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Contribution of Satellite Imagery to Hydrogeological Prospecting in Basement Aquifers (Méri, Far North Cameroon)

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Abstract. This work aims to map and analyze the role of fractures in the productivity of basement aquifers in the Far North Region of Cameroon. The analysis of data from existing boreholes and those collected during field campaigns made it possible to evaluate the existing resource. The superposition of the borehole map with that of fractures made it possible to analyse the link between the latter and groundwater circulation. The main direction of the fractures is determined through the analysis of the directional rosettes of these lineaments, those of the fractures of the geological map and those measured on the outcrops during field campaigns. The superposition of the drilling map to that of the lineaments reveals that fracture crossings are the most suitable areas for the implementation of future high-throughput drilling. Four classes of drilling potential are identified: bad 38%, average 30%, good 21% and excellent 11% of the study area.

Keywords: aquifers, fractures, groundwater, Far North

Introduction

The supply of water to populations in quality and quantity is a real challenge for developing countries, including Cameroon. The base area of the Far North Region of Cameroon, which is the subject of this study, is in a situation of difficult access to water during the dry season, which lasts about nine months. This difficulty of access to water persists despite the efforts made by the populations and the public authorities through the construction of hydraulic structures such as boreholes and wells. These water supply works are not only insufficient in number, but also dry up partially at the end of the day or completely in the dry season and therefore fail to cover the water needs of populations, especially rural ones.

To fill this gap, the exploitation of surface water must be complemented by that of deep aquifers (Aké et *al*., 2013). These aquifers are located in fracture networks that are generally well supplied and capable of providing fairly large flows (Dewandel et *al.*, 2011). However, not all fractures present in geological formations are active, i.e. do not participate in the overall flow of a fractured network (Chilès & Marsily, 1993). But when drilling is set up on major multi-kilometre (regional) accidents, the observed failure rate is less than 10%, and the flows obtained are often high (Guiraud, 1975; Guiraud & Lenck, 1975; Camerlo et *al*., 1977).

Existing structures in the Region are unable to cover the needs of the population due, among other things, to the lack of a study prior to their construction, the lack of information on geological aquifers, the absence of rapid prospecting tools. But also the complexity of hydrogeological transfers that depend in particular on the nature of the rocks, the geological structure, the rainfall, the connectivity between the faults, etc.

Boreholes that capture fracture water that are generally well supplied and capable of providing fairly large flows are now the safest and least influenced by seasonal fluctuations (Biemi, 1992). It is therefore identifying these fractures that is complex. However, with the

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advent of remote sensing, several studies have been conducted in the base areas going in this direction.

This work aims to map and analyze the role of fractures in the productivity of basement aquifers in the Far North Region of Cameroon in order to guide future implementations of high-flow drilling.

Study Framework

The district of Méri is part of the base areas of the Far North Region of Cameroon (Figure 1) and constitutes with the departments of Mayo Tsanaga, Mayo Sava, the Mandara Mountains. They are a group of rocks outcropping in long strips whose direction is NNE-SSW (Hallaire, 1991). In general, there are four major geological formations, namely basaltic formations (gabbros and andesite or volcanic rock), sedimentary formations (ancient sand, alluvium and sand dunes), granites and associated rocks and gneiss and similar rocks. The Precambrian crystalline base emerges continuously in the mountainous areas of the West and the Southern Peneplaine and sporadically in inselberg in the central zone.

The region's rivers are irregular and dry for much of the year. These are seasonal mayos of which the most important are: Mayo Tsanaga, Mayo Tchevi, Mayo Louti, Mayo Zouvoul. Their surface flow lasts only three to four months (July, August, September and October). The impermeable terrain, the steep slopes and the rather sparse vegetation lead to a very strong runoff. The flow of the Mayos is therefore of the Torrential type. The infiltration is very low and the flow deficit of the Mayo Tsanaga is almost 600 mm on average. Very high evaporation results in a rapid reduction in flows from upstream to downstream (PDC, 2016).

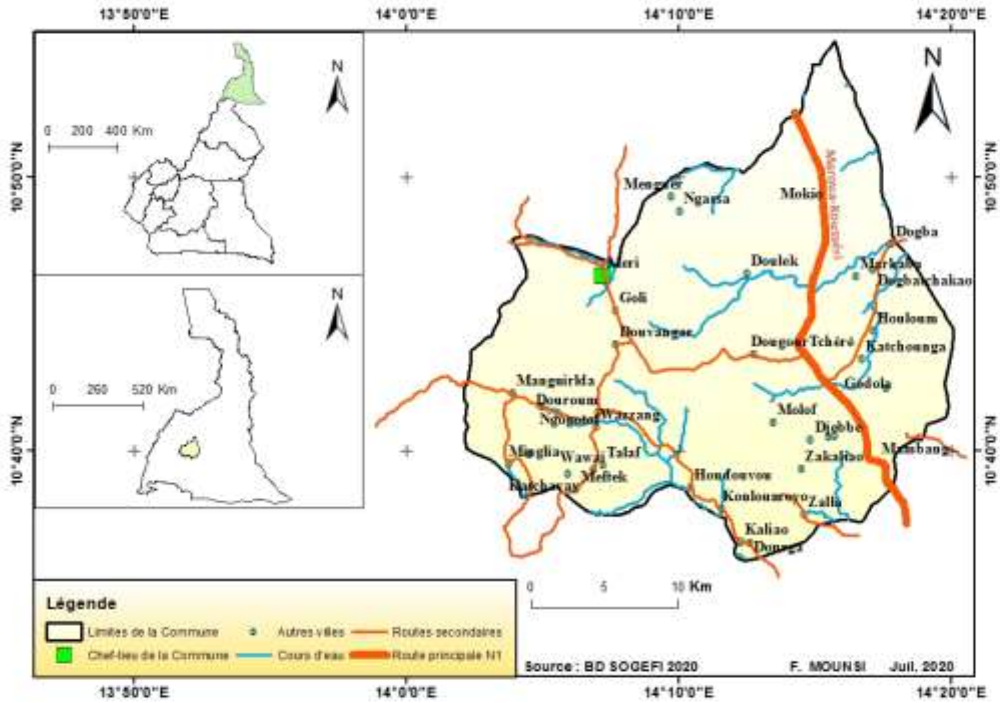

Figure 1. Study area location map

Materials and Methods

Data Used

Several types of data are used in this study. SRTM, radar and Landsat 8 images of May 2020 (beginning of the rainy season), the characteristics of the boreholes (location, flow, depth, quality of the boreholes), the geological maps at 1:200,000, fracking data (orientations) collected on the geological map (Detay, 1987) and those measured at the outcrop during field campaigns, the SOGEFI 2019 and 2020 database containing the elements of toponymy, road networks, river networks, etc.

The drilling database used for the study comes from the Mount Mandara Integrated Development Mission (MIDIMA). It is provided in the form of an Excel sheet that lists until 2015, 114 boreholes in the district of Méri. These boreholes are grouped into two classes according to their productivity because all these boreholes have flows of less than 1m3/h: positive boreholes, which are those that contain water all year round, and negative boreholes, which dry up as soon as the rainy season ends. For depth analysis, 73 selected boreholes from the entire study area were used. The main features of the satellite images used are presented in Tables 1 and 2.

Table 1. Characteristics of landsat 8 strips used

Canal	Spectral resolution (µm)	Domain	Specificity	Spatial resolution (m)
4	0,7-0,9	PIR	Vegetation stress induced by geological phenomena	30
5	1,5-1,7	MIR1	Sensitivity to soil water content	30
7	2-2,3	MIR2	Sensitivity to the vigor of the vegetation cover	30

Table 2. Radar System Characteristics

Elements	Characteristics
Altitude	500 km
Wavelength	5,6 cm
Spectral band	3,75-7,5 cm
Spatial resolution	50 m
Broke	50-500 km

Fieldwork

The database provided did not contain all the information sought (location, flow, depth, water level, borehole quality). Thanks to GPS, some boreholes are located and the depth and water level of some structures are obtained thanks to the electric probe during field campaigns. Out of 114 boreholes, only 79 had the complete information they were looking for. The rest was completed by fieldwork. In the field, we also measured the directions of the fractures on the outcrops, which was done thanks to the compass.

Image Processing and Manual Lineament Extraction

ENVI 4.7 software was used for image processing for lineament extraction. Methods used for image processing include importing two scenes and creating a global image of the study area, geometric correction, principal component analysis (PCA), image combinations (band additions and ratios), colored compositions, and spatial filtering techniques. Since remote sensing can only extract superficial lineaments, the geophysical method, in particular the gravimetric method was used to extract deep lineaments. The land gravity data used in this study were derived from the Bouguer gravity anomaly maps of the whole Cameroon, obtained by Collignon (1968) and Poudjoum (1996) on the behalf of IRD (Institut de Recherche pour le Développement). The gravity survey was achieved along roads or tracks suitable for vehicles. The measurements were made at intervals of 3 km while others were carried out at intervals varying from 4 to 10 km at least.

Before lineament extraction from satellite images, the road, network and high-voltage electrical wires are vectorized from several administrative maps wedged in the same coordinate system as the satellite images. Then, these different linear elements of anthropogenic origin (roads, tracks, electrical and telephone wires) are superimposed on the different photo-interpreted images in order to avoid taking them into account when extracting lineaments. According to Saley (2003), the observation scale can affect the number of lineaments identified, sometimes the dominant direction of a class of lineaments and suggest the scale 1:200,000 for maximum identification of lineaments.

Validation of the Lineament Card

The need to validate the map of lineaments obtained following image processing by confirming the supposed relationship between lineaments and fractures comes from the fact that the lineaments identified do not all reflect deep tectonic phenomena. After the lineament map is made, it must be validated, that is to say, show that the major lineaments identified on the satellite image are in accordance with the fracturing recorded on geological map and the fractures measured on the outcrops. This validation is based on the comparison of the directions of the major families of lineaments resulting from the processing of the satellite image with the fracturing directions recorded on geological map and the fractures measured on the outcrops.

Measurement of Fracture Directions, Drilling Data and Surveys

Measurements of fracture directions were performed. These measurements are made during field campaigns thanks to the compass. These measurements were carried out in mountain areas where the density of fractures is high. Thanks to the compass placed in a horizontal position at the fracturing plane, the fracture orientations are read in the compass dial. These measurements are recorded in a technical sheet to be compared with lineament data from satellite images and fractures recorded on the geological map. The measurement of the water level as well as the depth of the structures were carried out by the electric probe. These are the works whose information is missing from the acquired database. Surveys are also conducted among populations on seasonal fluctuations in water levels in structures.

Realization of the Directional Rosettes of the Lineaments

The directional rosettes of the lineaments are made using the RockWorks software. This software makes it possible to graphically represent the statistical distribution of the orientation of lineaments in DXF format of the map of the lineaments exported in the QGis software. The conventional method consists of producing directional rosettes proportional to the cumulative length of lineaments by classes of 10° orientation (Pretorius and Partridge, 1974).

Analysis of Lineaments and Their Orientations

The analysis of the mapped lineaments takes into account their number by Department, their orientation thanks to the directional rosettes made. These lineaments are then compared to the fractures found on the geological map and those measured in the field. This analysis not only identifies areas with high fracture density, but also identifies the main fracture direction of the study area in order to guide future high-flow drilling locations.

Analysis of the Role of Fractures

This analysis consisted of superimposing the linearity map with that of the positive and negative boreholes of the study area. The productivity of these boreholes is then compared to their position at the lineaments. In addition, this drilling map is also superimposed on the geological map of the study area as well as on a hydrogeological map. This makes it possible to identify potentially more productive sites in the study area.

Results

Mapping and Orientation of Lineaments

Satellite images after pre-treatment by enhancement filters and by the geophysical method (Figure 2) made it possible to make the lineament map. This enhanced image shows several linear structures of varying size and orientation. Figure 3 shows the circular histograms of lineaments from image processing and fracturing on a geological map. Analysis of the rosette of lineaments identified by treatment shows the main directions: North-South N10-20, N40-50, N50-60, N60-70, N120-130 and N130-140. In the low proportions, N20-30, N30-40 and N140-150 are also represented. The fracking histogram from the geological map shows the main North-South directions N10-20, N50-60, N60-70, N110-120, N120-130 and N160-170.

The measurement of fracture directions in the field shows the following main directions: North-South N10-20, N40-50, N50-60, N130-140 and N140-150. There is a similarity between the main directions present on the circular histograms of the lineaments of satellite images, fracking from the geological map and field data, with some differences. Classes N40-50, N130-140 present on the histogram resulting from image processing do not exist on that resulting from the geological map and classes N110-120 and 160-170 represented on the histogram of the geological map are poorly represented on that resulting from image processing. The directions N20-30, N60-70 and N110-120 are absent from the data collected in the field.

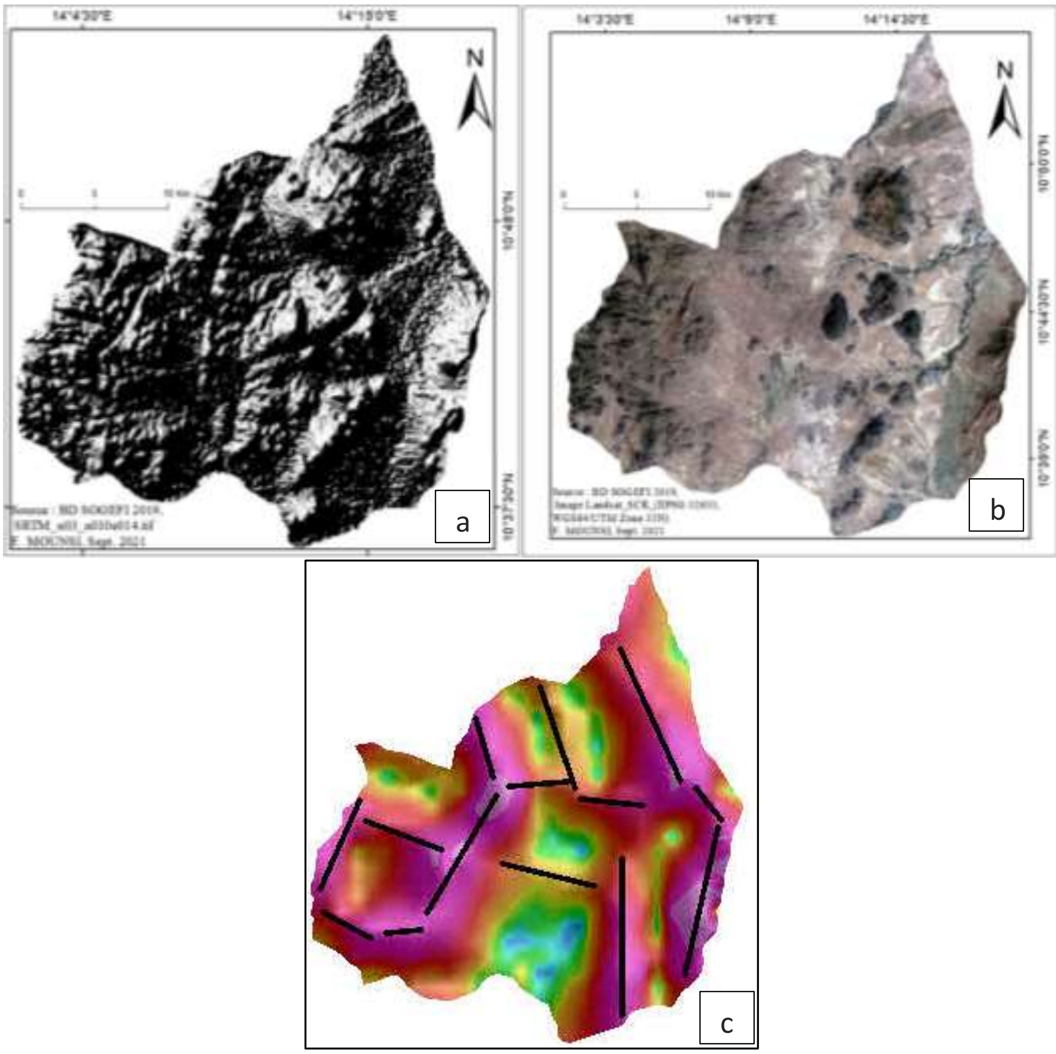

Figure 2. Directional filtering to enhance lineaments (a and b) by remote sensing, (c) by geophysics

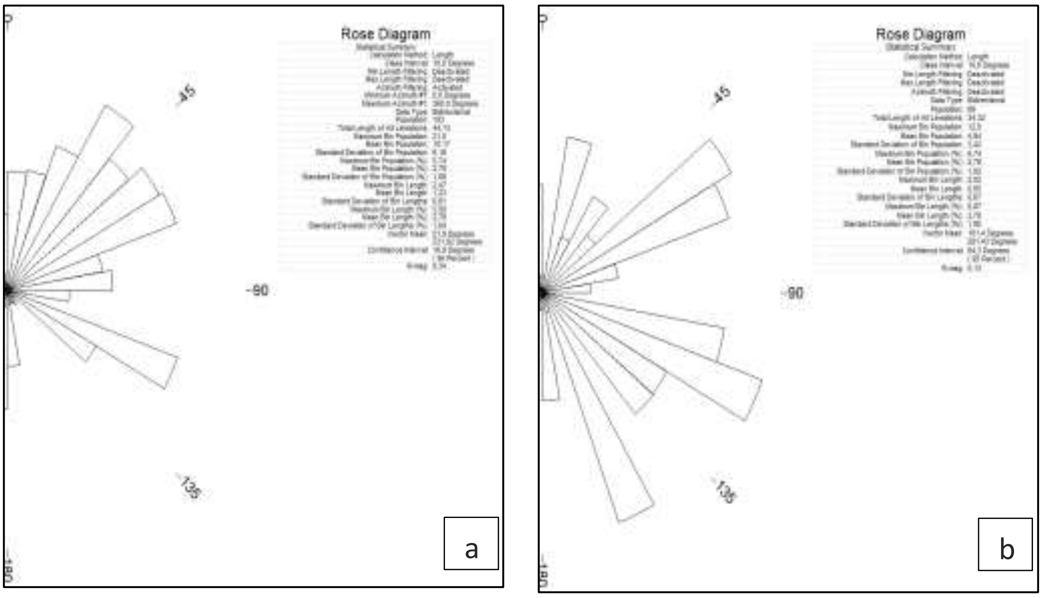

Figure 3. Circular histograms (a) lineaments from image processing, (b) fracking from geological map

The analysis of these different histograms reveals that the NE direction is the dominant one with 58% of lineaments oriented NE, corresponding to the direction of major tectonic deformations. Thus, fractures close to the NE can be considered as tension fractures and fractures of NW orientation, being orthogonal to the compression stresses, would therefore be located in the shear planes and, therefore, can be considered as watertight, results similar to those of Savane et al, 1995. NS steering fractures are fewer, barely reaching 5%.

Potential Drilling Location Areas

The areas favourable to the location of the boreholes were identified by combining lineament data, fractures recorded on the outcrops, positive and negative drilling data, slope data; with a relatively low slope (Figure 4) which allows a good recharge of the tablecloth.

The thematic map of the areas of implantation (Figure 5) is produced after combining three indicators: availability, operability and accessibility. This results in 68% of low production areas throughout the study area with poor (38%) and medium (30%) settlement areas. These are areas with low fracturing density and areas where drilling depth must be high. Flows in these areas are less than or equal to 0.5 m3/h. These include Meri, Dogba, Mokio, Godola, Mambang, Molof, Djebbe, etc.

Acceptable settlement areas cover 32% of the municipality with 21% good and only 11% excellent area for drilling. They are located mainly in the south-west of the commune and cover cities such as Talaf, Douroum, Markaba, Zigdeleng, Dougour, etc. In these areas, the structures can be shallower (about 20m) and with a high probability of success (85%).

Even as the method used makes it possible to identify areas favorable to the implantation of boreholes, it does not guarantee a 100% success rate of drilling. It is a preliminary prospecting tool to go through the prospecting stages on a very large scale.

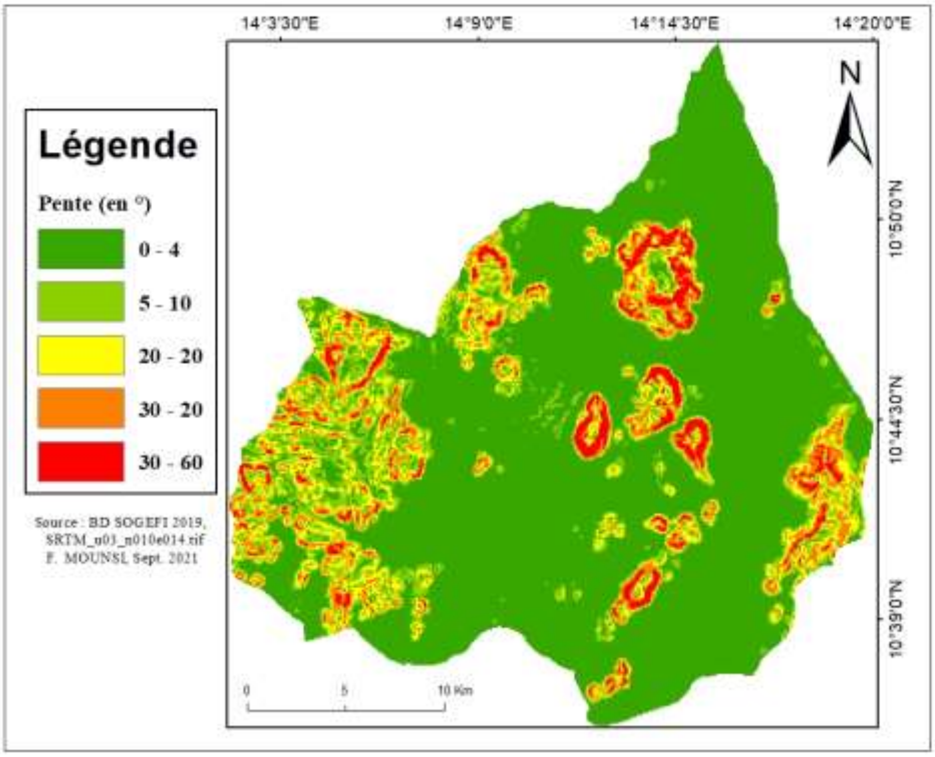

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Figure 4. Slope map

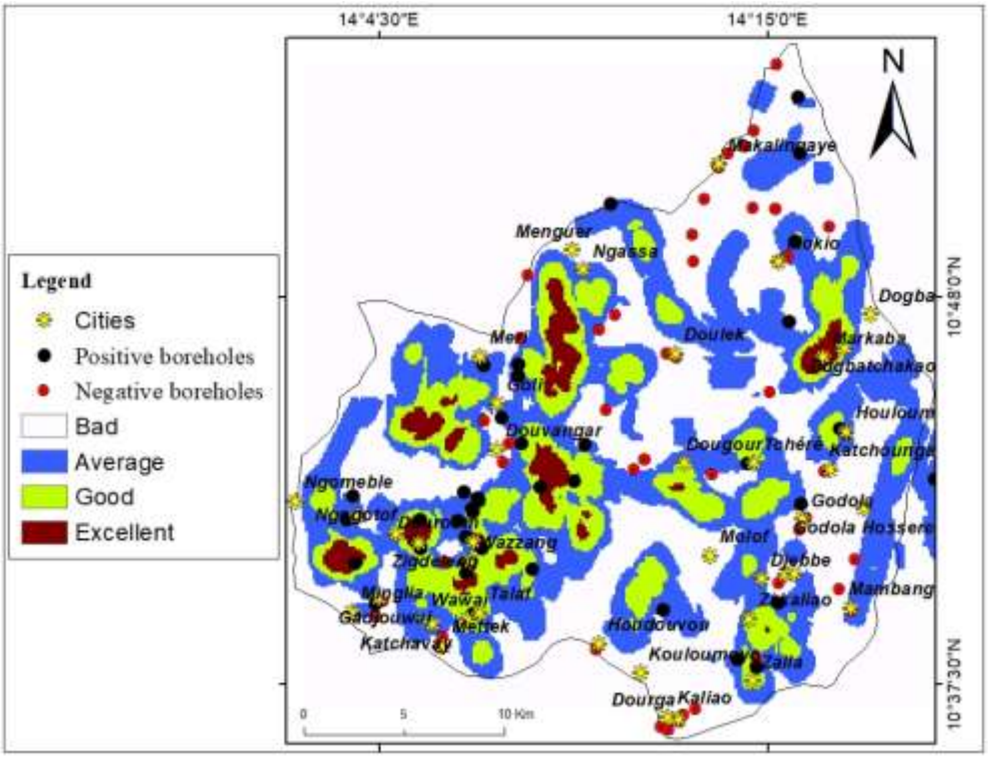

Figure 5. Drilling potential map

Discussion

Relationship between Fractures, Positioning and Drilling Productivity

The map resulting from the superposition of the map of positive and negative boreholes to that of lineaments (Figure 6) shows various arrangements of drilling in relation to lineaments. It shows the presence in places on or near the same lineament, both positive and negative drilling. But we notice in majority, the proximity of the positive boreholes of the lineaments or at their crossing and the distance of the low flow boreholes of the lineaments. This is consistent with the results of the work of Savane et *al.* (1995) for whom, obtaining broadband depends on the relationship between the structure and fractures. The most suitable position according to them, being that located on the intersection of two or more kilometric fractures or on these fractures. This shows that major accidents have an influence on the hydrodynamic behaviour of basement aquifers in the Far North Region.

The high flow of boreholes that are not located directly at the intersection of fractures, but rather nearby, can be explained by the presence of secondary fractures. Although these secondary fractures do not contribute to the overall flow of the aquifer, they allow some connectivity between drilling and major accidents (Wu et *al*., 2004). The more these secondary fractures are numerous in the vicinity of the borehole, the greater the hydraulic connectivity between drilling and major accident, which justifies the presence around the fractures, positive drilling.

The presence of negative boreholes at positions similar to those of positive boreholes also tends to demonstrate that drilling productivity is localized and not associated with a large base zone, in which underground circulations and productivity would be almost generalized (Koita et *al*., 2010). Similar cases (low-flow drilling near high-flow drilling) are known in the Jundiaí River basin in southeastern Brazil (Neves & Morales, 2007) and Sunnfjord in western Norway (Henriksen & Braathen, 2005).

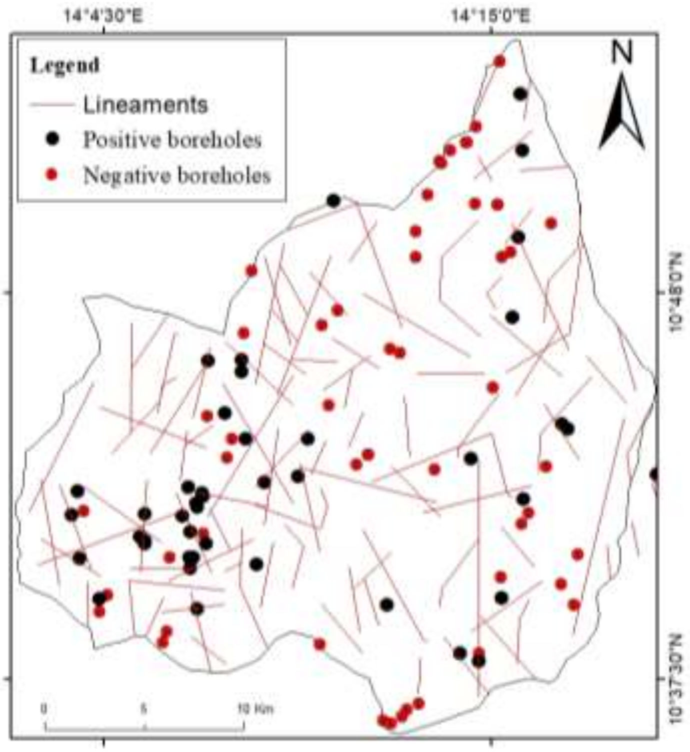

Figure 6. Overlay of positive and negative boreholes on lineaments

The failure of the boreholes even if they are located on the fractures can also be explained by the typology of these fractures. Indeed, there are three types of fractures depending on their origin: tension fractures, compression fractures and shear fractures (Lemieux, 2002). According to this author, only voltage fractures seem to be open and can provide good flow rates. These fractures are therefore likely to drain large amounts of water unlike shear fractures which appear to be closed and contain little or no water. The fractures or parts of fractures on which the negative boreholes are located may also be those that have undergone hydrothermal clogging.

The presence of negative boreholes on or near lineaments can be explained by the fact that not all fractured rocks necessarily contain water and especially not always in sufficient quantity. Moreover, these fractures do not necessarily all participate in the flow of water (Chilès & Marsily, 1993) making the aquifer discontinuous in this base zone as shown by Hassana, 2010. This result is in line with the work of Vaubourg (1980) for whom it is difficult to control the behaviour of fractured environments, because each fracture network is unique in its kind, in that it has hydrodynamic characteristics of its own and depends mainly on the length of the cracks, the degree of clogging and depth.

Relationship between Drilling Depth and Productivity

The position of the boreholes in relation to fractures alone cannot suffice to determine their productivity. To this is also added their depths. Almost all of the positive drilling in this study has a high depth. Unlike lowland areas where water is stored in sedimentary formations and at shallow depths, in the base zone, water is stored in deep fracture networks. And for Mouton (1971), these cracks gradually close in depth and the environment becomes sterile. This is in line with the work of Detay (1987). According to him, in the base zone, the aquifer is generally exploitable between 20 and 80 meters deep.

The correlation matrix (Table 3) determined for different characteristics of the boreholes (flow, depth, water height) reveals a significant correlation (0.580) between flow and depth. This shows that the depth of the borehole has a significant influence on the flow. The correlations between flow and height (0.237) and between depth and height (0.264) are also quite important. This shows that the deeper the borehole, the greater the water height and therefore the flow rate as well.

Table 3. Pearson Correlation Matrix

	Flow	Population	Depth	Height
Flow	**1**	-0,143	**0,580**	0,237
Population	-0,143	**1**	-0,133	0,023
Depth	**0,580**	-0,133	**1**	0,264
Height	0,237	0,023	0,264	**1**

Conclusion

The objective of this work was to map and analyze the role of fractures in the productivity of basement aquifers in the Far North Region of Cameroon. The acquisition and processing of satellite images made it possible to extract the lineaments from the study area. These lineaments were validated thanks to the superposition of artificial linear elements (road, cables, etc.) called in the same spatial reference system. The comparison subsequently of the main directions of these lineaments with those of the fractures recorded on the geological map and the fracturing measured in the field thanks to the directional rosettes carried out, made it possible to define the main direction of the fractures of the Region. The subsequent analysis of the data of the existing boreholes in the Far North Region according to their numbers, flows, depths and by Department, made it possible to establish the link between the productivity of the boreholes (flow) and their respective depth. The establishment and analysis of the directional rosettes of the mapped lineaments, the fractures of the geological map and that of the outcrops reveal that the NE direction is the dominant direction, corresponding to the direction of major tectonic deformations. NE-oriented fractures can be considered as tension fractures, therefore containing water.

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