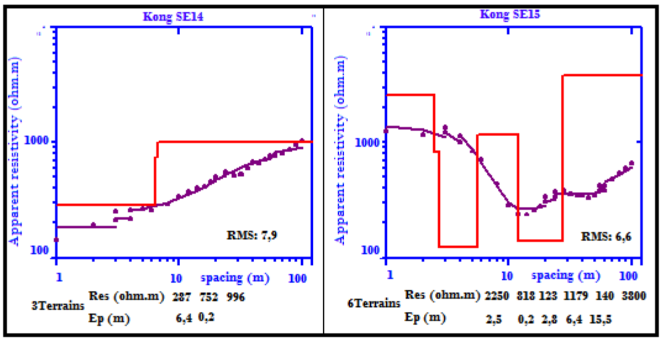

Figure 10 Curves of soundings SE14 and SE15

Site 6: at 3 km behind the local residence of republic President (on river N'gbinnin)

At the site 6, apparent resistivity values ranged 191 to 372 Ohm.m. The lineament with direction N30° was identified on the profile L8-0+00 through shattered fault zone characterized by anomaly seeming alphabetical letter "W" with depth reached 70m, and low fracturing index (Fig 11). The sounding SE18, realized at this anomaly seems alphabetical letters QH ($\rho_1 > \rho_2 > \rho_3 < \rho_4$). It highlights at its ending part of recovery a changed inflection indicating existence of low resistant fissured layer (200 Ω.m) at depth reached 33 meters. That kind of layer is the searched zone for prospectors (Fig 12).

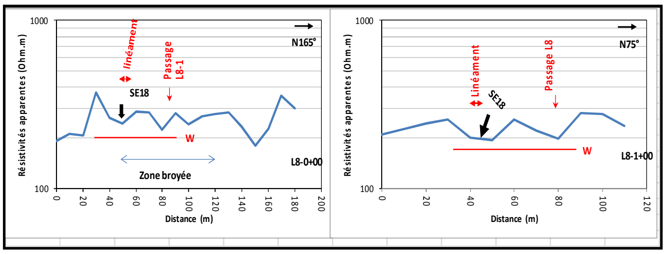

Figure 11 Electrical profiles at site 6

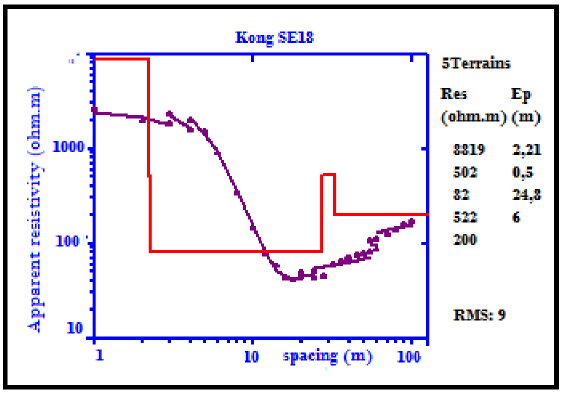

Figure 12 Curve of sounding SE18

Choice of drilling points to establish

According electrical resistivity values, four drilling points can be established in studied area:

Point A (Site 4)

Electrical profile testifies existence of lineament at direction N170° which is upholded by a thalweg and anomaly seeming letter "H". Here, highly fracturing index value (3.5) indicates a great aperture level of fracture which is favourable for groundwater flowing. Consequently, fractures can deliver great yield of groundwater due to its location with thalweg at convergence of hydrography network. Curve of vertical sounding (SE15) realized on fracture direction N170° presented an abrupt growth of weathered material thickness; that is a proof of real existence of fissured layer at downstairs (Fig 13). To corroborate this choice, the lowest value of apparent resistivity is obtained there, another testimony of intense fracturing occurred at the depth.

Point B (Site 1)

Electrical profile gave opportunity to identify secondary fracture (N140°) crossing the superstructure with direction N55° where the river Lakpohô is flowing. Then, the river can be connected that fracture. Anomaly "H" for that fracture is characterized by highly resistivity contrast and fracturing index reached 2.53, creating a good aperture. Sounding SE3 produced intermediate level of resistivity between conducting weathered materials and resistant fresh bedrock. That is the fissured layer searched (Fig 14).

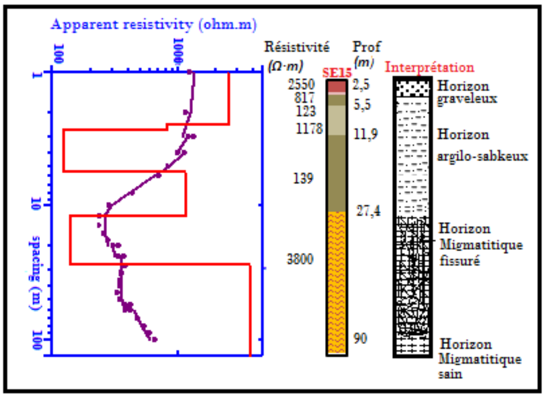

Figure 13 *Sounding model SE15 (A)*

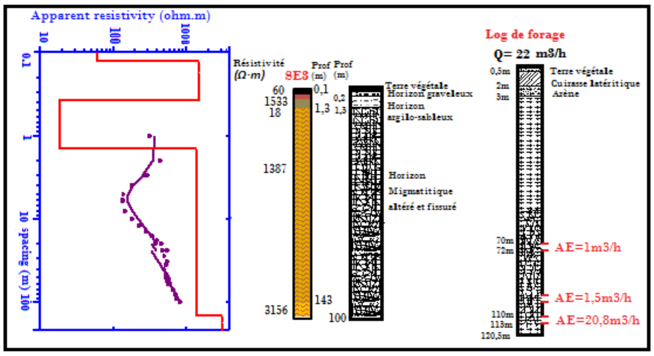

Figure 14 *Sounding model SE13 (B) and lithologic layers*

Point C (Site 5)

This proposal drilling point is located at convergence zone of hydrography network characterized by alignment of trees liking water on direction N140°. This position is suitable for getting great water yields. Electrical survey highlighted lineament N140° and anomaly like alphabetical letter "W" with fracturing index value 1.67. The curve of electrical sounding S10 anomaly revealed weathered materials estimated to 20 meters and slope value inferior to 45° for ending that indicates probably presence of fissured layer (Fig15).

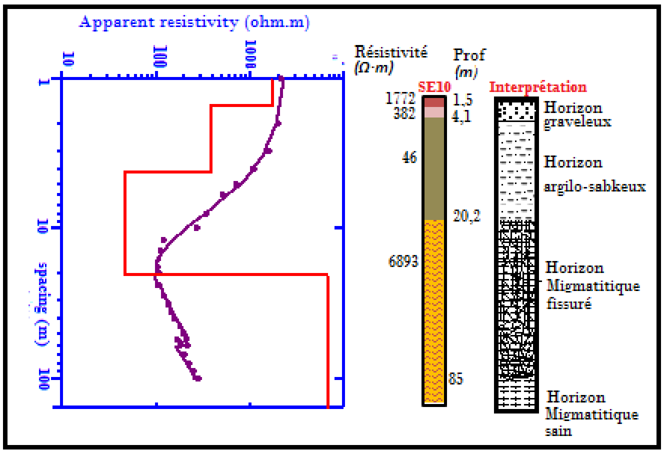

Figure 15 Sounding model SE10 (C)

DISCUSSION

According recommendations of African Council for hydraulics Studies (CIEH, 1979), all drilling in basement area must establish on the opened fracture that is a principal collector of fissures networks from upstair weathered materials. Then, using of remote sensing technics is essential for groundwater searching (Savané*et al,* 1999, Jourda*et al,* 2006, Youan Ta *et al,* 2014,). Remote sensing (RS) through the delineation of lineaments is useful and rapid tool in hard rock hydrogeology as it can identify rock fractures that localize groundwater (Das, 1990). At Kong locality, mapping of lineaments detected from satellite images ETM+ Landsat 7 showed a coincidence with many hydraulical structures following directions NE and SE. Analyzis of geological surface elements at outcrop (aperture of opened fractures, fracturing density) and results of geophysical investigations at selected areas of lineament map revealed that many of identified structures of satellite images corresponded to real geological accident occurred basement of Kong locality. So, field survey is necessary and complementary with remote sensing for getting the best using and interpretation of lineament maps. Conjunction of electrical profile and vertical soundings led to confirm and characterize many fractures according depth, direction and fracturing index value. Dieng*et al*. (2004) recommended that fracturing index value upper than 2 indicates a great fracturing occurrence. Works of previous authors (Same, 1999; Koussoubé, 2003; Kouakou*et al*, 2015) corroborate some findings of this study such as existence of horizontal fractures, inflection changing at recovery ending part , aberrant growth of conducting superstructure.

Some works of authors (Courtois*et al,* 2009 ; Koita, 2010 ; Kouakou, 2012 ; Lasm*et al,* 2012 ; De Lasme, 2013 ; Assemian*et al,* 2015) revealed that number and yield of water arrivals decreased, under the hydraulical productive layer depth , due to progressively locking of fractures by lithostatic charge. However, in this study, drilling at Kong delivered great yield at depth superior than 100 meters. This reality is not abnormal but it can be explain by the objective of hydraulic program and its investigation material and methods (Kouadio*et al,* 2010).

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CONCLUSION

Using of remote sensing evidenced many oriented structures in direction NE (N30-40° et N50-60°) and SE (N130-140, N140-150°). Geophysical investigation through field study exactly led to localize and characterize those structures (lineaments). Many fractures and various directions (N30°, N55° N110, N120°, N140, et N170°) were identified. Conjunction of geophysical investigation results (thickness of weathered materials, depth of fissured layer, fracturing index) with favourable morphological aspects (slope, thalweg) helped to select three sites for drilling. One of them delivered a great water yield (22 m3/h). Then, for future searching of groundwater in basement areas, combining of remote sensing with geophysical field survey can be highly recommend to find successfully fissured layer aquifers.

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