CONTRIBUTION OF REMOTE SENSING TO THE IDENTIFICATION OF GROUNDWATER RESOURCES IN MAYO-DALLAH DEPARTMENT, SOUTH-WESTERN CHAD

Abstract: Located in south-western Chad, the Department of Mayo-Dallah has a problem of access to groundwater in terms of quantity due to the complexity of the area (basement). The aim of this study is to extract the lineaments of the Mayo-Dallah Department using remote sensing to identify potential groundwater resources. To achieve this, a satellite image (Radar Sentinel 1-C) was downloaded and subjected to various processing operations. A total of 7193 lineaments were extracted, with lengths ranging from 0.30 to 3Km. 96.7% of the lineaments are small, less than 1Km. Lineaments of 1 to 3Km considered to be major represent 3.29%. The distribution of major lineaments on the directional rosette reveals two main directions E-W and N-S and secondary directions SE-NW, ESE-WNW and NE-SW. The lineament density map shows that the southern and western parts of the study area have good lineament density. These areas have a high water potential and could influence recharge.

Keywords: Chad, groundwater resources, basement, remote sensing, lineaments, Mayo-Dallah.

1 - Introduction

Groundwater resources are of vital importance to human life. In developing countries, they are the first choice for supplying drinking water to the population, due to their good quality. However, access to these resources is problematic in basement environments. Yet fractured basement aquifers are excellent groundwater reservoirs (Jourda et al., 2006). The Department of Mayo-Dallah, the subject of the present study, is characterized in this context.

The Department of Mayo-Dallah in south-western Chad belongs to the Sudano-Guinean climate zone. It receives an average of 1,000 m of annual rainfall. Despite this rainfall, the area suffers from water problems. Borehole flow rates are often low, and the failure rate is high. It has been observed that in the dry season, the flow of water in boreholes drops considerably and some wells dry up, forcing the population to resort to water of dubious quality. According to several authors, this situation can be explained by the poor choice of drilling sites and also by the lack of hydrogeological knowledge of the area's aquifers. More precise knowledge of fractured aquifers is essential for better location, exploitation and sustainable management of their resources (Lasm, 2000), (Koudou et al., 2014). Remote sensing is considered an ideal tool in the search for water. It is a preliminary method commonly used by hydrogeologists to identify potentially fractured structures considered as underground recharge and flow conduits (Mabee et al 2002), (Liee et Gudmundsson, 2002), (Gleeson et Novakowski, 2009). With this in mind, it is essential to extract lineaments, as their density indicates a high water potential.

2- Presentation of the study area

The Mayo-Dallah Department is located in south-western Chad, in the Mayo-Kebbi Ouest Province, between latitudes 8°57' to 10°15'N and longitudes 15°05' to 15°58'E (figure 1). It covers an area of 4,069 km2. It has a Sudano-Guinean climate with two seasons. The dry season runs from November to April, and the rainy season from May to October. Annual rainfall varies from 900 to 1000mm. Average annual temperatures range from 21.8°C to 34.9°C. The Department of Mayo-Dallah is home to several temporary watercourses, tributaries of the Mayo-kebbi river, with a sinuous morphology imposed by faults (Doumnang et al., 2021). The topography of the study area is marked by a succession of less accentuated reliefs with numerous small hills. Altitudes range from 300 to 500 m, with an average of 380m above sea level. The lowest points are to the west and slightly to the north-west of the study area (figure 1 b).

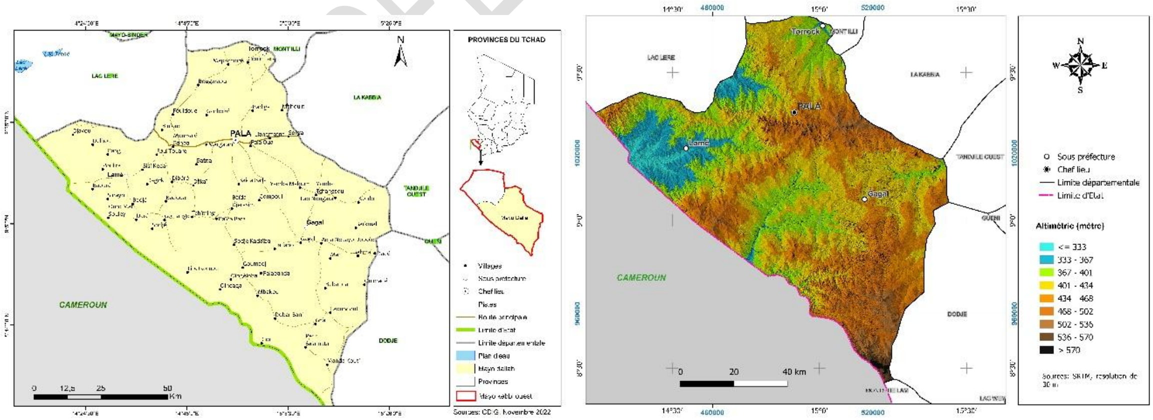

Figure 1 and 2: Location map and elevation map of Mayo-Dallah Department

2.1 - Geological and hydrogeological context

The Mayo-Kebbi West Province consists of a Precambrian basement in the north and sedimentary cover formations. The Precambrian basement of Mayo-Kebbi contains three groups of rocks : the greenstone belts, the mafic and intermediate complex and the granitoid batholith (Mayo-Kebbi batholiths) (Penaye et al., 2005), (Mbaguedjé, 2015). These structures are all oriented in a NNE-SSW direction. They contain ultrabasic rocks (pyroxenites, chloritoschists, talcschists), basic to acidic metaplutonic rocks (gabbros, dioritic gabbros, granodiorites and amphiboloschists) and metavolcanosedimentary rocks (amphibolites, metabasalts, metadolerites and metagrauwackes) affected by greenschist metamorphism [8]. The overlying sedimentary formations correspond to the Lamé series (Cretaceous) and the Continental Terminal (Doumnang, 2006).

Four phases of deformation mark the evolutionary history of the Mayo-Kebbi basement. The first two phases are E-W shortening and the third and fourth are represented by dextral and senestial detachments respectively (Isseini, 2011).

From a hydrogeological point of view, the Mayo-Kebbi basement aquifer is a multi-layered aquifer separated by impermeable layers. In the basement, groundwater is located in alterites and fracture zones at an average depth of 40m. The static groundwater level depends more generally on the strength of the alterites. The median specific flow rate is around 0.18 m3/h/m. There are also deposits with sandy formations, so permeable and capable of ensuring borehole productivity. Static level depths are moderate, but flow rates are rather low, of the order of 5 m3/h at most, with possible dependence on rainfall. Water levels are generally 10 m deep.

In sedimentary formations, aquifers are located in the most permeable layers. Water table depths and static levels tend to be moderate, while flow rates are higher and even locally interesting (in excess of 15 m3/h) (Durand, 2003).

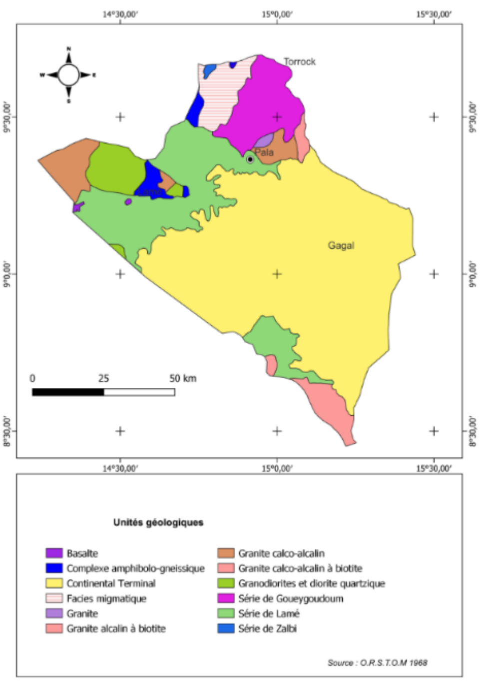

Figure 2: Geological map of the Mayo-Dallah Department

3- Materials and methods

3.1- Materials

The material used to achieve our objective is :

- The 1:1,500,000 geological map of Chad,
- Synthetic geological map of the town of Pala,
- Detailed geological map of Pala,
- IGN topographic map at 1/200,000 (sheets NC-33-9, NC-33-10, NC-33-11, NC-33-3 and NC-33-4),
- Satellite imagery (Radar Sentinel 1-C),
- Mayo-Kebbi fracturing map extracted from Landsat 7ETM images, scene p184r053, Hydrographic network map extracted from SRTM imagery,
- Borehole data (flow rate and depth).

These data are processed on several software packages, namely : SNAP, Arc gis, Geomatica and Rockwork.

3.2- Methodology

The methodology adopted for this study consists in applying remote sensing processing methods to extract the lineaments of the study area and to proceed with the control and validation of these lineaments on the one hand, and to show their relationship with productivity on the other. To do this, we downloaded an image from the Sentinel 1-C radar sensor satellites taken on March 16, 2024 from the Copernicus Data Space Ecosystem website. The satellite data obtained are dual-polarized (HV + VV). Those taken into account are HV horizontally-vertically polarized. As these are orthorectified images, we directly applied the Lee sigma 7x7 filter. The filtered image is then exported to Geomatica for automatic lineament extraction using the Line algorithm.

The lineaments obtained are then transferred to Rockwork software for directional analysis.

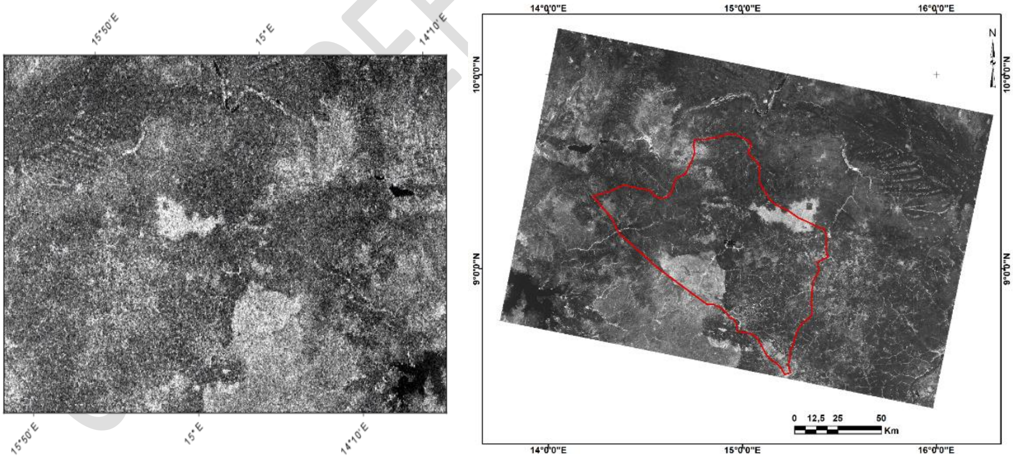

Figure 3: Satellite images Radar before and after treatment

4- Results

4-1 Automatic lineament extraction

Application of the LINE modulus algorithm extracted 7193 lineaments with sizes ranging from 295m to 3000m. Smaller lineaments (less than 1m) are more numerous (figure 4). They account for 96.7% of the total, while lineaments between 1 and 3m account for 3.29%. The latter are considered to be the major lineaments.

The distribution of lineaments on the directional rosette is fairly homogeneous. The frequencies in number and cumulative length are similar. No family exceeds 10% in number or cumulative length. The N-S and E-W families stand out from the others, with a percentage in number and cumulative length close to 4%. These are the E-W direction (N80° to 100°) and the N-S direction (N170° to 180°) (figure 8). These are followed by N160°-170°, N140°-150°, N0°-20°, N70°-80° with almost 3%. The N40-60° and N110-130° directions are poorly represented. We can classify these groups into 5 families: N-S (N0-20°, N160-170), SE-NW (140-150°), ESE-WNW (110-130°), E-W (80-100°), NE-SW (40-60°).

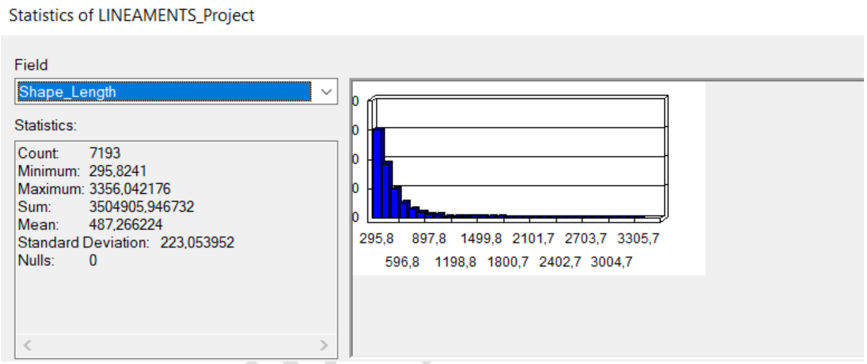

Figure 4: Lineament length frequency histogram

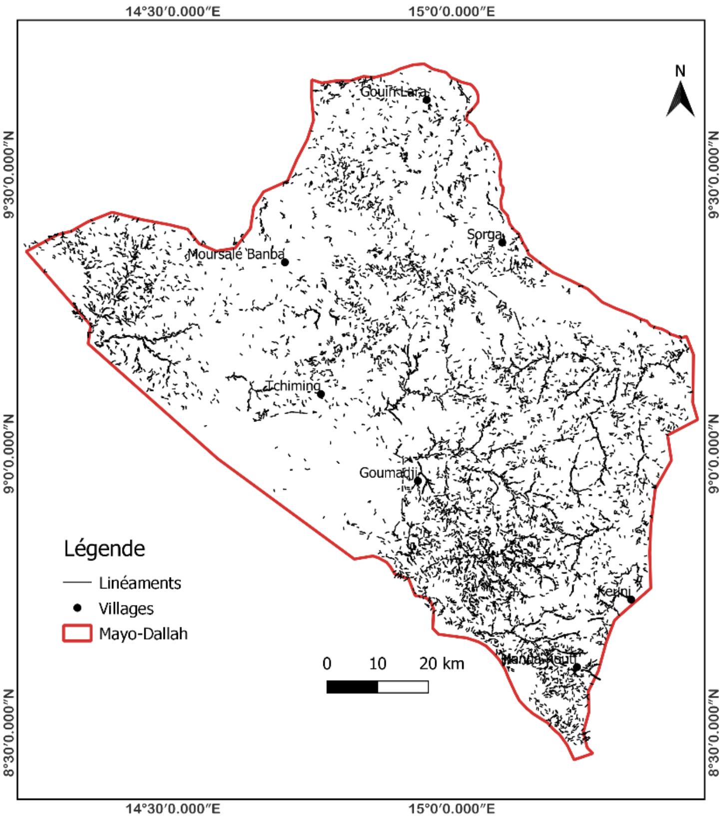

Figure 5: Lineament map of Mayo-Dallah Department

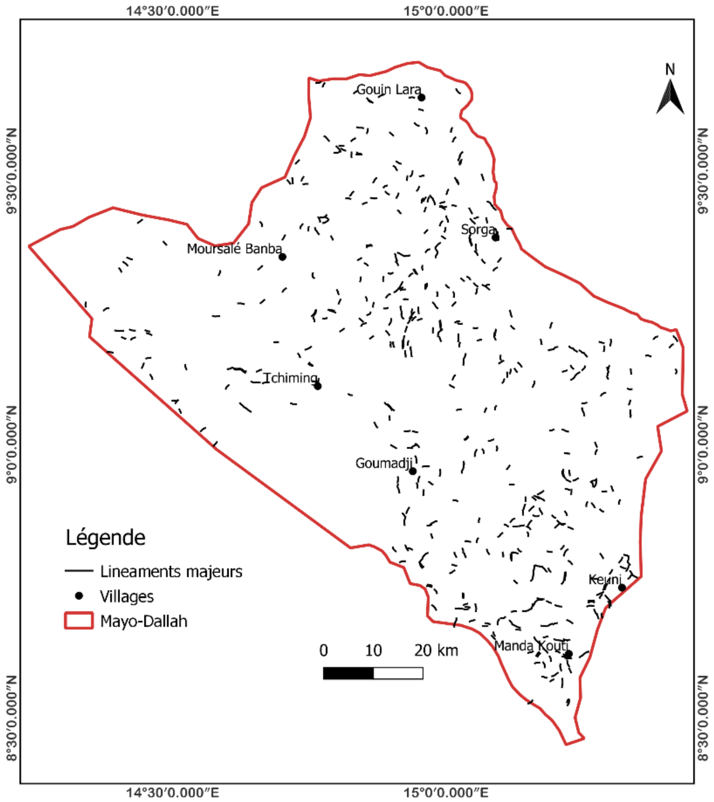

Figure 6: Map of major lineaments in the Department of Mayo-Dallah

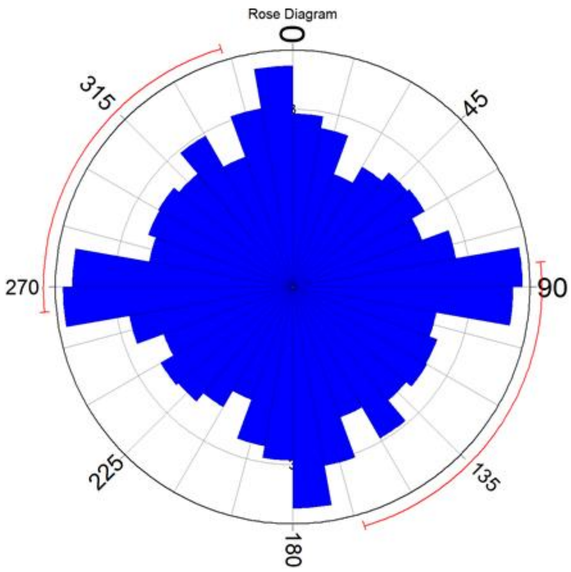

Figure 7: Directional rosette of the lineaments in the Department of Mayo-Dallah

5- Lineament control and validation

Validation enables us to check the reliability of the method used and to assign fracture values to the lineaments obtained. This stage is based on superimposing the major lineaments on the geoscientific data (hydrographic network, fracturing map and high-flow boreholes). By superimposing the lineaments on the hydrographic network of the study area, illustrated in figure 8, we can see that the lineaments follow the watercourses, which seems logical since, according to (Doumnang et al., 2021), the morphology of the watercourses in the Mayo-Kebbi is imposed by the faults. Figure 9 shows a correspondence of more than 50% between the lineaments and the fractures identified, although not all fractures were found in the field due to the poor outcrop in the study area mentioned by previous authors (Penaye et al., 2005), (Isseini, 2011). This result leads to the conclusion that the lineaments in the study area are of tectonic origin.

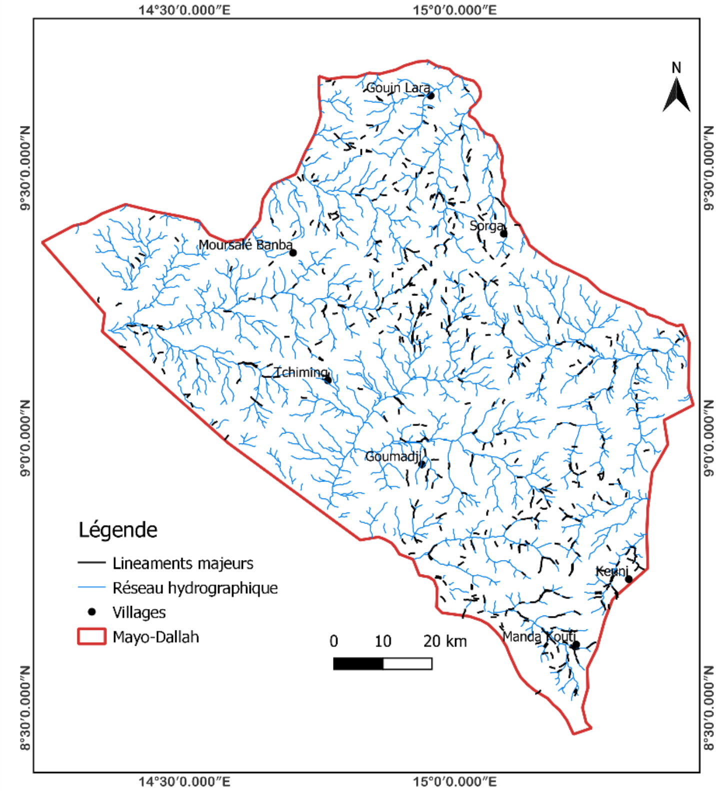

Figure 8: Map of lineaments and hydrographic network

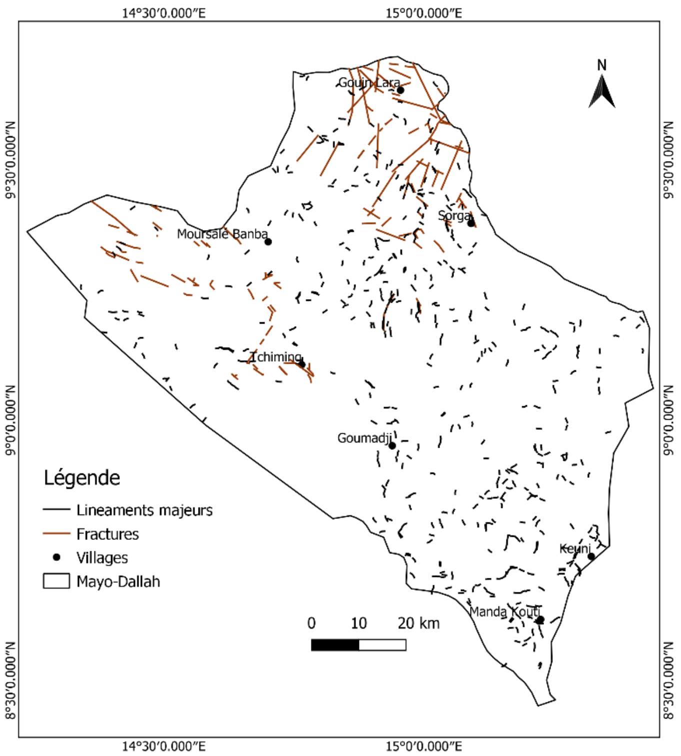

Figure 9: Map of major lineaments and fractures in the Department of Mayo-Dallah

6- Lineament density

Density calculates the frequency of lineaments per unit area. The density map shows the concentration of lineaments per unit area and provides an indication of water potential. Figure 10 shows that the study area is weakly fractured. However, there is good density to the south and west of the study area.

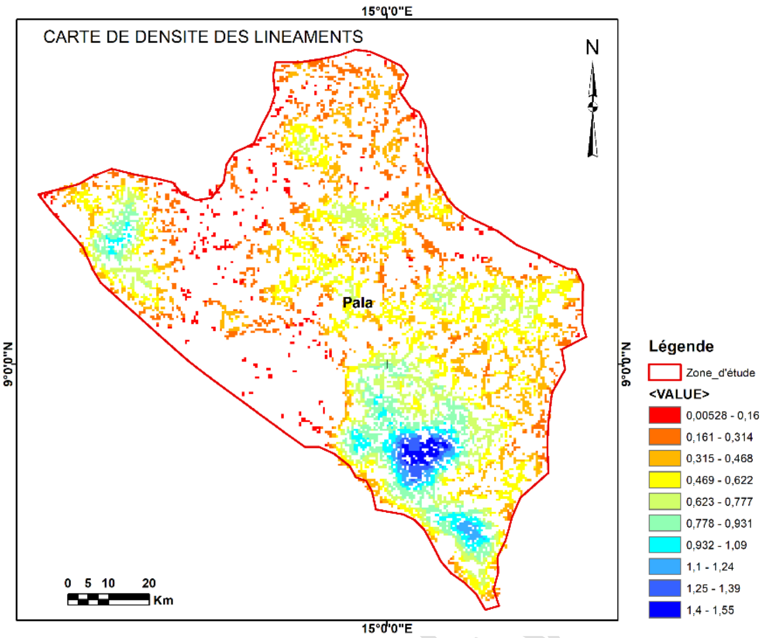

Figure 10: Density map of lineaments

6- Relationship between lineaments and borehole flow rates

(Krishnamurthy et al., 2000), (Sener, 2005) consider lineaments to be the conduits for groundwater recharge and flow, and their density indicates a high water content. Figure 12 shows the relationship between lineaments and borehole flow rates. Boreholes located near or at the intersection of two or more fractures capture significant flows. Characteristic fractures are highly productive. However, the fractures located to the west of the study area did not yield satisfactory results.

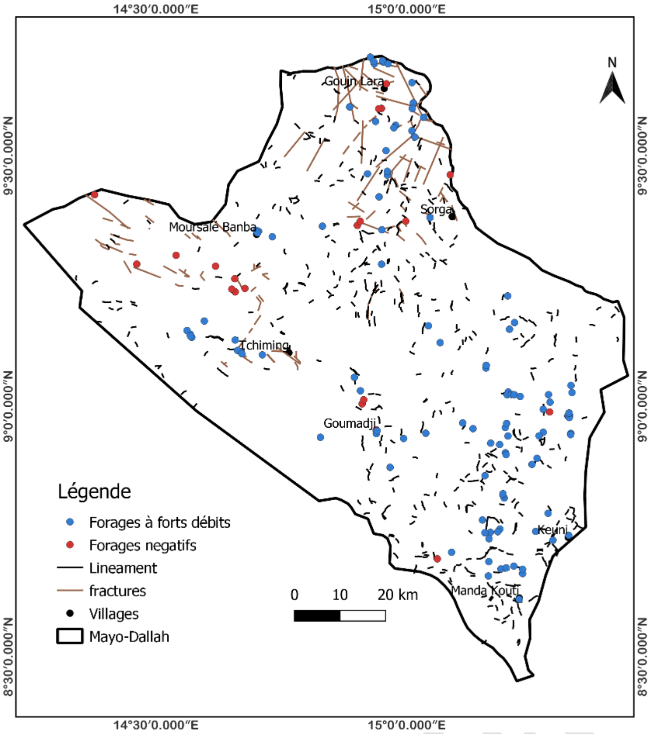

Figure 11: Map of major lineaments and flows

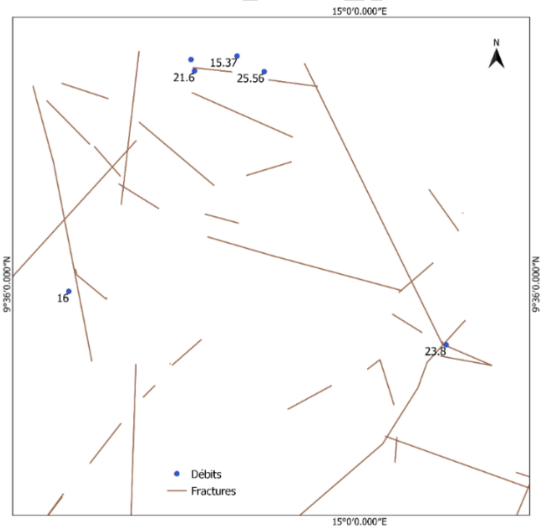

Figure 12: Fracture and high-flow map

3- Discussion

The method of automatic lineament extraction through the LINE module was chosen for this study in contrast to the visual interpretation method already used in previous studies of the study area. The new authors consider the automatic method to be innovative and objective. It saves time thanks to its rapid execution (Tam et al., 2004). The work of (Tam et al., 2004), (Hung et al., 2005) showed the potential of the LINE module to detect a maximum of lineaments for hydrogeological studies. Application of the LINE algorithm extracted 7193 lineaments with sizes ranging from 0.2 to 3m. (Doumnang, 2006), (Pouclet et al., 2006), (Penaye et al., 2006) have interpreted the lineament assemblages in the Mayo-Kebbi Province as being related either to the stratification, foliation or schistosity of the rocks, or to their diaclase, fracturation, dyke or vein nature. The distribution of lineaments on the directional rosette shows a homogeneity of lineaments, but the E-W (80-100°) and N-S (170-180°) directions stand out from the others in terms of number and cumulative length. These directions are similar to those of the N170° and E-W (70-100°) normal faults mentioned by (Penaye et al., 2006) in the Mayo-Kebbi basement. These directions are followed by minority directions. A total of five lineament families emerge: E-W (80-100°), N-S (N0-20°, N160-170), SE-NW (140-150°), ESE-WNW (110-130°), NE-SW (40-60°). These fracture directions correspond to the directions of the Pan-African (schistosity and shears) and post-Pan-African (Cretaceous fault) structures. The NE-SW direction (N40° and N60°) characterizes the fracture plane of the Mayo-Kebbi greenstone. It is similar to the schistosity directions highlighted by (Isseini, 2011 ; Mbaguedjé, 2015) in the Goueygoudoum series. The SE-NW direction is the same as that of the Doba and Bosso normal faults. This direction is more likely to be “open” and therefore hydrogeologically productive. The ESE-WNW direction is similar to local shear zone directions and structures appear to control certain flow channels (Osinowo et al., 2021). The lineament map of the study area shows all fracture directions in the Mayo-Kebbi basement. However, these lineaments are subject to validation by hydrographic, geological and hydrogeological data from the study area to confirm their nature and existence in the field. The validation of lineaments by the hydrographic network is the very first validation method used by previous authors. The result shows that the lineaments are drawn on the watercourses. This result seems logical since, according to (Vidal et al., 2007), the morphology of Mayo-Kebbi streams is imposed by faults. Fractures guide the path of rivers and allow lakes to settle in the Mayo-Kebbi Province. Further validation of the lineaments with the geological and fracture maps of Mayo-Kebbi shows that the majority of the lineaments are superimposed on the fractures observed in the field. In view of this result, we can confirm the reliability of the method used and attribute the fracture values to the lineaments. The density map shows that the south and west have a good density of lineaments. From a hydrogeological point of view, good fracture densities provide a good understanding of the aquifer. These zones have a high water potential and influence recharge (Mabee, 2002). The coupling of drilling points and fractures shows that there is a relationship between productivity and fracture interconnectivity. Boreholes located at fracture intersections or close to kilometre-scale fractures capture significant flows, up to 25m3/s. This hypothesis has been validated by (Biemi et al., 1991), (Savané, 1997), Jourda et al., 2006). However, not all fractures are fed. They may be clogged. This is the case for the boreholes located near the fractures to the west of the study area. In fact, these fractures run in the same direction as the old E-W faults. The old faults are likely to be clogged or vein-filled. The relationship between depth and flow is not significant. It would be important to establish the relationship between alteration depth (thickness) and flow rate to gain more information.

4- Conclusion

The remote sensing tool has made it possible to map the lineaments in the Mayo-Dallah Department and has demonstrated their hydrogeological interest. This study leads to the conclusion that lineaments alone do not guarantee the identification of an aquifer potential. It would be advisable to combine lineaments with other approaches to obtain more detailed information.

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