Watersheds Morphometry and Structural Interpretation of Lineaments Extracted from SRTM Data in the Mayo-Kani Division Far-Nord Region, (Cameroon)

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Abstract In the Far-North Region of Cameroon, the high rate of weathering and erosion of rocks do not allow to map the hydrological and geological structures in the field. This paper aims to test the combined use of field topographic data and Shuttler Radar Topography Mission (SRTM) data to define watershed morphometry, highlight the different erosion factors, and characterize the structural lineaments of the Mayo-Kani Division, within the Far-North Region of Cameroon. All these are done using; watersheds, hydrographic network, slopes, manual lineaments and automatic lineaments maps. These treatment techniques used (filtering, enhancement and slope analyses) allows: to morphologically characterize the ten identified Mayo-Kani watersheds, to measure the erodibility rate of the watersheds using the Universal Soil Loss Equation (USLE) and to compute the fracture maps. This last operation was validated using ground truth field observations and the literature review. Fracture networks were analyzed using statistical analysis techniques by studying fracture length distribution laws.

Keywords: satellite imagery, SRTM, GIS, morphometry, structural fracture

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1. Introduction

The contributions of new methods of analysis (GIS, automata) and the growth of the computing capacity today have upset the use of morphometry in geomorphology, hydrology, hydrogeology and geology [1-5]. These inputs facilitate the delimitation of watersheds, the measurement of geometry, the slope hypsometry, the organization of the hydrographic network and lineaments [1-5]. Geographical Information Systems softwares, including ArcGIS, provide interesting tools for calculations and hydro morphological measurements from the Digital Terrain Model [6-11]. A Digital Terrain Model (DTM) is a three-dimensional representation of the Earth's surface, created from terrain elevation data [11]. In 2009, the DTM of the Shuttler Radar Topography Mission (SRTM) was made available to the public free of charge. This DTM provides a resolution of 30 meters, and covers 99% of the Earth's surface. It was created stereoscopically from pairs of ASTERR (Advanced Spaceborne Thermal Emission and Reflection Radiometer) aerial photographs by NASA and the Ministry of Economy, Trade and Industry of Japan. The data structure is simple and available, and makes it a popular tool for land characterization [2,4,7,11].

In the Far-North Region of Cameroon, the high rate of weathering and erosion makes it extremely difficult to map the geological structures in the field. In addition, land and aerial topographic data are rare or non-existent in this region. Several authors suggest, however, that remote sensing and particularly SRTM satellite data can be effectively used in structural mapping to compensate for the absence and scarcity of terrestrial and aerial topographic data [6-11].

The Mayo-Kani Division, which is a part of Far-North Region of Cameroon, is a large area with small variation in altitude. These small differences in elevation result from the peneplanation and coalescence of watersheds. This area is sensitive to runoff and represents an advanced

stage of soil erosion by the river systems. The aim of this study is to determine the morphometric aspects of the watersheds of the region, to highlight the main erosion factors, to characterize the hydrological behavior of the watersheds and to analyze the structural lineament networks.

The article consists of five parts: the geologic setting of the study area; data collection, processing and methods; results and interpretation of the obtained maps and discussion.

2. Geologic Setting

The Mayo-Kani Division, is one of the six Divisions of Far-North Region of Cameroon. The geological history of this study area and the Far-North Region of Cameroon (Figure 1) is closely related to that of the Lake Chad Basin

[12,13,14]. In this region, sedimentary deposits are dependent on a succession of regression and transgression regimes caused by the alternation of arid and wet periods [12,14-18]. The major structural directions encountered here are [14,16,18-24]: N12°E, N28°E: Cameroon volcanic line, N58°E: Somali direction, N73°E: Adamawa line, N117°E, N135°E to 142°E: Eritrean direction. These directions control the folding and faulting of crystallophyllian basement rocks, the location of volcanic and subvolcanic devices, and the ultimate post-tectonic intrusive massifs and much later the hydrographic network. The basement rocks are Precambrian in age and have been reactivated during the Pan-African orogeny (~600 Ma) and this signature makes it possible to integrate the local geological evolution and structural framework of the Far-North of Cameroon in a global context [14,16,18-24].
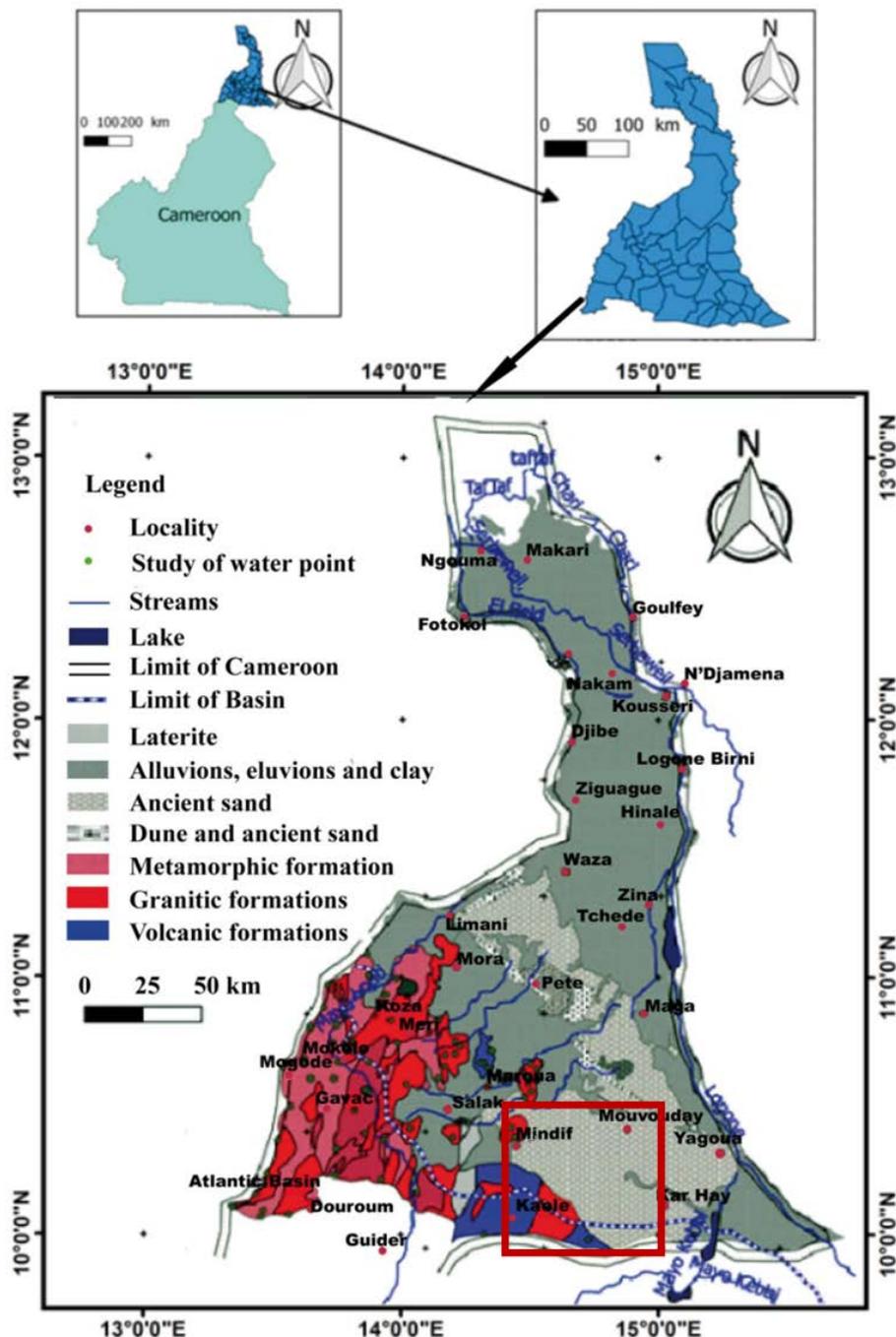
Figure 1. Geological map of the Far-north of Cameroon, the red frame contains the Mayo-Kani zone (from [12,13,14])

Far-North Region of Cameroon (Figure 1) is represented by Precambrian crystallophyllian basement rocks, sedimentary formations and volcanic formations [12,13,14]. In this region, the Precambrian crystalline basement outcrops continuously in the mountainous western areas, the Southeast peneplain sporadically, and inselberg in the central zone [12,13,14]. This basement consists of three main units [12,14,16,18-24]: an epi-metamorphic complex covering most of the northern part and forming a band to north of Maroua; a migmatitic meso-metamorphic ensemble covering about 50% of the basement surface and forming with the granites all of the Mandara Mountains; a non-migmatitic meso-metamorphic ensemble covering about 10% of the surface of the basement flush in the Kaele peneplain and Moutourwa. The sedimentary formations extend from the foot of the Mandara Mountains to the eastern Diamare Plain; all this together constitutes the sedimentary cover; its thickness varies from a few meters at the foothills to several tens of meters at Lake Chad [12,13,14]. These are mainly lacustrine clays and ancient sands overlain by alluvia from the Logone river and the Mandara Mountains.

In more detail, sedimentary rocks such as alluvium, clay, limestone and sandstone make up most of the surficial rocks of the Far-North Region [12,14,16,18-27]. These deposits follow the rivers of the region, such as Logone and Mayo Tsanaga, which flow into Lake Chad in the north. In the south of the region, a strip of granite separates the sedimentary zone from an area of metamorphic rock located to the southwest. The latter region includes outcrops of micaceous gneiss and shale (Figure 1). The Rhumsiki Valley, a mountainous field littered with extinct volcano cones and necks, is a small area of volcanic rock, such as trachyte and rhyolite. The soils in this region are a bit more complex. They are dominantly young soils rich in raw minerals. This is the case for much of the land south of Lake Chad and the Mandara Mountains on the western border with Nigeria [18-27]. Here, the soil consists mainly of black clay (alluvial soil). The seasonal floods of the Logone River give rise to a north-south band of hydromorphic soils on the Chadian border. The rest of the territory, comprising the Diamare plain and the river El Beïd valley, consists of ferruginous soils. Seasonal wet/dry variations in the region create relatively shallow, ferrous or lateritic soils [18-27].

In terms of relief, most of the Far-North Region of Cameroon is at a relatively low altitude. This low part forms portion of the Lake Chad plain and its gentle slopes vary from 500 m in the southwest to 200 m at the edge of the Logone river. The average elevation of this basin is 280 m (Figure 1). The Diamare plain occupies the lower third of the Lake Chad plain and is characterized by a number of isolated inselbergs. The Mandara Mountains on the southwestern border with Nigeria form the highest point, between 500 m to 1000 m above sea level, with an average of about 900 m [18-27]. The Tourou Mountain is the highest point culminating at 1442 m. These mountains are probably the result of the same tectonic activity that led to the Benue trough in Nigeria. The area was once volcanically active, as evidenced by a number of trachyte and rhyolite extrusions of extinct volcanoes. The most spectacular of them is in the valley near the tourist village of Rhumsiki. The part of the chain located in the far-north is on a medium plateau located between 800 m and 900 m. Isolated mountains continue in the Diamare plain, at Mindif, Boboyo, Kaele and Lara. The northern expanse of these mountains is dissected by several rivers [18-27].
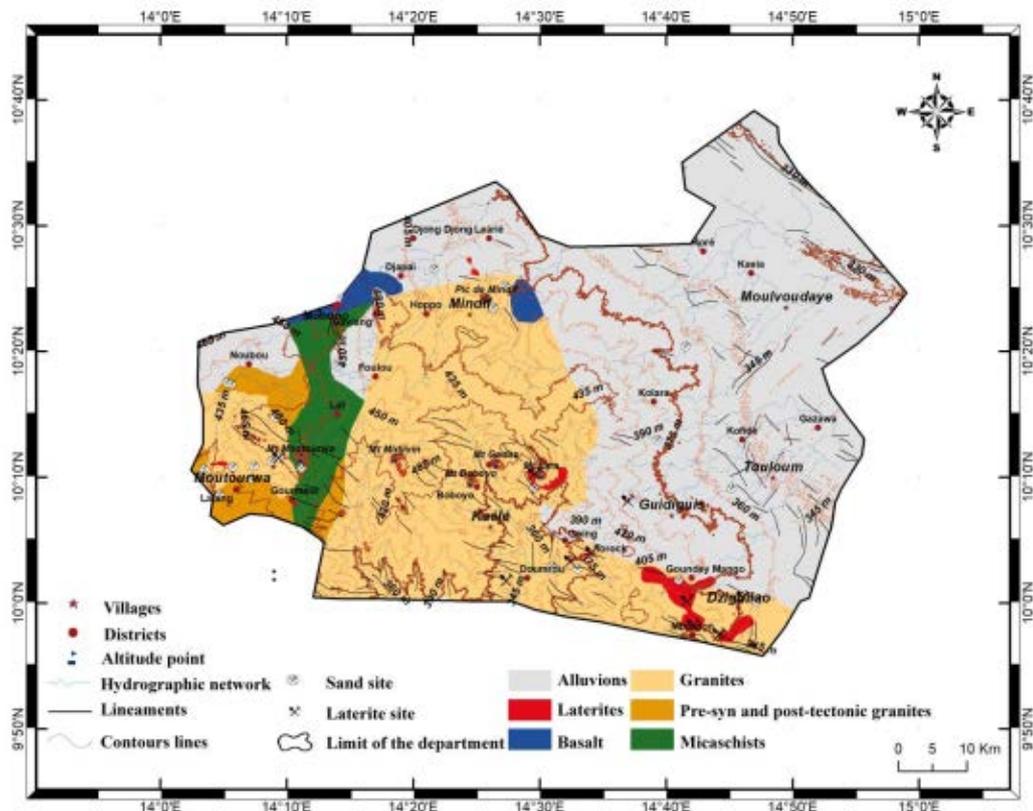
Figure 2. Geological map of Mayo-Kani (from [27])

The study area (Figure 2) is located in the far-north of Cameroon. It is bounded by latitudes (9.50°N-10.40°N) and longitudes (14.00°E-15.50°E). This area is covered with sedimentary formations and magmatic formations represented by a set of isolated and chaotic rock masses. The geological formations generally listed are [27]: granites, sandy clays, micaschists, clay sands, laterite, basalts and rhyolites.

The geological maps that we have just described (Figure 1 and Figure 2) enable to make a mining inventory of the region. They include a legend that lists and describes the formations found there. These formations are a projection on the topographic surface, of the rock layers organization in depth. The realization of these maps was based on the "entities" recognition that make up the subsurface and on the geologic formation's geographical distribution and their mutual relations.

3. Data Collection, Materials and Methodology

3.1. Data Collection

The data collection was done in several phases: the documentary research, the interviews with the competent authorities (mayors and village chiefs) and the inhabitants. Then a preliminary study was carried out for the development of the logical framework of the study, to define the incomes necessary for the work and to establish the activities chronogram. The topographic data used are derived from the SRTM (Shuttle Radar Topography Mission) model. The processing of the collected data and the realization of the maps were done with the software [27]: Excel, MapInfo 15.2.3, Global Mapper 18.1, Google earth pro, Garmin Bescame, Surfer, Arcgis 10.5, Geomatica 2016 and Adobe illustretor.

3.2. Materials

The materials used are: a computer, a GPS, the Cameroon DTM, the administrative map of Cameroon, the Earth explorer sites and Global Mapper to extract the topographic data SRTM (Shuttle Radar Topography Mission).

3.3. Methodology

To carry out this study, a set of operations were carried out [28,29,30]: Georeferencing has been applied to the SRTM map to match each pixel in the raster with a pair of geographic coordinates. The more control points you have, the better the adjustment and correction of the georeferencing distortions. This process displays the raster in a spatial context. The digitization of all the information present on the scanned raster maps was carried out and organized in layers of information. These layers of information include among others [28,29]: the boundary of the study area, contours, sidelines, hydrographic network, roads, runways and localities. The alphanumeric data entry and integration phase allowed the development of a database consisting of the description of each graphic object on each information layer. The Digital Terrain Model (DTM) was made by digitizing contours and dots from the sector's SRTM map. The map set was tied to the geographic coordinate system: GCS-WGS-1984 and the UTM projection system zone 33N.

The following functions have been applied in ArcGis to get all maps [28,29]: The cut-off function allows to cut the study area on the Cameroon DTM; The Fill function enables to fill the cells identified as being points of depression; The flow direction function allowed the flow directions on the DTM map to be identified; The flow accumulation function enables to calculate, for each cell, the quantity of water accumulated in the cell due to upstream flows; The vectorization function of the hydrographic network allow to generate a layer corresponding to the hydrographic network and the level of detail of the network, by using the number of cells varying from 200 to 2000; The stream to feature function has converted the network into a linear shapefile representing the hydrographic network; the function designating an outlet has enabled to place a particular outlet on the watercourse and delimit the watershed connected to this outlet; The watershed function was used to classify the river system. Various other functions enabled to generate the hypsometric slope maps and lineament maps.

4. Results and Interpretation

An important part of economic activities depends significantly on the development of the resources of the soil and the subsoil. It is therefore imperative to be able to identify and locate these different resources [28,29]. To achieve this, hydrologists, hydrogeologists, geologists and geophysicists must rely on visible surface and subsurface clues [28,29]. For example, the accumulation of a metal in a particular geographic area is frequently due to the presence of a shallow or underground watercourse; indirect consequence of a deep geological event often having surface repercussions. These impacts are in the form of watersheds or lineaments. The mapping of watersheds and lineaments is particularly important in the mineral and oil fields exploration and water management [28,29].

In this part, we will interpret the erosion structures that are watersheds, slopes and lineaments. Fractured structures that can significantly influence all fracturing of the study area.

4.1. Interpretation of the Map Cut on the Cameroon DTM

Figure 3 shows the procedure for cutting the DTM of the Mayo-Kani Division. It was carried out by superimposing the Cameroon MNT raster map and the vectorial administrative map of Northern Cameroon.

4.2. Interpretation of the Digital Terrain Model

Nowadays, we cannot speak of morphological characterization of a given region without involving the notion of digital terrain models (DTMs) [28-37]. Figure 4

shows the digital terrain model of the Mayo-Kani Division. This model is the numerical representation of the region by a field of altitudes. This representation can be either in the form of a slowing of points characteristic of the region, or in the form of a vector constituting a contour plane, or in the form of a regular grid with square meshes known under the name of representation "raster" [37]. In this study we chose the last representation because it is the most used.

The cut function allows to obtain this DTM. It is a homogeneous model and comes from a single SRTM input source. In the case of a DTM from several sources, supplementary steps can be added to treat each zone with the corresponding parameters, again using the elastic grid [37]. The map (Figure 4) shows multiple undulations of the relief that result from the coalescence of the watersheds. It also presents an advanced stage of soil erosion due to river systems. The exploitation of this DTM for the purposes of mapping the lineaments will be realized in the following.

4.3. Interpretation of the Watershed Map

The map (Figure 5) shows all ten watersheds in the Mayo-Kani Division. The outlets were selected respecting the field constraints. The ten watersheds are mainly drained by different Mayos and have a very dense hydrographic network. The capacity of each of these watersheds depends on its geometric shape. In general, they are hexagonal and most of the streams that feed them are seasonal and only flood during the rainy season. The different watersheds (Figure 5) have static characteristics and are presented in a flat space where they are easier to describe in the face of the complexity of the processes that take place there. The larger the size of the watersheds, the more diverse the forms and internal configurations of the river system. These watersheds are sensitive to fast floods and their rate of flow concentration is mainly related to the combination of the slope system and the organization of thalweg networks. Overall, most of these watersheds experience heavy runoff during the rainy season.
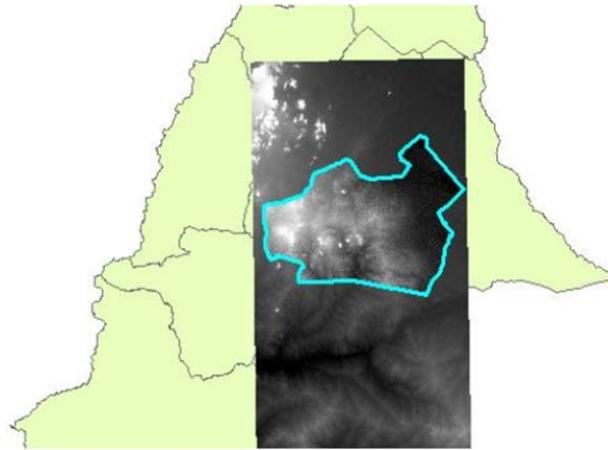
Figure 3. The administrative map of Northern Cameroon and the Mayo-Kani DTM superimposed
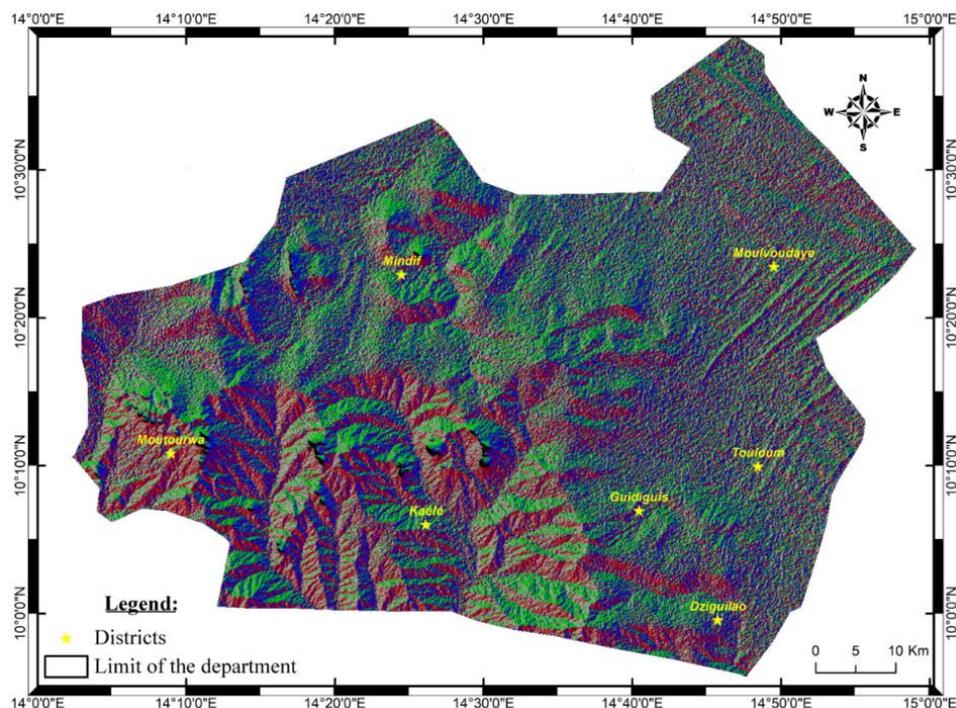
Figure 4. Map of Mayo-kani Digital Terrain Model
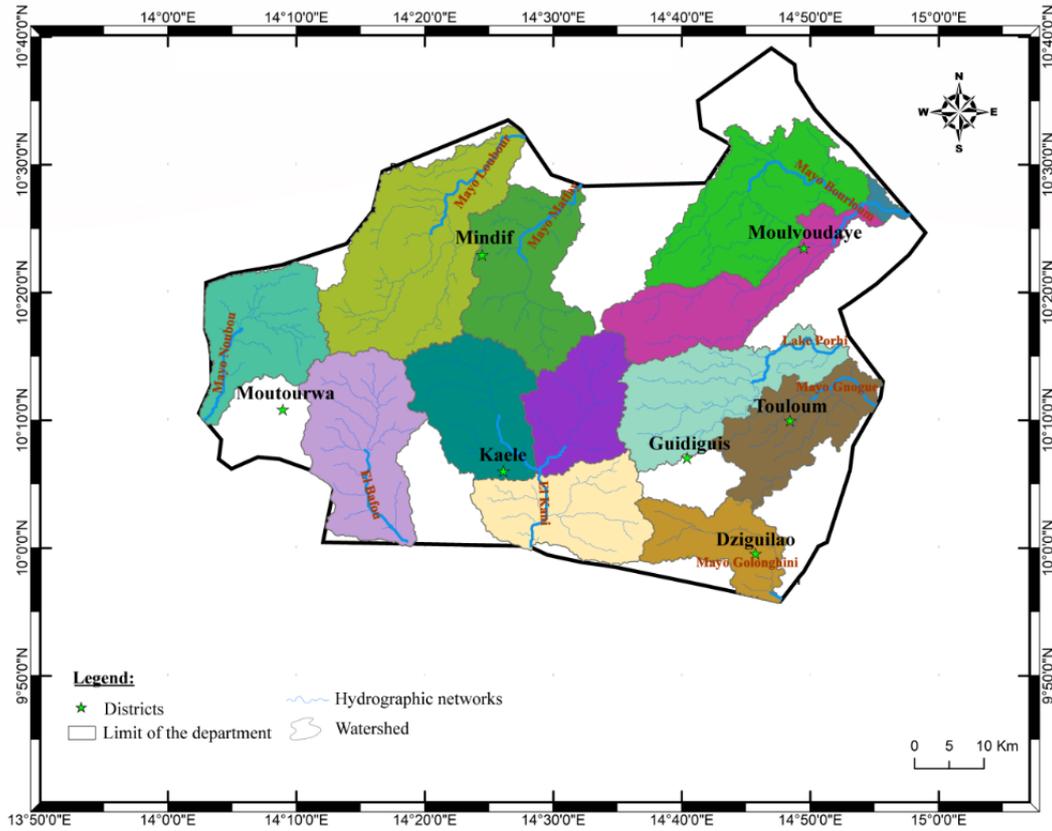
Figure 5. Map of Mayo-kani watersheds. Some areas lack watersheds due to a nonexistence of rivers: they are probably reward deserts

The knowledge of the various watersheds is fundamental in the context of this study because it will allow in the future: to make a hydrological cartography of the region; to set the general framework for urban water studies, to know the level of abstraction, to plan the prevention of flood risks, to identify floodplains or wetlands, etc. In mining geology, knowledge of the different watersheds can identify: the direction of transport of ores and particularly heavy metals (gold, diamond, rutile, etc.); deposit points (gold traps); the source of the sedimentary rocks.
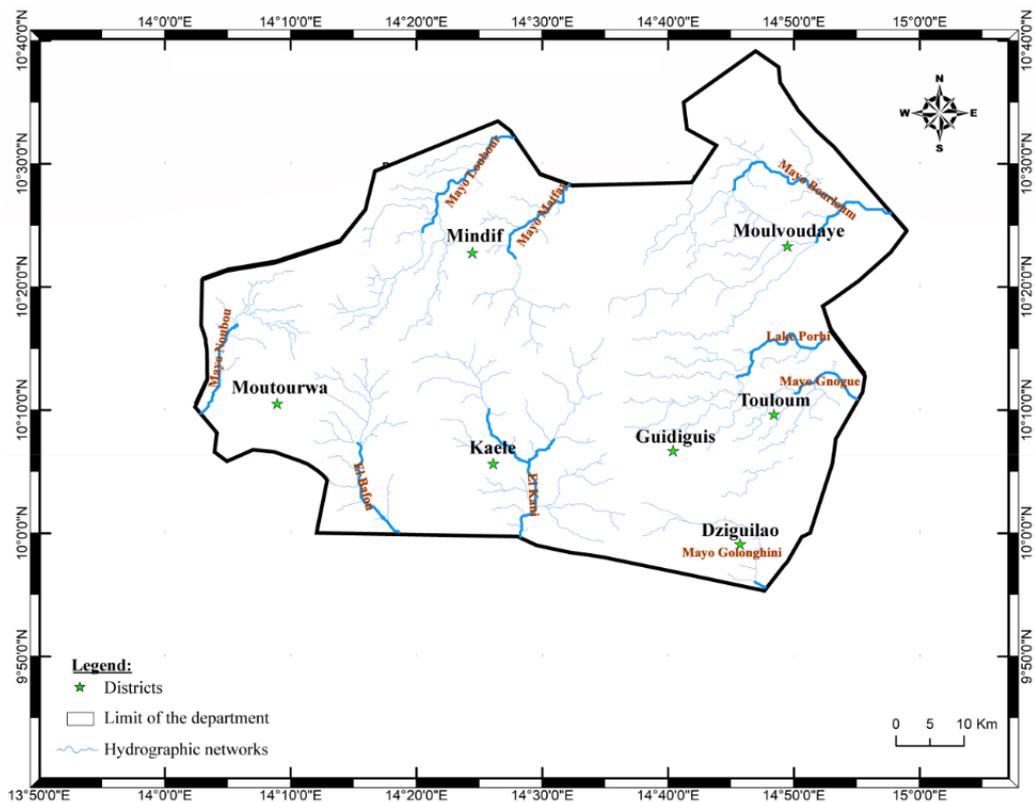
Figure 6. Map of the Mayo-Kani hydrographic network. The main rivers (Mayos) are seasonal

4.4. Interpretation of the Hydrographic Network Map

On the map (Figure 6), the simulation of surface flows was carried out on the twelve watersheds whose average surfaces vary between 30km^2 and 40km². We observe that the organization of the hydrographic network is diversified and dense for some main Mayos and is minimal for others. All of this has some influence on the size of watersheds. The layout of the hydrographic network is largely related to the structural phenomena evolution that affected the region during geological time. The hydrographic scalp practically follows the major accidents that affected the Precambrian granitic formations of the region and which have changed with the evolution of tectonics [27].

In the region of Mayo-Kani we generally note the undermining of the banks of the main Mayos [27]: this phenomenon appears during floods. The waters scour the base of the banks that collapse because they are overhanging. These waters allow the creation of meanders with the sediments torn from the concave banks that settle on the convex banks. But most of these sediments move towards the outlet [27]. In the zone (Mayo-Kani) there are two erosion factors: On the one hand, there are natural factors, and on the other, agro-socio-economic factors. The natural factors are the aggressiveness of the climate, the nature of the soils, the geological substrates, the reliefs and the vegetation. The agro-socio-economic factors are mainly population growth, the practice of unsuitable farming techniques and overgrazing.

4.5. Interpretation of the Hypsometric Slopes Map

The hypsometric slopes map allowed us to quantify the rate of erosion of the region using the slope length factor (X) and the stiffness factor (S). These factors are the result of the influence of topography on erosion. They are considered in the Universal Earth Loss Equation (LS) which combines the effects of a slope length factor (X) and a steepness factor of the slope (S) [38,39,40]. The slope stiffness reflects the influence of the slope on soil erosion, the amount of runoff increases due to the continuous accumulation along the length of the slope (factor X). Likewise, the runoff rate increases when the slope stiffness (S factor) increases [39,40]. The LS earth loss is estimated in our case by the following formula:

$$LS = (X/22.1)^m \left(0.065 + 0.045S + 0.0065S^2\right)$$

Where: X: slope length (m) = (flow accumulation * resolution); S: Slope gradient (%).

For our study, X and S values were constrained from the Digital Terrain Model (DTM). To obtain the X value, flow accumulation was introduced from the DTM after several flow direction and fill tests in ArcGis.

The gradient of the slope S (%) was also constrained from the DTM after several stalls with the ArcGis software. The value of the parameter m has been chosen equal to 0.2 because the class of slopes with the largest area has remained greater than or equal to zero [39,40].

The map (Figure 7) shows the LS factor distribution over the study area. The range of LS values varies between (0-1) to (5-9) which corresponds to low erosion and high erosion of the plain's areas [39,40]. The map shows us that areas of high erosion in the Mayo-Kani region are found in Boboyo, Moutourwa, Kaele, Mindif and mountainous areas.
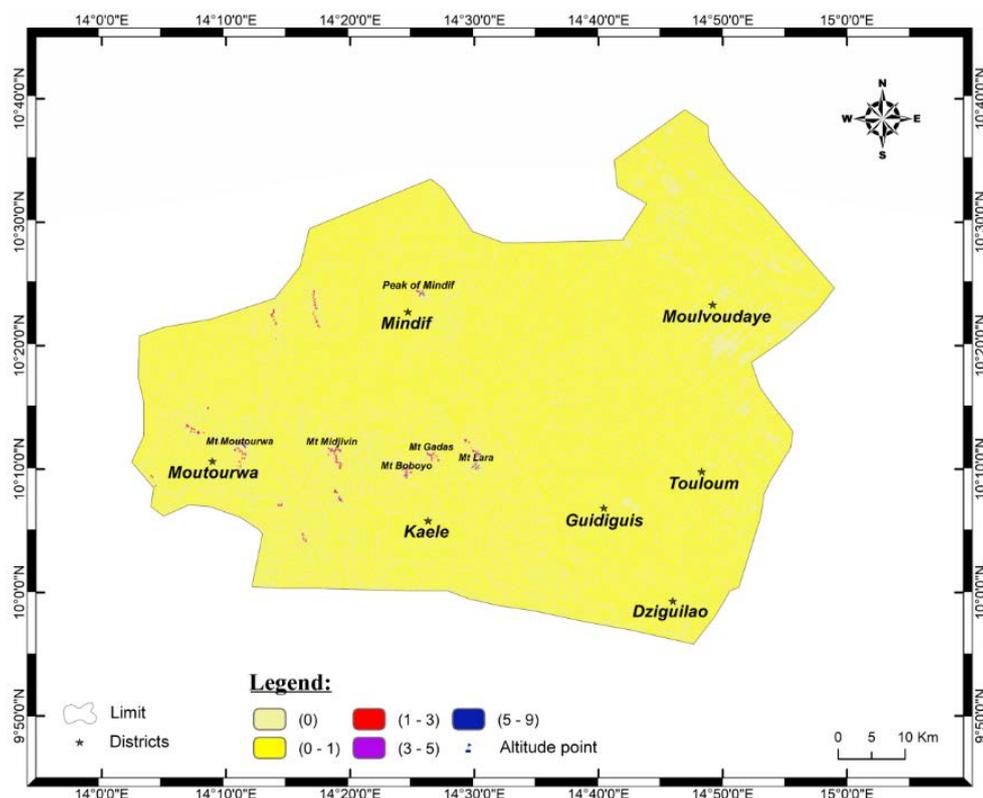
Figure 7. Hypsometric slopes map. It reflects the LS factor distribution in the Mayo-Kani Division
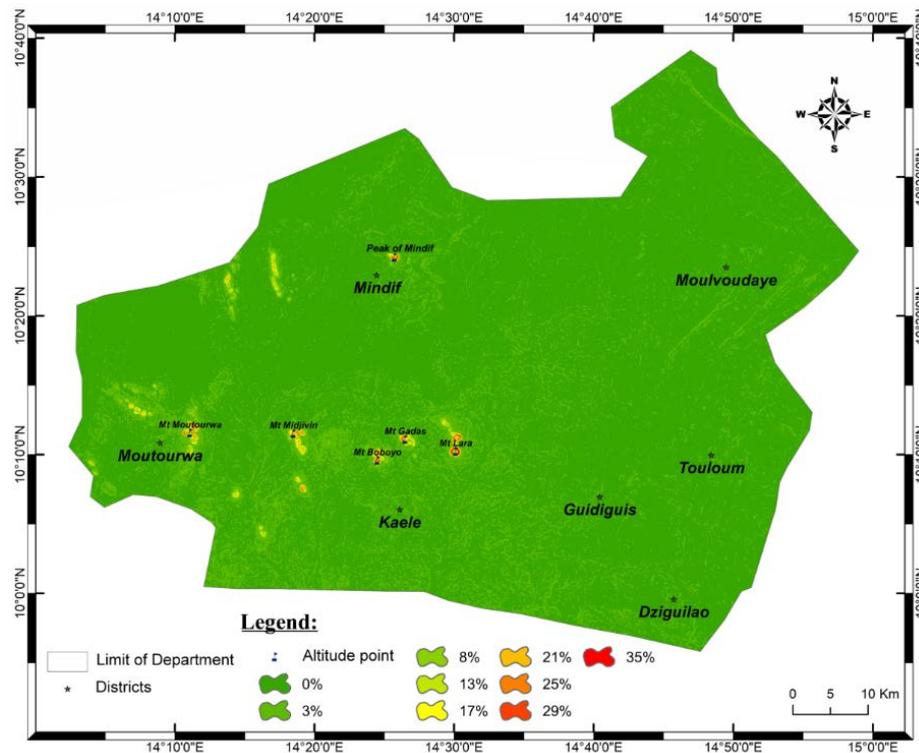
Figure 8. Map of the slope cover of Mayo-Kani Division. It allows to observe the distribution of slopes in the region

4.6. Interpretation of the Slope Coverage Map

The features of landforms that influence erosion are slopes [39,40]. Indeed, the high slopes favor the acceleration of the runoff and consequently the erosion. The map (Figure 8) shows the slope cover in the Mayo-kani department. It can be used in determining areas sensitive to erosion. For this reason, we chose three classes of slopes: low slope (0 to 3%), average slope (3% to 8%), high slope (>13%). The slopes were constrained by a hydrological model in ArcGis. The map (Figure 8) shows the distribution of slopes in the Mayo-kani region. Areas of high erosion correspond to areas of high slopes: Boboyo, Moutourwa, Kaele, Mindif and mountainous areas.

4.7. Interpretation of Lineament Maps

The extraction of the lineament can be carried out in two ways [11,30-37]: manual and automatic (numerical). Manual extraction of lineaments requires complete interpretation and pure user analysis. The automatic extraction of lineaments uses a 3D image (DTM). Directional filters are applied to enhance some features of the DTM. The different results enhance in a more or less clear way the lineaments of the sector. After that, error correction is performed by erasing the lineaments as hills or ridges. This correction assumes that lineaments are structural lineaments identified as valleys, rivers, or lines of erosion [34-40].

In this part we analyze the lineaments resulting from manual and automatic extraction for cross-validation.

4.7.1. Interpretation of Manual Lineaments

The detailed map of the lineaments (Figure 9) was made through an interpretation of the images derived from

the various techniques of manual treatments. This map has a high density of lineaments of varying sizes ranging from a few hundred meters to several kilometers. It highlights different nodes of the fractures. These nodes constituted by the intersections of the fractures would have significant water potentials. They often appear with a more or less marked shift; but at the satellite observation scale, they are sometimes difficult to observe [11,30-37]. The map (Figure 9) shows 233 lineaments unequally distributed over the study area. These lineaments are structural, their size varies between 0 and 13 km. The main lineament has a length of 13 km, the secondary lineament has a size of 10 km, the average length of lineaments is 3.19 km. The total length of the mapped lineaments is approximately 743.808 km. The main lineament (13 km length) diagonally crosses the study area in the NW-SE direction. According to their directions, the lineaments thus listed are grouped into 17 directional classes of 10-degree intervals. The symmetric rose diagram highlights the following preferred directions: NW-SE, NNW-SSE, WNW-ESE, NNE-SSW, ENE-WSW, NE-SW, N-S and E-W.

The histogram (Figure 10) of manual lineaments distribution grouped in class numbers according to their lengths is antisymmetric. Table 1 shows the percentage of manual lineaments according to the different orientations. The major percentage is SE-NW (33%).

4.7.2. Interpretation of automatic Lineaments

The detailed map of the lineaments (Figure 11) was made through an interpretation of the images derived from the various automatic processing techniques in the Geomatica software. This map has a high density of lineaments of varying sizes ranging from a few hundred meters to several kilometers. It highlights different nodes of the fractures. These nodes (points of intersection of the

fractures) constituted by the intersections of the fractures would have non-negligible hydric potentials [11,30-37]. They often appear with a more or less marked shift, but at the satellite observation scale, they are sometimes difficult to observe. The map (Figure 11) shows 169 lineaments unevenly distributed over the study area. These lineaments are structural, their size varies between 0 and 16 km. The main lineament has a length of 16 km, the secondary lineament has a size of 15 km, the average length of lineaments is 3.7 km. The total length of the mapped lineaments is about 669 km. The main trend is 16 km long

and diagonally crosses the study area in the NW-SE direction. According to their directions, the lineaments thus listed are grouped into 16 directional classes of 10° intervals. The directional rose diagram is symmetric and highlights the following preferred directions: NW-SE, NNW-SSE, WNW-ESE, NE-SW and N-S.

The histogram (Figure 12) of automatic lineaments distribution grouped in class numbers according to their lengths is antisymmetric. Table 2 shows the percentage of automatic lineaments according to the different orientations. The major percentage is SE-NW (30%).
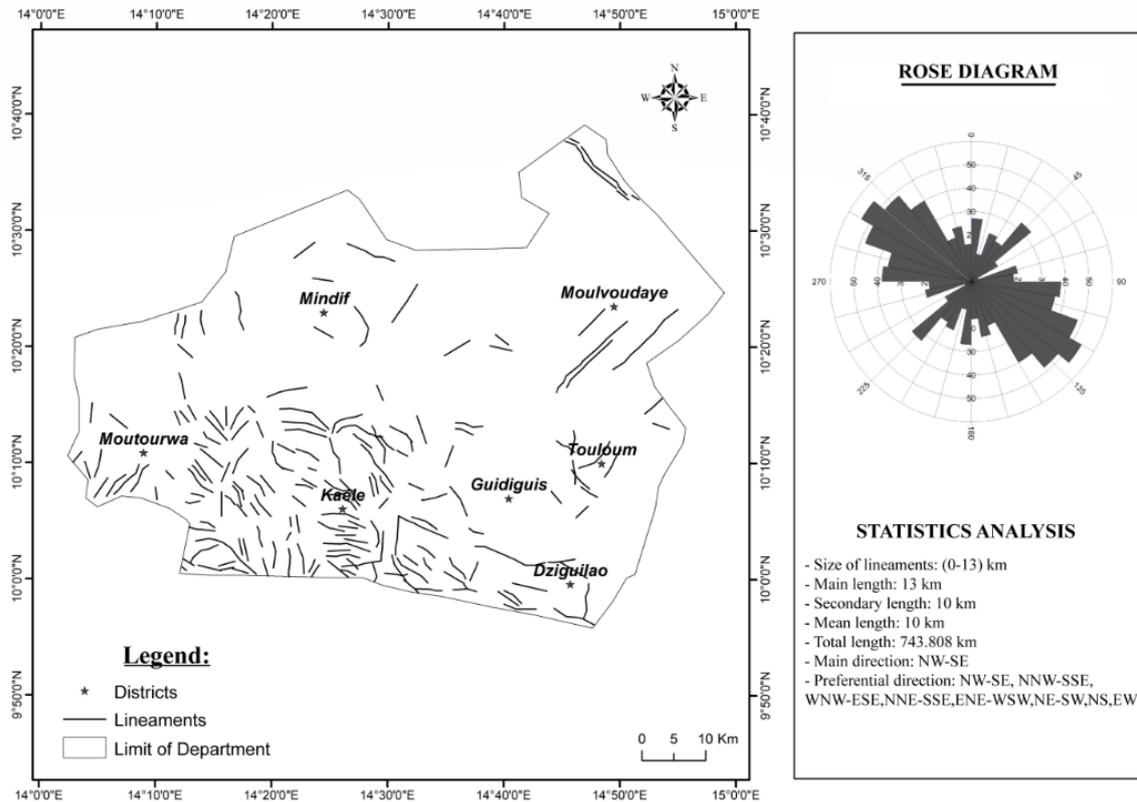
Figure 9. Manual lineaments map and its rose diagram
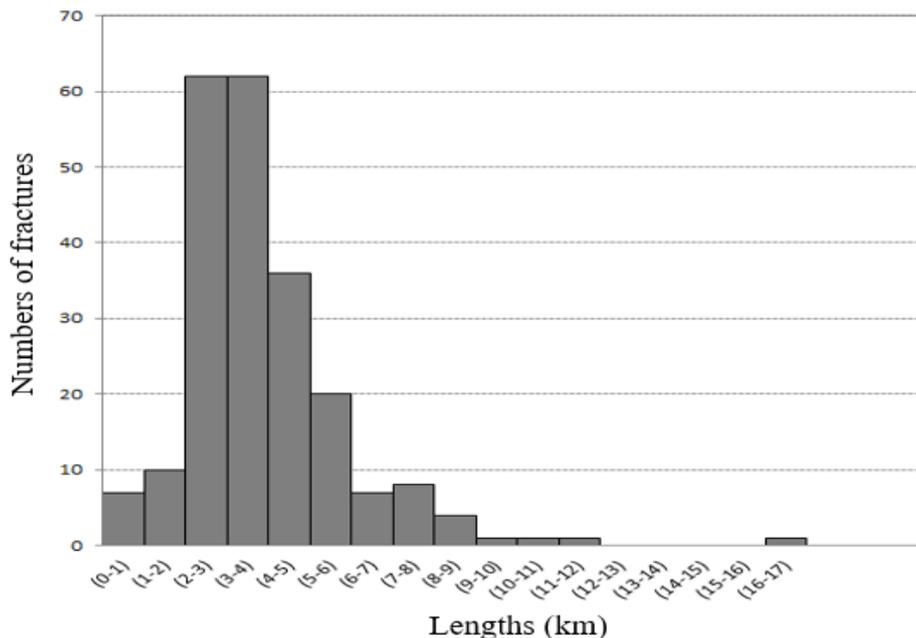
Figure 10. Histogram of manual lineaments distribution grouped in class numbers according to their lengths

Table 1. Percentage of manual lineaments according to different orientations

Guidance Directions	N-S	NNE-SSW	NE-SW	ENE-WSW	E-W	ESE-WNW	SE-NW	SSE-NNW
Number of lineaments	22	5	7	3	29	35	56	12
Percentages	13%	3%	4%	2%	17%	21%	33%	7%
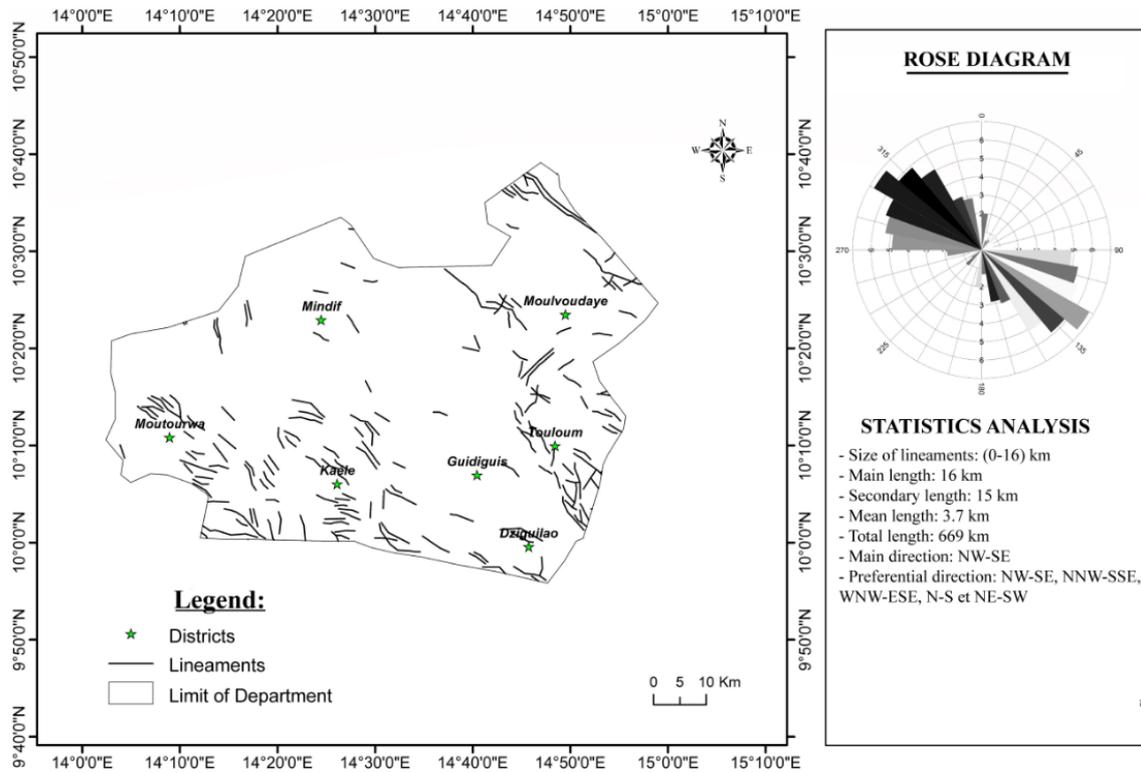
Figure 11. Automatic lineaments map
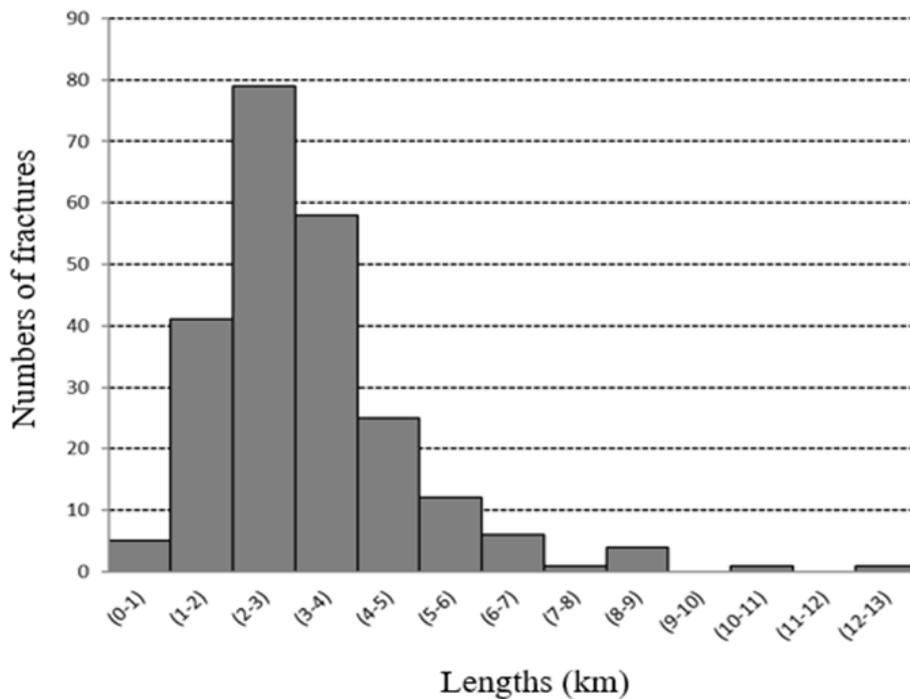
Figure 12. Histogram of automatic lineaments distribution grouped in class numbers according to their lengths

Table 2. Percentage of automatic lineaments according to different orientations

Guidance Directions	N-S	NNE-SSW	NE-SW	ENE-WSW	E-W	ESE-WNW	SE-NW	SSE-NNW
Number of lineaments	27	13	21	6	35	41	33	7
Percentages	12%	6%	9%	3%	15%	18%	30%	9%

Hydrographic network maps, slopes and field data were used to validate the lineament map of the study area. The approach consisted in: Identifying and listing the coordinates (veins, fault) of some structures that come online in the field; Plot this data on the SRTM image processed in GIS software; Manually extract the lineaments while taking inspiration from the different identifying lines in the field; Complete lineaments harvested on land by taking inspiration from the azimuthal orientation of the sun by drawing the boundary between dark and illuminated surfaces; Extract automatic lineaments using the Geomatica software; Overlay these automatic lineaments with the different maps (hydrographic map and slopes).

5. Discussion

The application of pretreatment and processing techniques on the Cameroon SRTM map resulted in maps of the Mayo-Kani Division. The enhancement of images has made them more expressive and finer for structural mapping. Several studies have shown the major contribution of SRTM images or remote sensing for the recognition of discontinuous reservoirs [11,30-37]. These images offer both spectral and spatial resolution suitable for hydrological or hydrogeological studies [11,30-37]. In contrast, [42] presented a synthetic and critical analysis of the use of satellite imagery in hydrogeology.

Detailed maps of the satellite imagined lineaments in Mayo-kani include many regional extension discontinuities. These discontinuities were poorly known because they were never recorded or reported by previous work in the study area. Recall that previous studies on fracturing in the region are very fragmentary [27,30-37].

The results of this study show a great variability of orientation of fractured structures. These results are nevertheless similar to those obtained by several authors who make fractures in satellite mapping [11,30-37]. Some of these authors used combinations of images, ACP, texture analysis and 7x7 dimensional direction filters to produce detailed fracturing maps. The set of techniques used in the Mayo-kani region has updated watershed, slope and fracturing maps, highlighting numerous fractures that were known in the field but not yet mapped.

The statistical analysis of fracture networks emphasizes that the studied fracturing behaves as a regionalized variable. The spatial organization of Mayo-kani fracture networks is similar to that of the Mayo-Tsanaga, Diamare, Lake Chad regions of the far north of Cameroon as evidenced by the work of [14,26,27,30-37]. These regions have the same geological and tectonic context as the Mayo-kani region. The fractures highlighted in this study probably played a major role in the formation of the Precambrian nucleus of northern Cameroon during Archean tectonics [14,26,27,30-37]. These results imply that the different regions of the far north of Cameroon have grieved deformations similar to those of the sedimentary basin of Lake Chad [14,26,27,30-37]. Statistical analyzes of fracture networks support this hypothesis.

6. Conclusion

SRTM images are a powerful tool for groundwater prospecting research. The treatment and analysis of these images allow to map the morphometry of the watersheds, to highlight the various erosion factors, to characterize the fractures network in the Mayo-Kani region, which until then were poorly known.

GIS analysis of watersheds, hydrographic network, slopes, manual lineaments and automatic lineaments, however, did not indicate whether the identified fractures were hydraulically active, i.e. whether these fractures constituted groundwater reservoirs. Fracturing maps derived from this analysis should necessarily be coupled with hydrogeological data for better exploitation of water resources. This approach would enable to identify with greater confidence the areas favorable to the implantation of boreholes for the supply of drinking water to the rural and even urban populations of Mayo-Kani. Fracture networks were analyzed using statistical analysis techniques. The distribution laws of fracture lengths were studied.

Conflict of Interest

The authors declare that they have no competing interests.

Acknowledgements

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