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# Contribution Of Landsat 7 Etm + Satellite Images And Electrical Methods To The Structural Mapping Of The Aquifer System Of Agnibilekrou Department (East Of Cote D'ivoire)

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***Abstract:****This study aims to improve knowledge of fractured aquifers in the bedrock formations in the Agnibilékrou department (East Côte d'Ivoire). Its main objective is to map the network of fractures in crystalline and metamorphic rocks using an approach integrating remote sensing and geophysics.*
*The processing of Landsat 7 ETM + satellite images made it possible to highlight the lineaments network. The rosettes produced show five (5) predominant directional classes of lineaments which are in order of abundance NW-SE (N120-N150), NS (N0-N10), NE-SW (N40-N60), NNW-SSE (N150 -N180) and NNE-SSW (N10-N40). These directions were confirmed by geophysical work carried out on three sites (3) chosen in the study area. The resistivity and chargeability maps established made it possible to identify certain minor directions on a regional scale. This is the case of the E-W direction (N80-N100) observed in Mossikro and N'guessankro. The fracturing density map produced showed a spatial variability of the fractures. The positioning of certain holes already drilled on the fractures testifies to the presence of groundwater. These fractures could therefore constitute interesting aquifers for the supply of drinking water to populations.*

***Key Word****:Landsat 7 ETM + images; electrical methods; fractures; aquifer; Agnibilékrou*

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## I. Introduction

As a natural resource essential for the good functioning of living beings, water continues to be at the central development policies. Less vulnerable to various types of pollution, groundwater is the main source of drinking water for the Ivorian population. They have the advantage of being sheltered from seasonal fluctuations[1,2,3,4]. However, problems with the supply of drinking water to certain localities, notably those of the Agnibilékrou department, have been noted. ILO social services mapping has shown that some primary schools like Kongodja and Damé do not have potable water. In search of water for their families, some pupils return very late for afternoon lessons or never return. Faced with this deplorable situation, the sustainable supply of drinking water to the populations necessarily requires better knowledge of the fractured aquifers of Agnibilékrou department. The complexity of water flows in geological terrain in fractured environments has favored a combination of appropriate prospecting techniques, thereby helping to improve the success rate of drilling[1,3,5,6,7]. The present study therefore aims to map the fracture network using the Landsat7 ETM + satellite images and electrical methods.

Located at 270 km from Abidjan, in the east of Côte d'Ivoire, between latitudes 6°46 and 7°22N and longitudes 3°04 and 3°40 W, the department of Agnibilékrou belongs to the region of Indénié-Djuablin (Figure 1).

Geological formations were structured during the Eburnian orogeny and are of Proterozoic age. Several works[8,9] have focused on the geology (petrography and tectonics) of this region. It turns out that tectonics is polyphase and has resulted in the establishment of many fractures of varying sizes ranging from a few meters to several kilometers. The formations in this area have been affected by a regional metamorphism. From a petrographic point of view, the granitoids estimated at 9% and the volcano-sedimentary formations composed of 80% schists and oriented NE-SW are the main geological formations encountered in the study area (Figure 2).

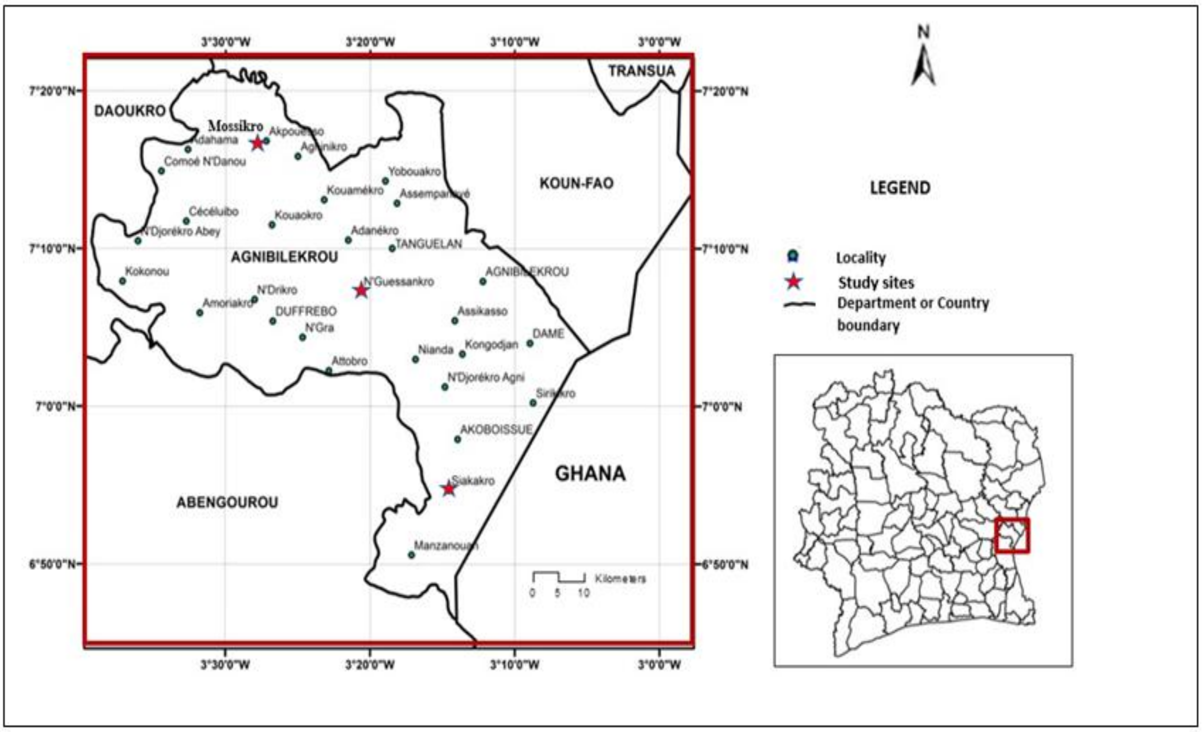


**Figure 1 :** location of the study area

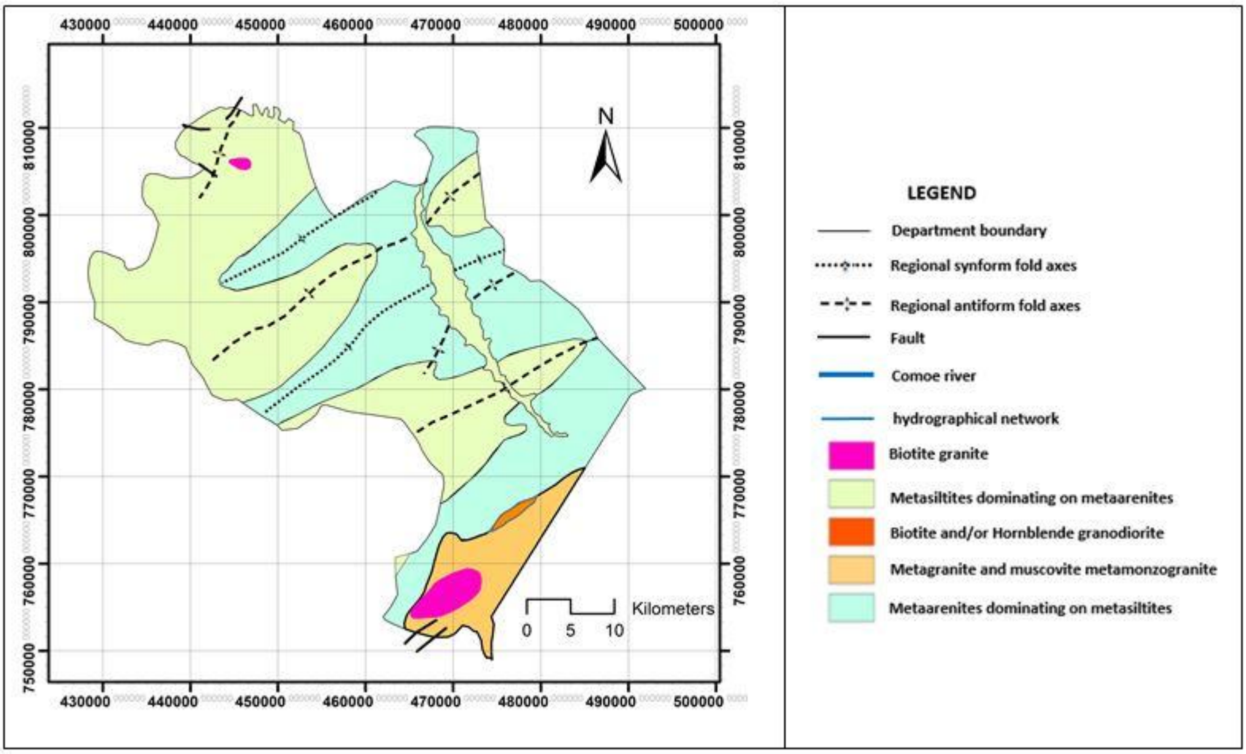


**Figure 2 :**geological map of Agnibilékrou department[9]

## II. Material And Methods

### 2-1 Satellite images

The LANDSAT ETM + 7 satellite images used come from the georeferenced scene 195-55. Their processing was done in different stages summarized in figure 3.

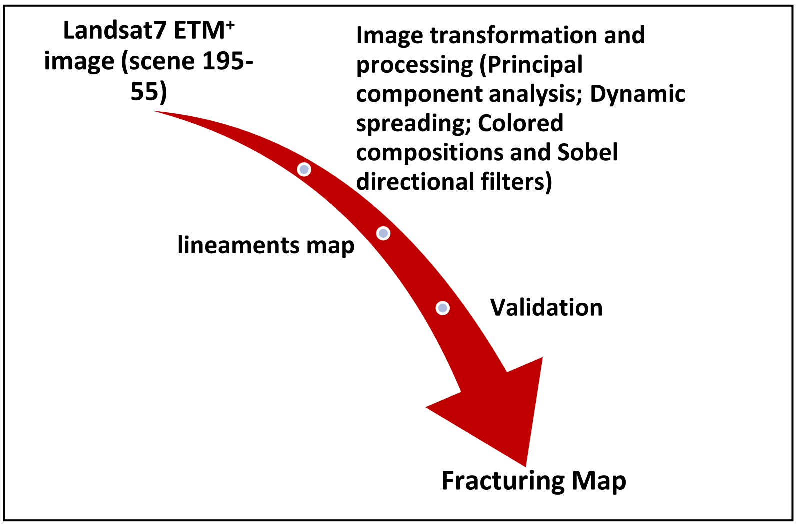


**Figure 3:**Landsat7 ETM + image processing techniques used in Agnibilékrou department

### 2-2 Electrical methods

### 2-2-1 Electric profiling

The electric profiling provides qualitative information on lateral variations in the electrical properties of the subsurface[10,11,12,13,14,15]. It allows to follow the lateral continuity of a layer and to highlight the areas of geological discontinuities. It consists in moving the ABMN quadrupole of fixed dimensions along a path parallel to itself. At each station, we measure the current intensity I, the potential difference ΔV and we determine the apparent resistivity (ρa) that we assign to the center O of the device. The measured values correspond to resistivity values over a constant depth of investigation.

In the field, the surveys were carried out on 3 different sites according to the fracturing density obtained from the lineaments map produced by remote sensing. These sites concern the localities of Siakakro, N'guessankro and Mossikro (Akpouesso). Eleven (11) parallel profiles of 1000 meters each were carried out on each site. The middle profile, 3000 meters long, was used for injecting electrical current at the ends. The current injection was carried out with the rectangular gradient device. The characteristics of this device are: AB / 2 = 1500 m and MN = 20 m. The data of electrical profiling was processed with Geosoft software in order to establish resistivity imaging .

### 2-2-2 Induced polarization

A continuous current was injected into the subsurface for a certain period of time and the potential difference was measured. Schlumberger (1930) showed that the potential does not return to zero instantaneously after the injection current is cut off, but it decreases rapidly until reaching a value V then it decreases almost exponentially over time. This decrease or relaxation is observed and recorded to calculate the apparent chargeability of subsurface.

Chargeability $M$ $(mV/V)$ is defined as the ratio between the secondary voltage $V_s(mV)$ measured after switching off the current at a time t and the primary voltage $V_p(V)$ measured just before the cutoff of the injected current :$M = \frac{1}{V_p}\int_{t_1}^{t_2} V_s(t).dt$

## III. Result

**3- Results and interpretation**

**3-1 Lineaments map of Agnibilékrou department**

Figure 4 shows the lineaments map obtained after the extraction of the different lineaments on the Landsat ETM + 7 images. The identified lineaments form a very dense network of different size and direction. The influence of several tectonic phenomena would be at the origin of the intense fragmentation of geological formations. This map of the lineaments network is not exhaustive, but it is very representative of the region studied.

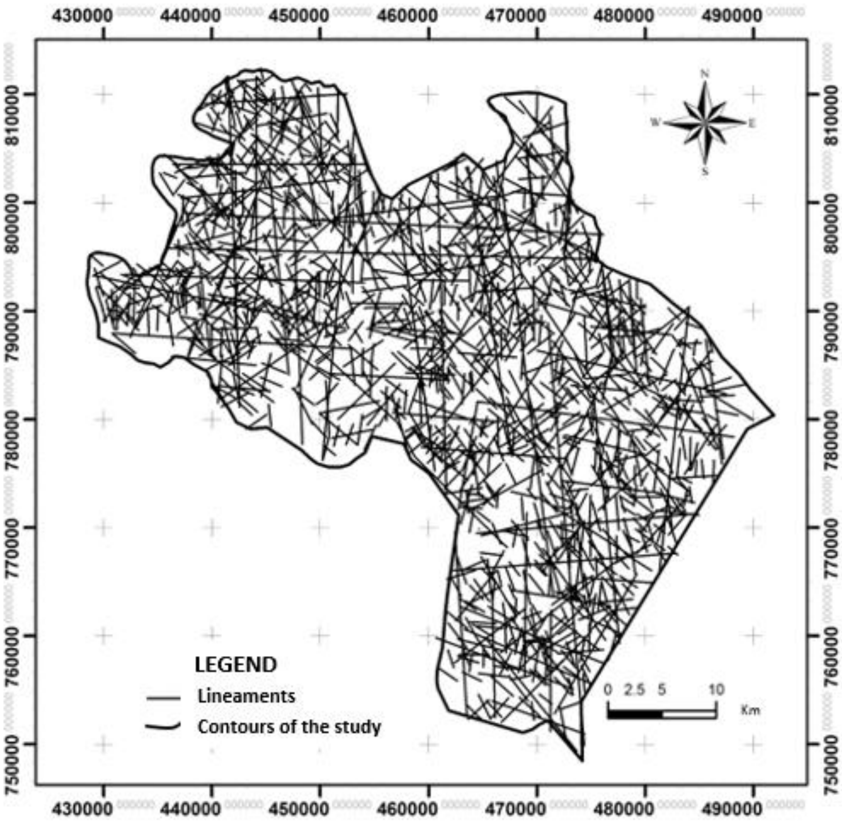


**Figure 4 :**lineaments network map of Agnibilékrou department

**3-2 Fractures identification by electrical methods**

The resistivity and induced polarization maps were performed on three (3) sites where a high density of fracturing was observed by remote sensing (Figure 1).

**A- Siakakro Site**

The apparent resistivity map (Figure 5) highlights elongated structures distributed in two (2) different resistivity domains. A resistant domain is located to the north, south and in the central part of the site studied. The conductive area occupies the eastern and western parts of the study area. The resistivities vary from 3143.8 to 10047.1 Ω.m.

The resistive domain has a resistivity which varies from 6595.3 to 10047.1 Ω.m while the relatively conductive domain is materialized by a variant resistivity between 3143.6 to 4294.2 Ω.m, this variation is translated by the colors yellow to magenta for resistant structures and blue for conductive structures. The green screen indicates the apparent resistivities of the intermediate formations.

The apparent chargeability map (Figure 6) highlights polarizable (loadable) structures. The chargeability values vary from 2.5 to 10.8 mV / V. These elongated structures are divided into three (3) NE-SW oriented polarizable corridors which alternate from the North West to the South East with the weakly polarizable corridors.

The low chargeability values are represented by the color blue on the induced polarization map. This weakly polarizable domain is materialized by two (2) elongated structures with low or intermediate resistivity corresponding to the sandy-clay formations.

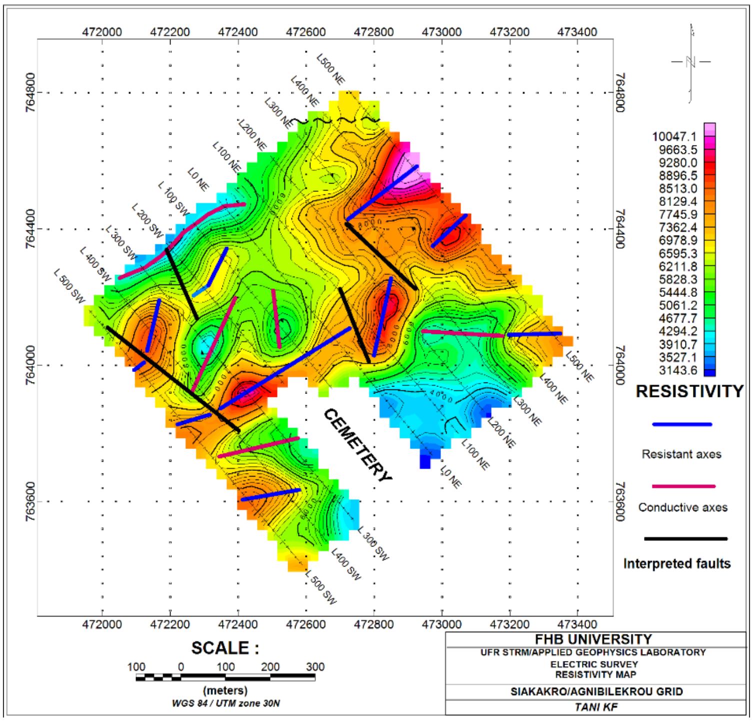


**Figure 5 :** apparent resistivity map of Siakakro site

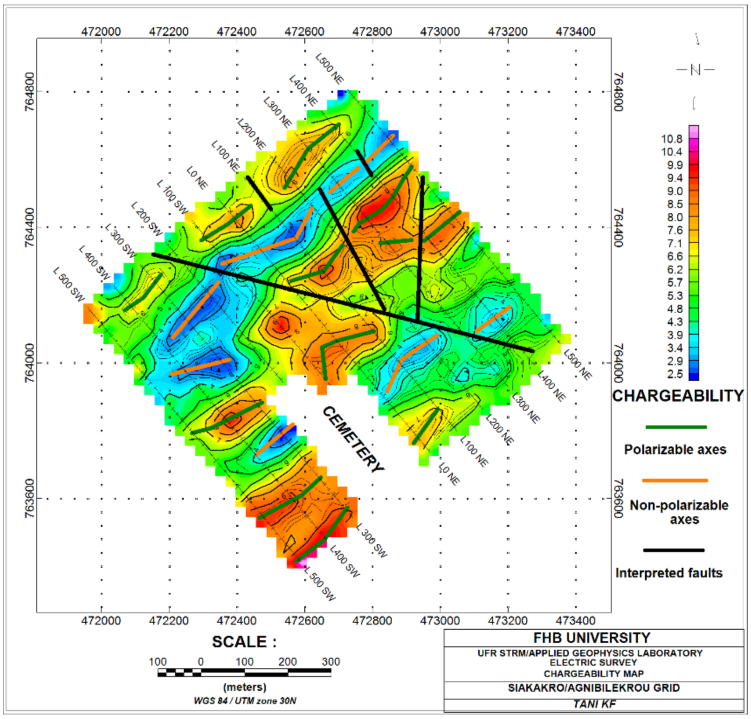


**Figure 6 :** chargeability map of Siakakro site

The high chargeability values are represented by the colors changing from yellow to magenta. This polarizable domain materialized by three (3) elongated structures occupies the Center, the North-West and the South-East of the site of Siakakro.

The PP anomaly located in the Center is the most important because it crosses all the profiles and has a pronounced width. With regular contours, this anomaly is affected by many distortions. It corresponds to a resistant zone on the resistivity map and could reflect the presence of metallic particles in metamonzogranites and muscovite metagranites.

The PP anomaly located to the northwest has a less pronounced width than that of the Center. It crosses all the profiles, fading in places. This is explained by the fact that it is affected by many distortions.

The PP anomaly located in the Southeast is as wide as that of the Center. However, it does not cross all the profiles, especially in the eastern part.

B- **N'Guessankro site**

On this site, the apparent resistivities vary from 916.7 to 3917.4 Ω.m while the chargeability values vary from 3.8 to 9.4 mV / V. (Figures 7 and 8). The resistivities are relatively low compared to those observed at the Siakakro site. These resistivities are due to the presence of the dominant metaarenites on metasiltites, the main geological formations encountered.

The high resistivities represented by the colors yellow to magenta correspond to the resistant formations while the low resistivities, represented by the blue color, correspond to the conductive formations. The resistivities of the intermediate formations are translated by the color green.

Resistant formations with high chargeability (6.9 to 9.3 mV / V) are very pronounced in the northeast and extend to the west. The resistant formation observed in the Northeast has a discontinuous axis. This testifies to the presence of fractures.

Two (2) conductive formations are observed at the N'guessankro site. The first, much expressive, is located in the Southeast and is oriented NE-SW. It generally has a low chargeability (3.8 to 5.4 mV / V).

Also elongated in the same direction, the second conductive structure is located to the northwest. It is less pronounced and seems to extend over the neighboring area not covered by this site. However, it has a high chargeability.

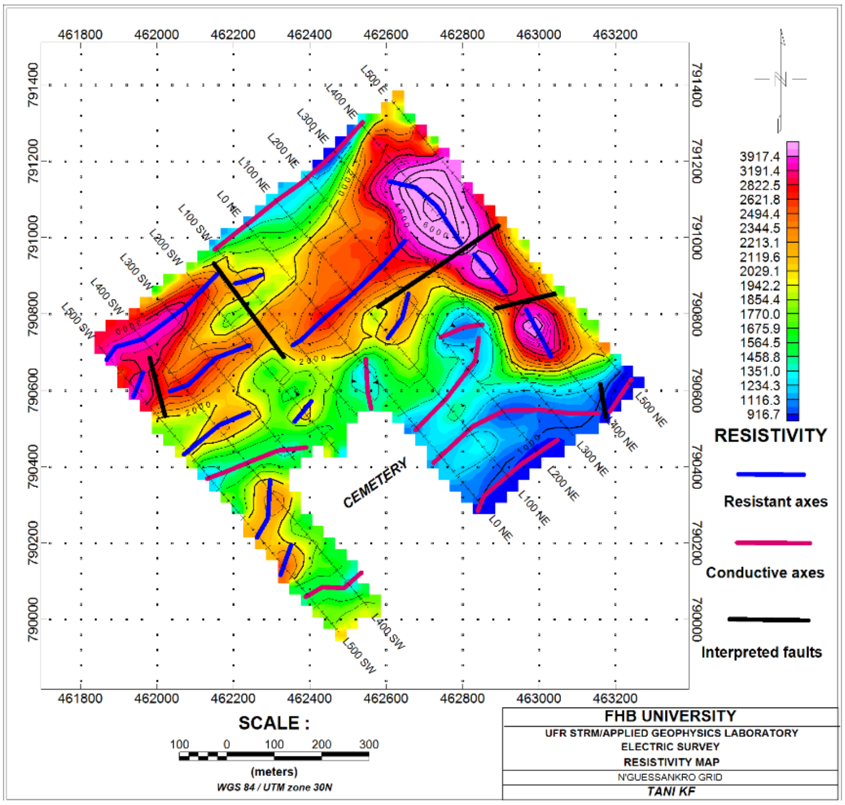


**Figure 7 :** apparent resistivity map of N'guessankro site

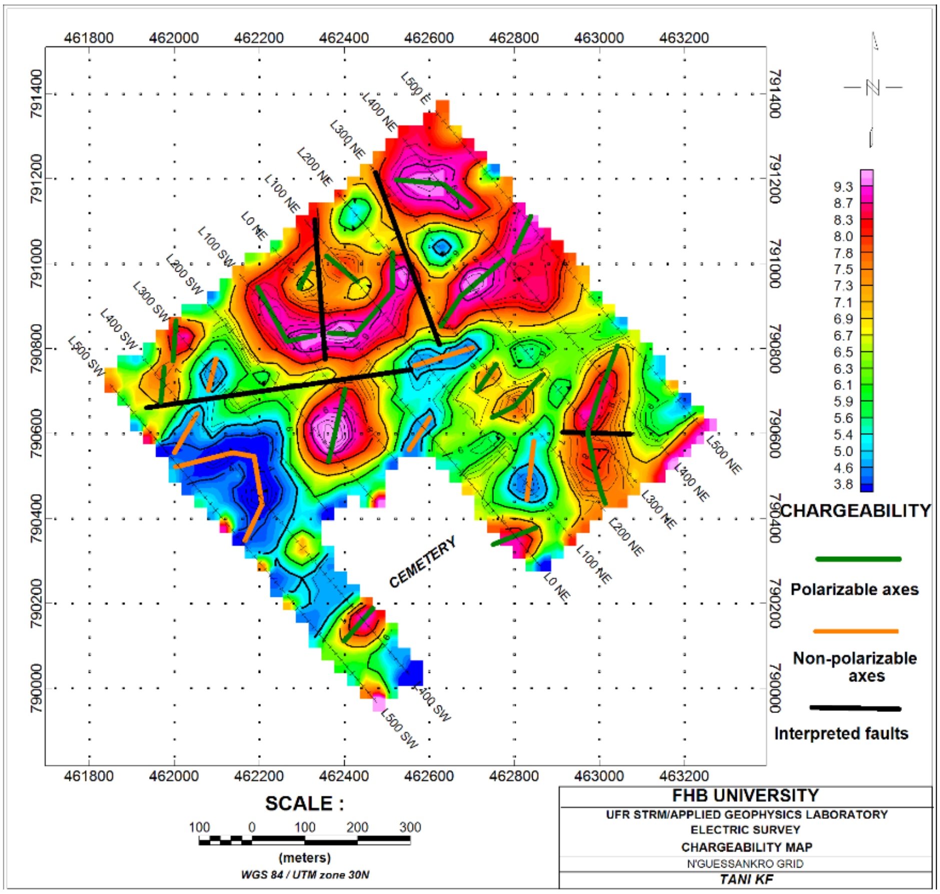

**Figure 8 :** chargeability map of N'guessankro site

**C- Site de Mossikro**

Depending on the apparent resistivity, three (3) categories of formations are observed on this study site (Figure 9).

The colors yellow to magenta express the presence of resistant formations while the color blue translates the presence of conductive formations.These two formations are separated by intermediate formations materialized by the color green. Compared to the apparent resistivities of the two (2) previous sites, the apparent resistivities of the Mossikro site (1274.3 to 4237.6 Ω.m) are substantially equal to those measured on the Nguessankro site (916.7 to 3917.4Ω .m). This result confirms the presence of shales in Mossikro as shown on the geological map.

Unlike previous sites, the chargeability values are relatively low. They vary from 2.5 to 5.5 mV / V (Figure 10). This could be explained by a low clay content and a predominant presence in sandy rock. The low chargeability values are represented by the blue color while the high values are represented by the colors changing from yellow to magenta. The polarizable and non-polarizable structures are distributed throughout the site.

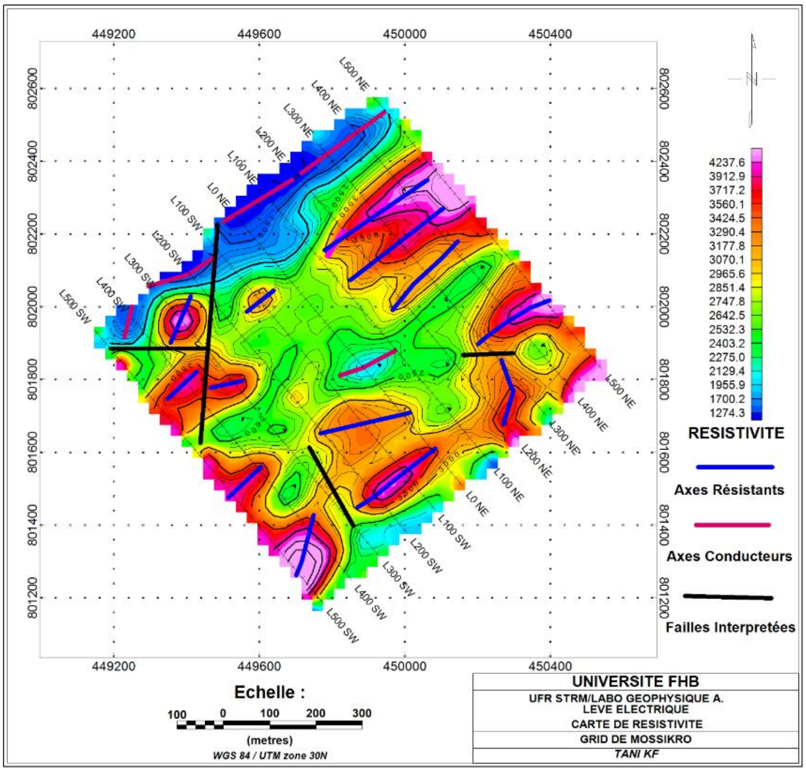


**Figure 9 :**apparent resistivity map of Mossikro site

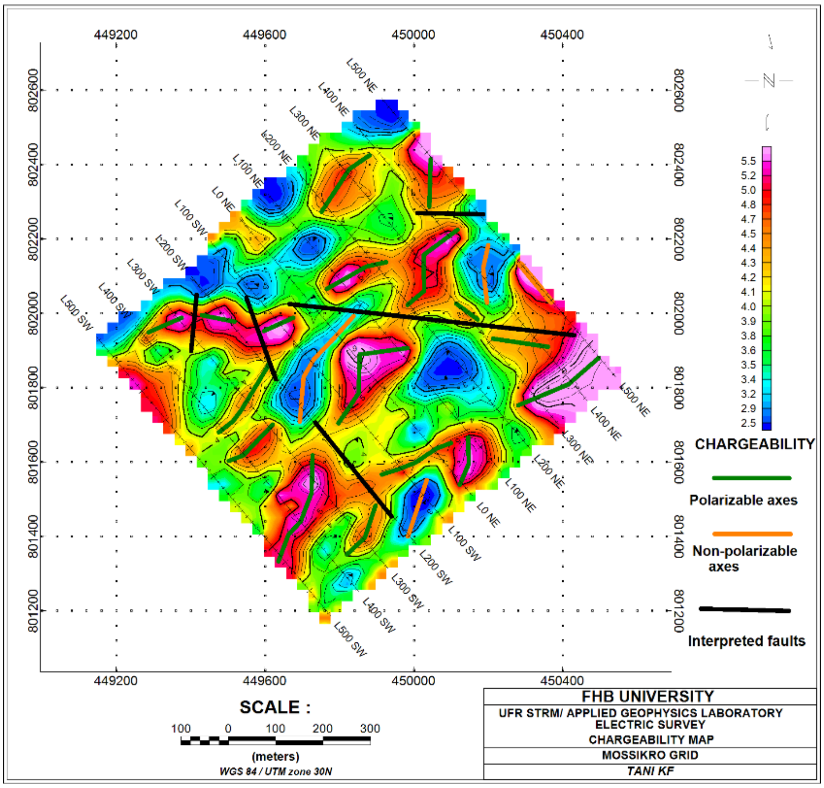


**Figure 10 :**chargeability map of Mossikro site

### 3.3 Structural interpretation

The resistivity and induced polarization maps made it possible to demonstrate the fracturing at the three (3) sites. The axes of the resistant and conductive formations represented on the structural interpretation maps (Figures 11, 12 and 13) are generally oriented NNE-SSW and are marked by variations in direction thus reflecting the passage of fractures. They affect all formations perpendicularly.

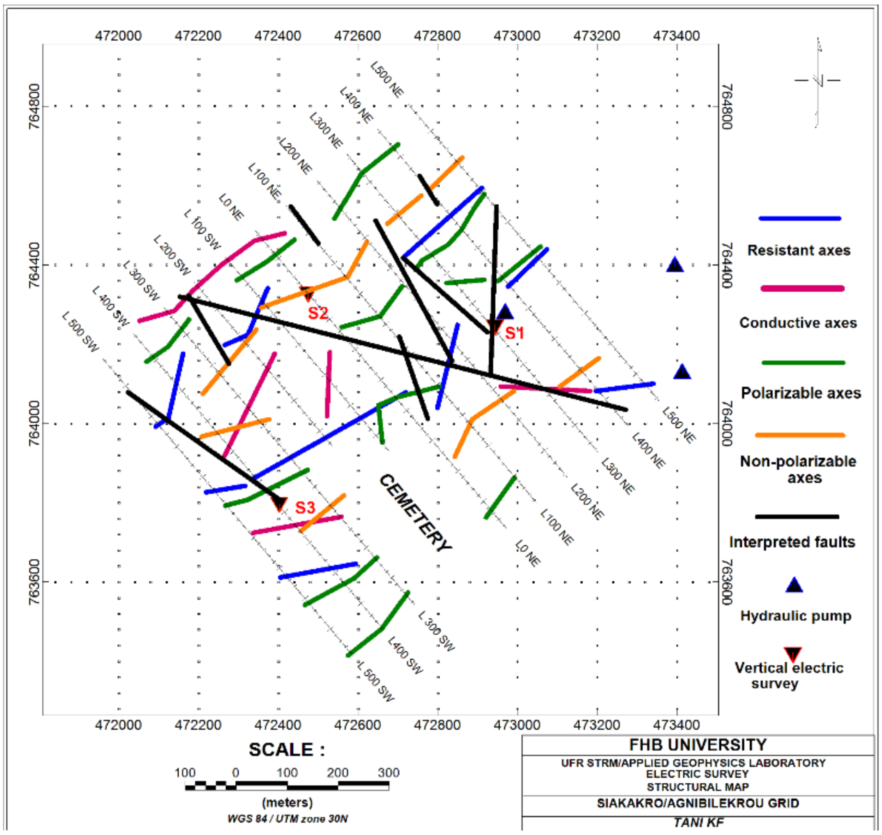


**Figure 11 :** Structural map of the Siakakro site

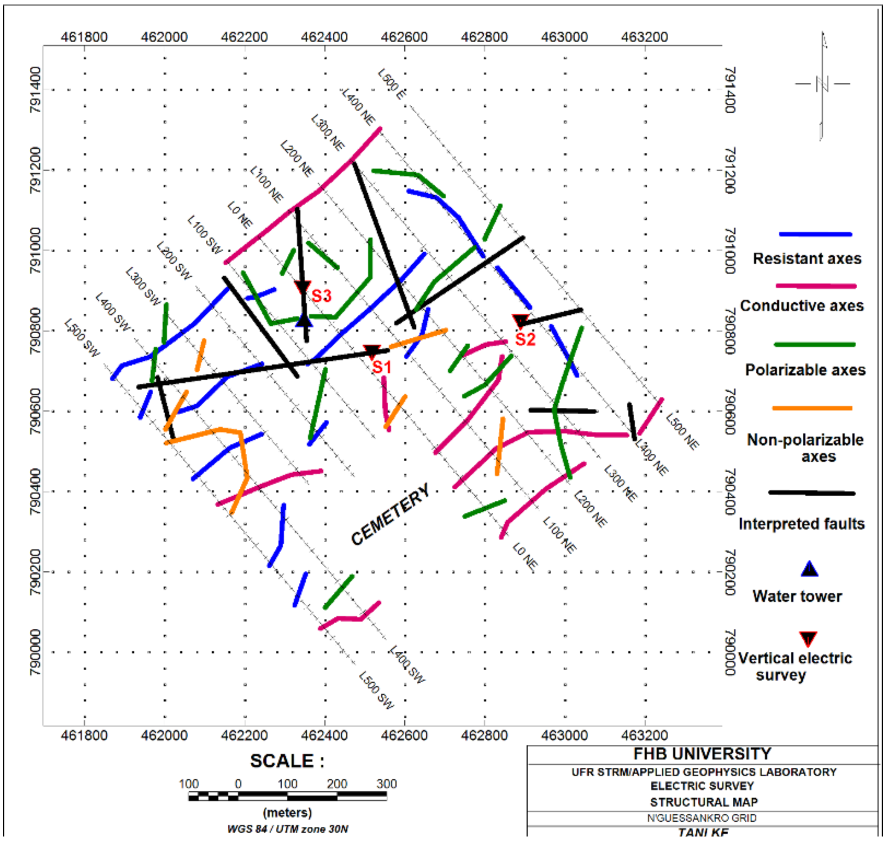


**Figure 12** : Structural map of the N'guessankro site

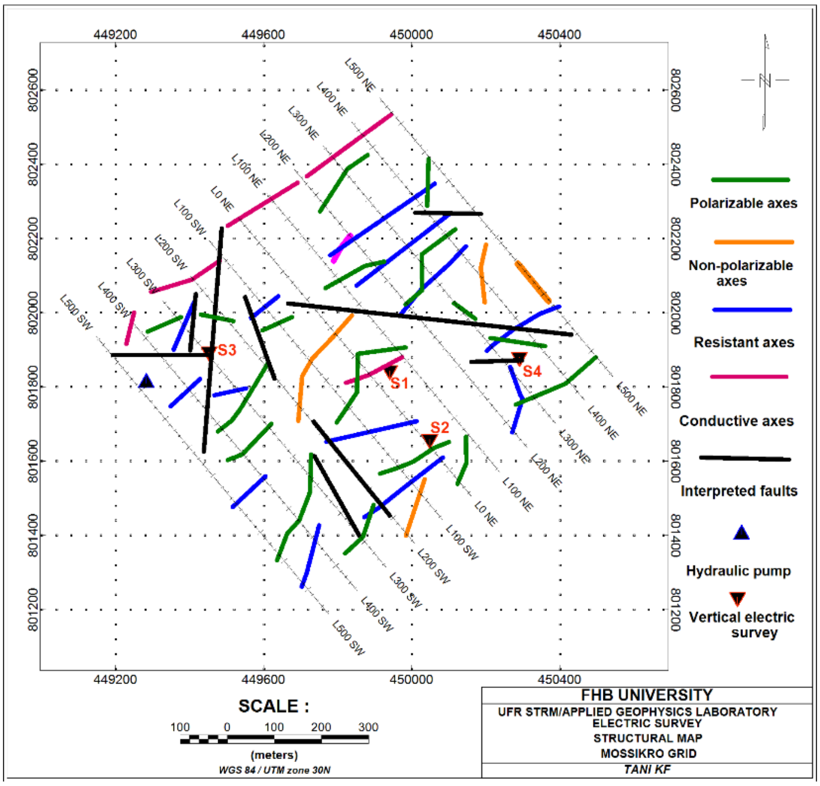


**Figure 13 :**Structural map of the Mossikro site

The directional rosette made at Siakakro shows that the fractures have a direction which varies from N to NW with a mean direction NW-SE. This direction corresponds to that highlighted by the aeromagnetic method[16]. The main direction is NNW-SSE. In N'guessankro the N-S, NNW-SSE, NE-SW and ENE-WSW orientations, fractures are observed while in Mossikro, the identified fractures are oriented E-W, NS and NW-SE (Figure 14).

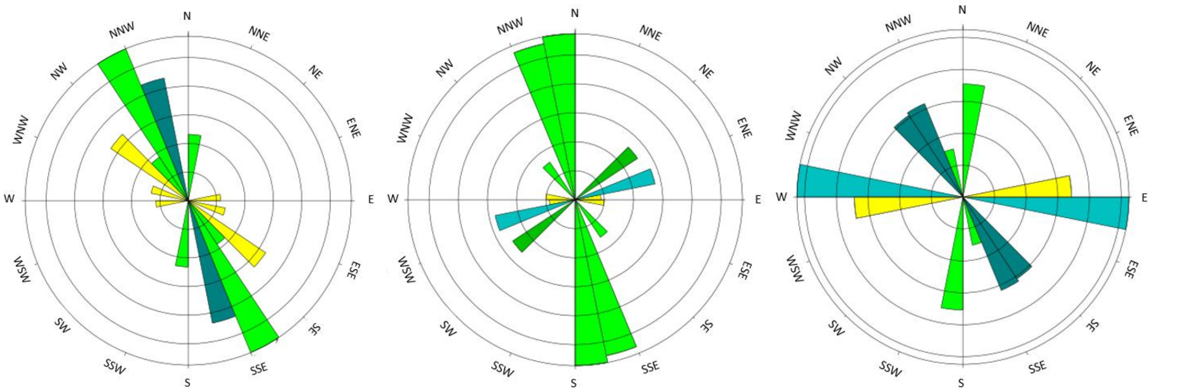


**Figure 14 :**Directional rosettes of fractures observed on electrical maps (a) Siakakro ; (b) N'guessankro and (C) Mossikro

### 3-4 Validation of the lineaments map

The resistivity and chargeability maps carried out at Siakakro, N'guessankro and Mossikro made it possible to highlight the fracturing. The superposition of these maps on the lineaments map allows us to observe similarities (Figure 15). On the Siakakro, N'guessankro and Mossikro sites, 80% of the lineaments were recognized by the established resistivity and chargeability maps.

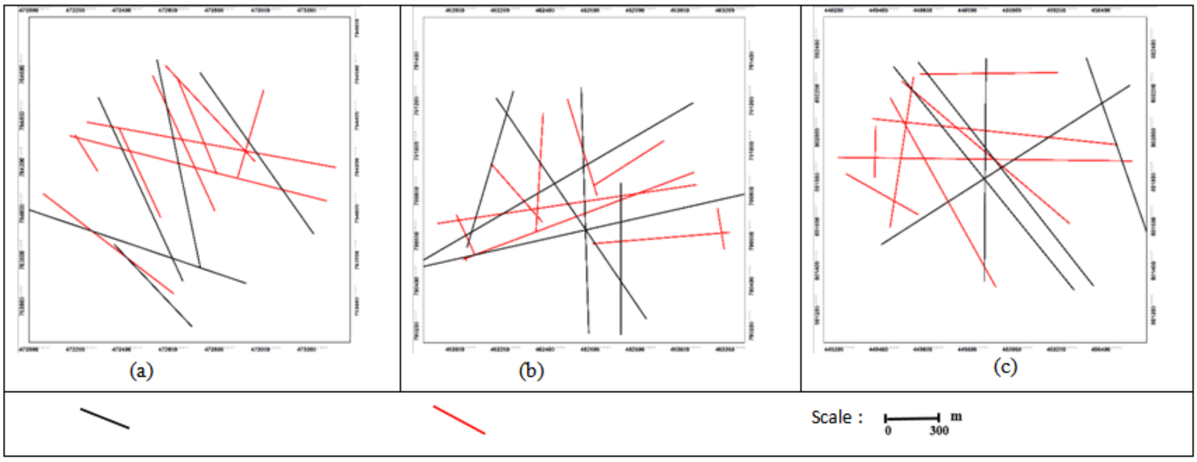


**Figure 15 :**Lineaments and fractures comparison map at Siakakro (a), N'guessankro (b) and Mossikro (c)

The directional rosette of the lineaments identified by remote sensing in the department of Agnibilékrou presents five (5) predominant directional classes (Figure 16). The main direction of the lineaments is NW-SE (N120-N150) followed by the secondary directions NS (N0-N10), NE-SW (N40-N60), NNW -SSE (N150-N180) and NNE-SSW (N10-N40). These directions are confirmed by the directional fracture rosettes from the resistivity and chargeability maps of the three (3) sites (Figure 16). The main direction of the NW-SE lineaments (N120-N150) appears clearly on the three (3) sites. She's more expressive at N'guessankro. The direction NNW-SSE (N150-N180) is more observable in Siakakro and N'guessankro while the directions N-S (N0-N10) and NE-SW (N40-N60) are more noticeable in N'guessankro. The EW direction, not very expressive on the rosette of the lineaments, is clearly observed in Mossikro.Certain identified lineaments have been observed in the field. The most obvious is the fault of the IFOU river already mapped with the aeromagnetic method[16].

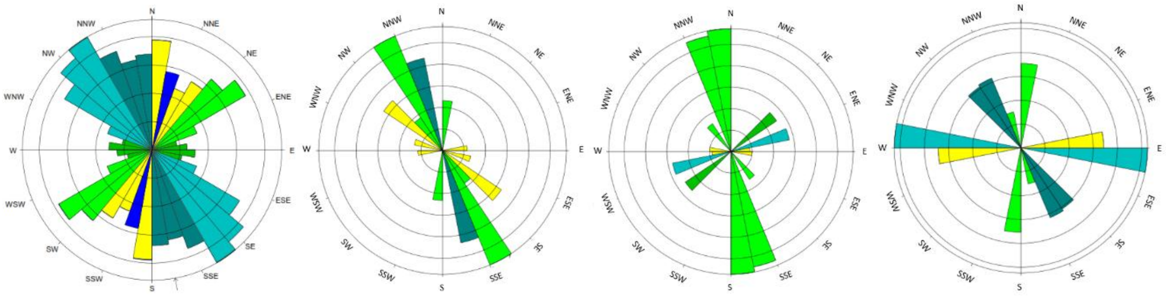


**Figure 16 :**Comparative directional rosettes of lineaments (a) and fractures identified with resistivity maps at Siakakro (b), N'guessankro (c) and Mossikro (d)

**3-5 Fracture density and fracture productivity**

The fracturing density map expressed in cumulative fracture lengths shows a variable spatial distribution of the fracturing (Figure 17). The high densities can be observed over almost the entire study area. From a geological point of view, the high fracturing intensities characterize the area of volcano-sedimentary shales covering more than 80% of the department of Agnibilékrou. A high density is also observed in the granite domain located in the Southeast. It shows that the fracturing is after the granite intrusions. It also shows the intensity of fracking.

The superposition of boreholes on the fracture network allows to highlight the productivity of aquifers. Figure 18 shows that 90% of the holes drilled are located on the network of major fractures. This high rate confirms that prior geomorphological, geophysical and / or hydrogeological studies were carried out before drilling was carried out.

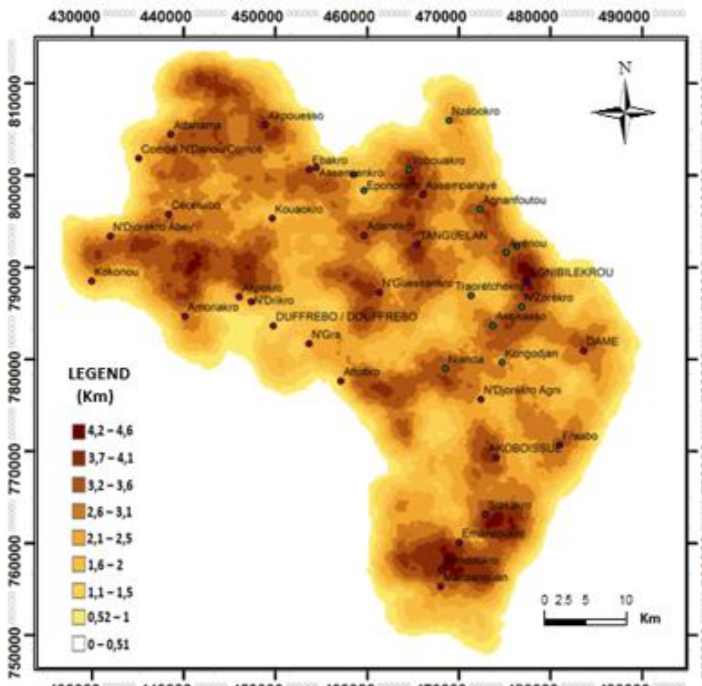


**Figure 17** : fracture density map of Agnibilékrou department

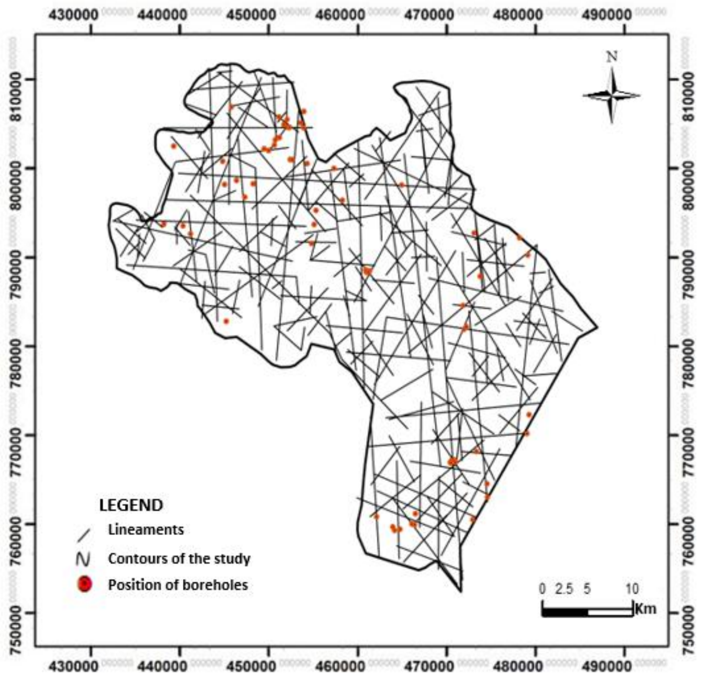


**Figure 18 :**superposition of borehole coordinates on the mega-fractures network identified on the ETM + images of Landsat 7

## IV. Discussion

Remote sensing and geophysical methods have revealed fractures generally oriented NW-SE (N120-N150), NS(N0-N10), NE-SW (N40-N60), NNW -SSE (N150-N180) and NNE-SSW (N10-N40) and EW (N80-N100).

Already recognized in several works[17,18], the NW-SE fractures, could result from a late deformation, characterized by a schistosity (S4) of crenulation of direction N120. In the Center-East of Côte d'Ivoire revealed similar directions ranging from N120 ° to N140 ° senestre and N150 ° to N160 ° senestre[19]. Also, other authors[20,21] have identified these directions in the Dimbokro-Bongouanou region. In the North of the study area, more precisely in the Bondoukou region, the NE-SW and NW-SE fractures are the preferred directions[4].

The directions NS, NE-SW, NW-SE, EW of the fractures have already been observed during the morpho-structural study of the canyon of the bottomless hole of the off-shore sedimentary basin of Côte d'Ivoire[22]. According to the author, they correspond to the large structures encountered both on the Ivorian margin and to the old lineaments of the Precambrian basement. In the study area, they were also highlighted by other works[9]. The direction N-S corresponds to the shear corridors accompanying the schistosity S2. The NE-SW direction generally characterizes the S1 and S2 schistosity plans of the palaeoproterozoic formations. The S1 schistosity translates a gravitational movement and / or a synchronous metamorphic crystallization of the intrusions with an NNE-SSW elongation of the massifs[23]. The schistosity S2 is very penetrating and corresponds to the axial plane of the isoclinic folds folding S0 / S1 oriented NNE to ENE. The direction E-W corresponds to a foliation S3 marked by dextral notches oriented N60 ° which offset the foliation S2.

## V. Conclusionof result

The integrated use of Landsat ETM + 7 satellite images and electrical methods has demonstrated fracking in the department of Agnibilékrou. The study area is characterized by five (5) predominant directional classes which are in order of abundance NW-SE (N120-N150), NS (N0-N10), NE-SW (N40-N60), NNW-SSE (N150-N180) and NNE-SSW (N10-N40). Certain minor directions on a regional scale are much more expressive on the sites studied. This is the case of the E-W direction (N80-N100) observed in Mossikro and N'guéssankro. The fracturing density map produced showed a spatial variability of the fractures. The superposition of boreholes made with the network of fractures testifies to the presence of groundwater. However, a detailed study of reservoir productivity based on hydrodynamic and piezometric properties could contribute to a better characterization of cracked aquifers in the Agnibilékrou department.

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