Journal of Geosciences and Geomatics, 2021, Vol. 9, No. 2, 83-95
Available online at http://pubs.sciepub.com/jgg/9/2/5
Published by Science and Education Publishing
DOI:10.12691/jgg-9-2-5

Morphotectonic Analysis of Mboula Area in Relation with Central Cameroon Shear Zone (CCSZ) and Lithology Using Remote Sensing and Field Data

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Received May 13, 2021; Revised June 16, 2021; Accepted June 21, 2021

Abstract The field studies, the Landsat 8 OLI/TIRS processing and the digital elevation model of the Alos Palsar images enabled us to map the lineaments of the Mboula area, in the Adamawa-Yadé domain of the Central Pan-African Fold Belt. The use of the OLI 8 band on Landsat 7 × 7 window made it possible to highlight these lineaments. The result depicted in more than 12,417 segments of lines and curves corresponding to potential fractures and geological contacts. Note that the maximum number of main lineaments after treatment (3,274 lineaments) are oriented NE-SW. The second lineament trend in the study area is NNE-SSW and NNW-SSE respectively. The DEM of the Alos Palsar sensor made it possible to establish four geomorphological units in the study area: hilltop, mountain, plateau and alluvial plain. By superimposing these on the lithological map and tectonic, the coincidence is quite obvious. Thus, field and remote sensing analysis reveal that lithology and the CCSZ have influenced significantly the geomorphological evolution of the Mboula area. These results also illustrate the interest of remote sensing analysis in mapping tectonic structures, with benefit of time saving and precision.

Keywords: *Mboula area, Geomorphology, CCSZ, Field data, Remote sensing*

Cite This Article: Awé Wangméné Salomon, Tchameni Rigobert, Daouda Dawaï, Danra Moh Guela Guy Basile, Haskandi Kalaza Josué, Bisségue Jean Claude, Bayanbé Gaoussou, and Sini André, "Geomorphology and Linear Analysis of Satellite Images of the Mboula Watershed (Central Cameroon Shear Zone): Contribution of Landsat 8, Alos Palsar Images and Field Data." *Journal of Geosciences and Geomatics*, vol. 9, no. 2 (2021): 83-95. doi: 10.12691/jgg-9-2-5.

1. Introduction

The CAFB is comprised of crust that occurs between the Congo Craton, the Saharian Metacraton and the western Nigerian Shield [1,2,3]. It therefore mainly outcrops in Cameroon, Central African Republic and Chad. In Cameroon it is classically subdivised into three major domains: South Cameroon domain (SCD), the Adamawa-Yadé domain (AYD), North-West Cameroon domain (NWCD) [4,5]. The AYD, in-between the SCD and NWCD, is especially crosscut by a set of continental-scale shear zones [5,6] that sometimes juxtapose terranes with different evolutions. Several studies [7,8,9,10] allowed to identified and characterized these shear zones, among which the CCSZ. However, very less study has been carried out on the relation between the local geomorphology and these shear zones. Although the geomorphological elements usually present a narrow relationship with the geology (lithology and tectonic) and the geologic processes that give rise to and modify them [11]. Tectonic geomorphology describes the relationship between the tectonic processes and the surfacial processes resulting in the formation of geomorphic features [12] and seeks to shed light whether exhumation in mountain ranges is controlled primarily by climate-induced erosion or tectonics, or by a complex interplay of both [13,14,15]. Remote sensing generally plays a significant role in providing spatial information needed for this type of analysis [16] and offer the possibility of regional morphotectonic analysis in a fast and inexpensive way.

The main purpose of this work is to combine modern tools and technologies such as Geographic Information Systems (GIS), geomorphology on DEM with field analysis to assess in detail the structural control of the geomorphology of the Mboula area, located toward central east part of the AYD, in relation with the Central Cameroon Shear Zone.

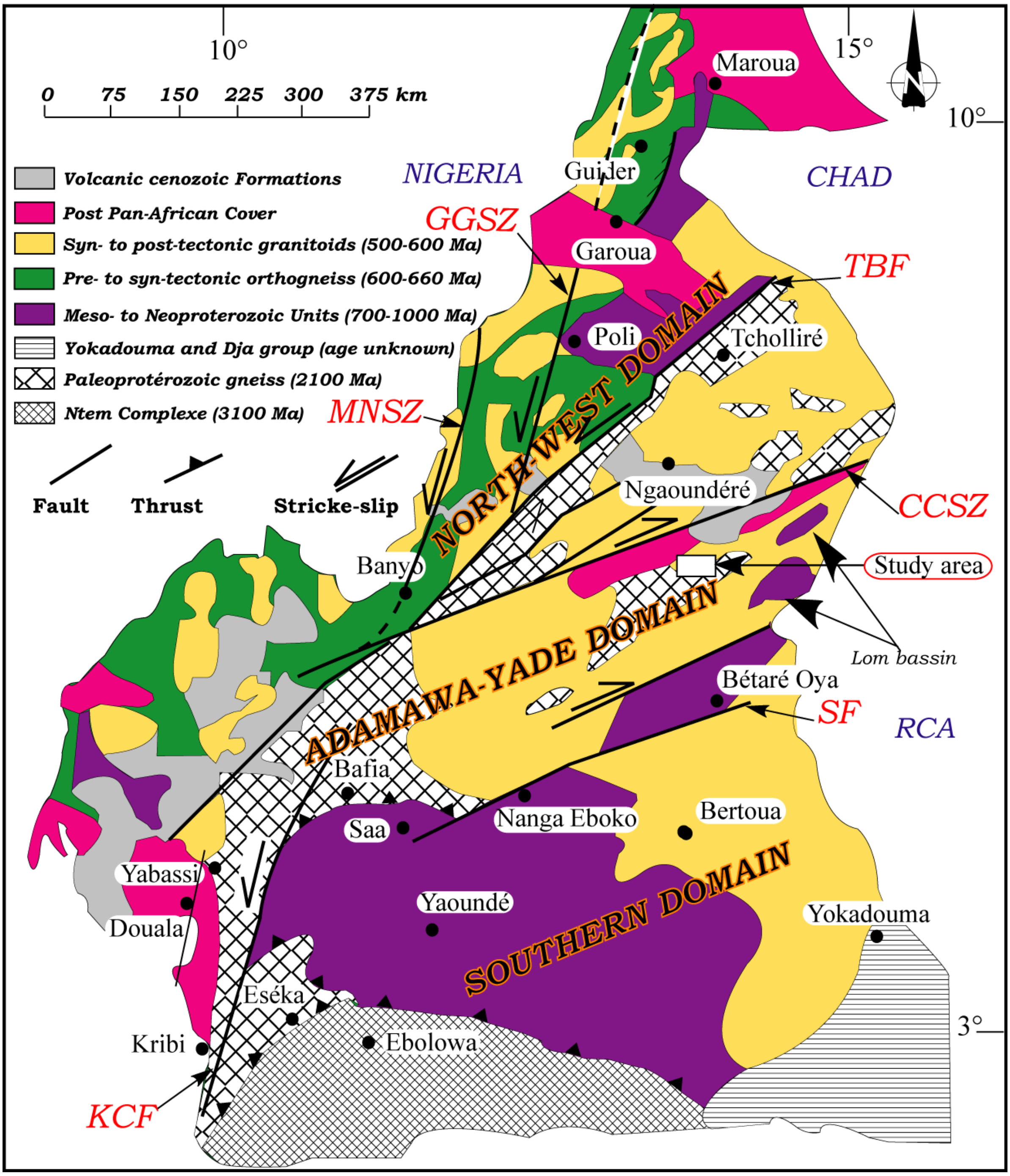

Figure 1. Simplified geological map of Cameroon modified from [17,18]. CCSZ: Central Cameroon shear zone; GGSZ: Gode-Gormaya shear zone; KCF: Kribi-Campo fault; MNSZ: Mayo-Nolti shear zone; SF: Sanaga fault; TBSZ: Tchollire-Banyo Shear Zone

2. Geological Setting

The study area is a watershed that covers an area of approximately1467 km² and limited by the geographical coordinates: 6.7647 and 6.4249 North latitude and 14.1390 and 13.6947 East longitude (Figure 2). Geologically the Mboula area is dominated by the Mboula pluton which is a part of the Adamawa-Yade batholiths, located near the Central Cameroon shear zones system.

It occurs in and around the city of Mboula. According to the geological map (1/500,000) of [8], the Mboula pluton is intrusive in syn-tectonic granitoids. The extensive Cenozoic basaltic cover and soil make the contact between the pluton and the host rocks hardly observable. Therefore, the limits of the Mboula pluton reported here (Figure 1 and Figure 2) are deduced from the geological map (1/500,000), completed by our field observations.

Adamawa-Yadé domain is characterized by widespread of granitoids, many in close association to the transcurrent shear zone [4,7,19]. The hosted rocks are ortho- and paraderivative gneisses, of various composition (Amphibole biotite gneiss, biotite gneiss), of Paleoproterozoic ages [20,21]. They have been considered as belonging to the West Central African Fold Belt and which have been reworking during the Pan-African orogeny at Neoproterozoic [22,23]. The Paleoproterozoic ages referred to igneous and contemporary metamorphic ages. Archean crustal inheritances have been demonstrated in these rocks [24,25].

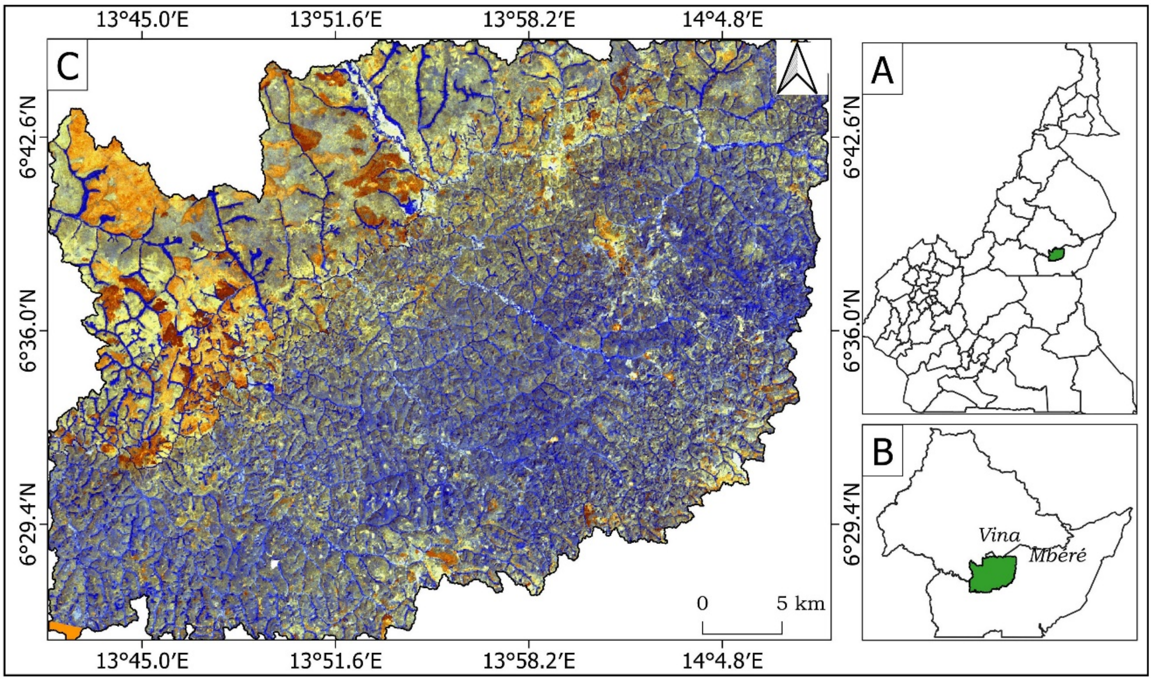

Figure 2. Location of the study area. (A) Administrative map of Cameroon showing the study area in the Adamawa; (B) Administrative distribution of *Vina-Mbere*; (C) Map of the study area obtained from the 765 band of landsat 8

In Ngaoundere, granitoids are amphibole biotite granite, biotite granite and biotite and muscovite granite of crustal origin [7,18]. In the Meiganga and Doua area, granitoids are amphibole biotite granite (ABG), biotite muscovite granite (BMG), metadiorite with metaluminous to slightly peraluminous in character [4,26]. They show crustal, mantle, and/or metabasalt or metatonalite melt signature. Emplacement and crystallisation of metadiorite and pyroxene-amphibolebiotite granite were dated at 614-619 Ma and 601 ± 1 Ma respectively [20]. BMG shows zircon with various shape and various internal structures which are divided into two sets [26]. The first set regarded as xenocryst from Paleoproterozoic granitoids emplaced at 2126 ±36 Ma or from sediments which detritus comes from such granitoids. The second set of zircons shows effects of recent lead lost and a subconcordant U-Pb age of 646 ± 39 Ma. ABG was emplaced during the D3 deformational phase, date at 607 ± 3 Ma, while BMG was trigger because of syn-D1 activity of the CCSZ at 647±46 Ma in association with the collisional process.

Central Cameroon Shear Zone

The CCSZ [27,28] (Figure 1), locally designated the ‘‘Ngaoundéré”, ‘‘Foumban” or ‘‘Adamawa” faults [29,30], corresponds to the SW extension of the Central African Shear Zone which is outlined by a broad mylonite belt directed N70E, and extending from Cameroon to Sudan [31,32]. The CCSZ displays a complex structural evolution which include Pan-African [17,27,28], Cretaceous [33] and Tertiary tectonic events [34], respectively.

Indeed, it represents a deep crustal structure [35] originally interpreted as a transform fault and correlated to the direction of the Pan-African convergent movements in central Africa [36,37]. Most recent studies consider this shear zone as post-collisional [5,28,38] although still poorly integrated in a global tectonic model.

All these studies are focused on petrographic, geochemical and geochronological characterization. They only provide some lithology and tectonics data, but hardly provide any information at the watershed scale, on the relationships between morphology and geology (lithology and tectonics). However, field and satellite data from the area seem to reveal a particular morphology.

3. Materials and Methods

3.1. Software

The softwares used for this research include: Erdas imagine 2013, Envi 5.2, QGIS 3.16, Surfer, Global Mapper 20.0 and PCI Geomatics 2012 mainly used for processing and analysis of multi-spectral and single band images. ArcGIS v10.3 and QGIS 3.16 have been used to georeference, digitize and add various maps into the database.

3.2. Remote Sensing Data Set

Several studies have demonstrated the strengths of satellite images from different sources in geological mapping [39,40,41]. In this study, two types of images were processed: (1) radar images from the PALSAR sensor of the ALOS satellite. The choice of this image is motivated by the spatial resolution (12.5 m) and the high wavelength (band L = 23.6 cm) interesting for a good structural and geological mapping; (2) Landast 8 images which provide medium resolution images, ranging from 15 meters to 100 meters, of the earth's surface and polar regions. They are made up of two types of spectral bands: OLI and TIRS. These orthorectified images appear very clear and crisp.

3.3. Preprocessing of Images

The preliminary phase of processing satellite images consists of eliminating radiometric noise in the OLI / TIR bands of Landast 8 and correcting the geometric distortions in order to make them perfectly superimposable on existing thematic maps (topographic, geological and photogeological maps) [42]. The OLI images used here appear without major radiometric noise and therefore do not require significant processing. This operation allows the normalization of the acquired images. The digital processing was carried out using ERDAS Imagine 2013 software and QGIS 3.16 for digitization, spatial analysis and the production of maps.

3.4. Directional Filters

The automatic lineament extraction in this study is performed by the directional filter and Canny Algorithm of ENVI v5.1, PCI Geomatics 2012, and QGIS 3.16 software respectively. The image enhancement is one of the useful tools to improve interpretability. One of those enhancements is edge sharpening enhancement technique for enhancing the edges of an image. Directional filters (edge detection filters) are designed to enhanced linear features such as roads, streams, faults, etc. The filters can be designed to enhance features which are oriented in specific directions.

Directional filter is applied to Landsat 8 image in N-S, E-W, NE-SW, and NW-SE directions to increase frequency and contrast of the image.

The filtering operation will sharpen the boundary that exists between neighbor units [43]. Directional filters are applied to images using a convolution process by means of constructing a window normally with a (7×7) pixel box of Sobel-kernels filters (Table 1). The directional filter of Sobel kernel is a faster way to evaluate lineaments in four principal directions [44]. The best results were obtained for single band using the following matrix (Figure 3).

Table 1. Sobel-kernels in four principle directions

N-S					E-W					NW-SE					NE-SW				
-1	-1	1	1	1	-1	-1	-1	-1	-1	0	0	-1.4	-1.4	-1.4	-1.4	-1.4	0	0	0
-1	-1	1	1	1	-1	-1	-1	-1	-1	0	0	-1.4	-1.4	-1.4	-1.4	-1.4	0	0	0
-1	-1	1	1	1	1	1	1	1	1	1.4	1.4	0	0	0	0	0	1.4	1.4	1.4
-1	-1	1	1	1	1	1	1	1	1	1.4	1.4	0	0	0	0	0	1.4	1.4	1.4
-1	-1	1	1	1	1	1	1	1	1	1.4	1.4	0	0	0	0	0	1.4	1.4	1.4

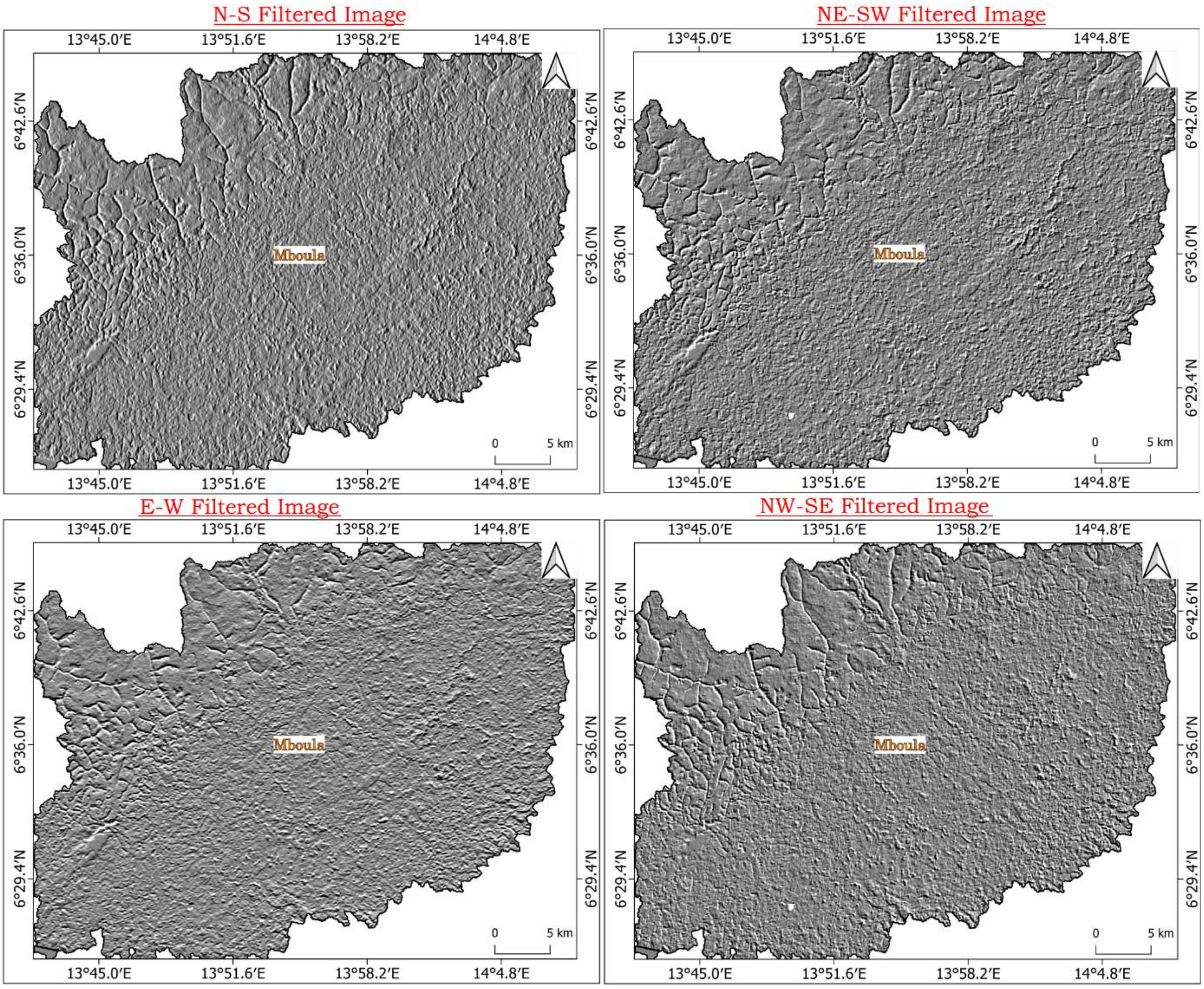

Figure 3. Four subset filtered images derived from panchromatic band of Landsat 8 OLI/TIR

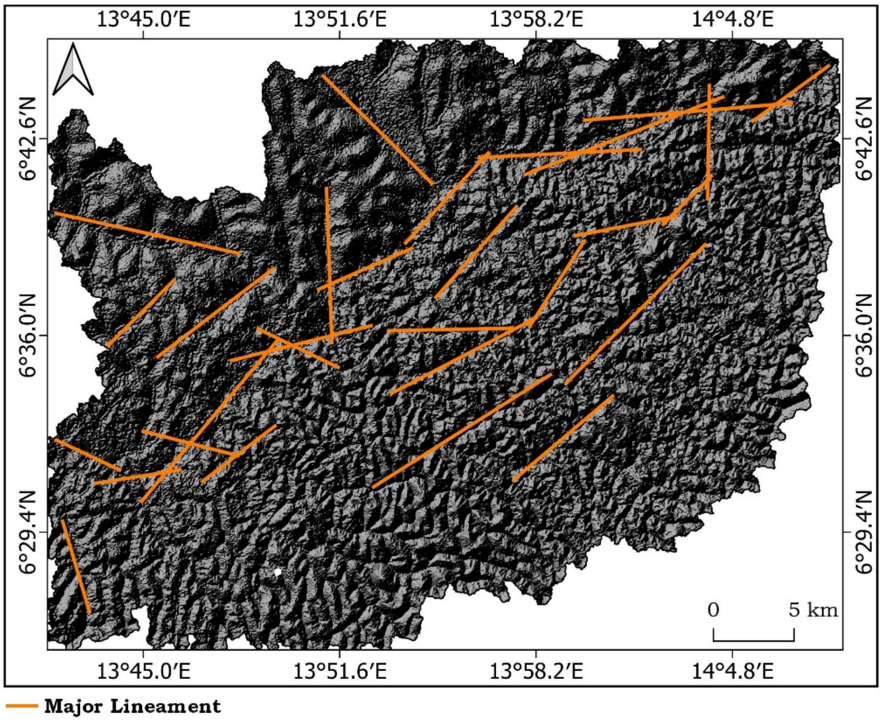

Figure 4. Alos Palsar radar images highlighting major regional lineaments

4. Results

4.1. Identification of Major Regional lineaments

On the satellite images of the study area, the identification of the main regional corridors was possible thanks to the analysis of the Alos Palsar radar images. It consisted in the identification of major geological accidents. Analysis of this image revealed a major direction (N80E to N90E) and a secondary (N60E to N70E) (Figure 4 and Figure 5).

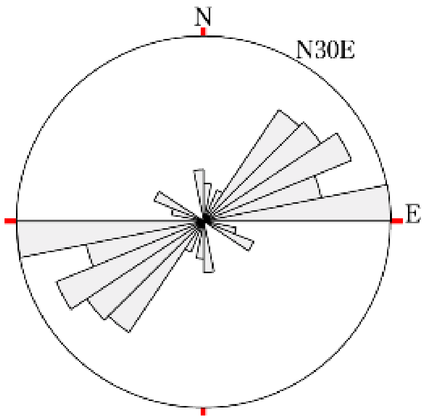

Figure 5. Rose diagram of major regional lineaments

The lineaments are either in the form of curvature or in the form of a staircase. These areas of lineaments usually show curvatures or a geometric staircase shape. Most often in the field, these structures are associated with particular structures, such as faults and strike-slip zones with which mylonites are associated.

The additional major lineaments were enhanced and identified from the digital elevation model. This model also allows the vectorization of the alignment of the massifs and the main hydrographic network and possibly the geological events associated to it.

The peculiarities and anomalies detected at the level of the hydrographic network make it possible to reinforce the reliability and the validity of the linear data as tectonic markers sometimes masked by the vegetation cover and alterites [32,45,46,47,48].

4.2. Hydrographic Network

The configuration of the hydrographic network and the flows following the NE-SW, N-S, NW-SE and E-W directions in the two watersheds of Mboula suggests a parallelism with the alignment of the hill tops, the valleys and the distribution of the slopes. The dendritic nature of the network indicates a development on an impermeable basement [42].

The study sector can be subdivided into seven (07) sub-basins: Gbassoum, south Gbassoum, Ngambaka, Pangando, Sarsam, Mangoli and Mawoul (Figure 6) whose waters flow globally from the NE to the SW like the regional Djérem collector. Its parallel and angular tendencies would testify to its tectonic control. The shape of the basin (or hydrographic network) generally reflects the type of tectonic structure and the type of basement [49].

The orientation N45E to N70E of the rectilinear parts is comparable with most of the large rivers in the Central part of Cameroon. These rectilinear lines could correspond to the traces of the Central Cameroon Shear Zone. The sinuous parts in the Pangando, Vimiyi and Gbassoum stream correspond to a zone of mylonitization described by [8]. The relative and combined influence of tectonics, geomorphology and nature of rocks would have contributed to the establishment of the architecture given to these hydrographic networks.

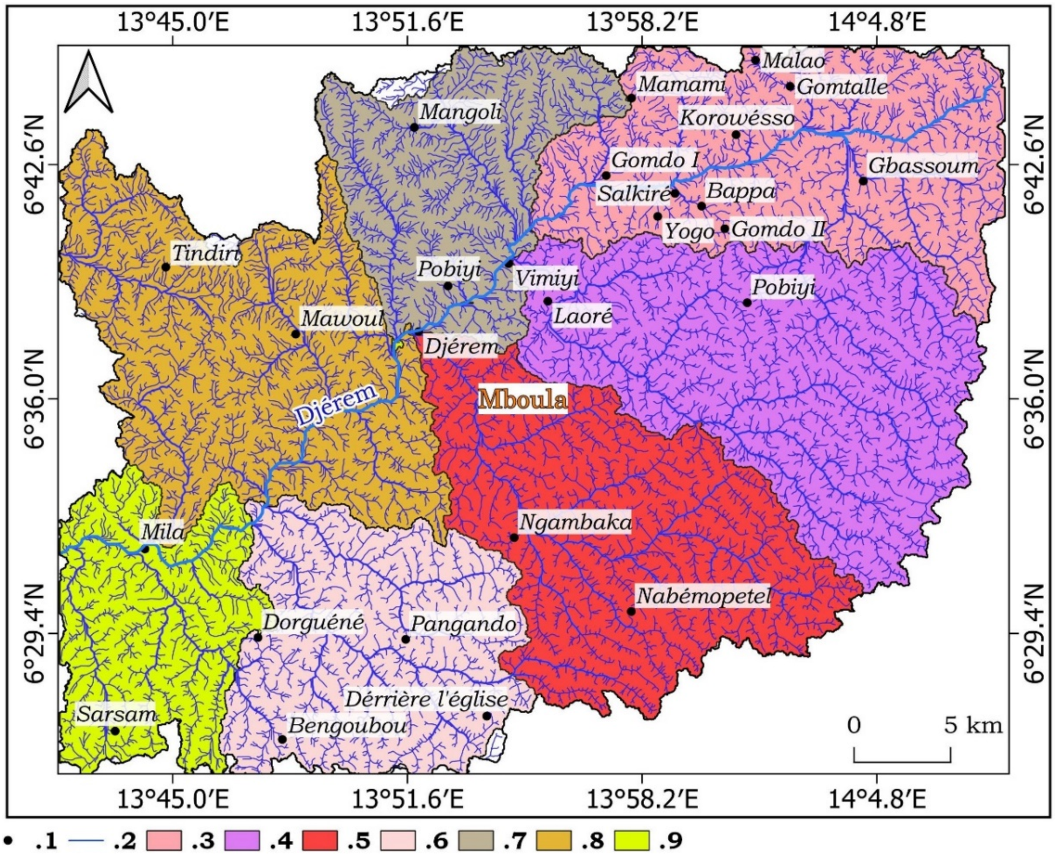

Figure 6. The sub-watersheds of the Mboula watershed. 1. Locality; 2. Stream; 3. Northern Gbassoum; 4. southern gbassoum; 5. Ngambaka; 6. Pangando; 7. Sarsam; 8. Mongoli; 9. Mawoul

4.3. Confrontation of Lineaments with Structural Geological Data

The superposition of the four lineament maps obtained (Figure 3) from the filtered images led to the creation of a synthethic lineament map (Figure 7a). For this work, we opted to use the Semi-automatic extraction. In our methodological approach lineaments were automatically extracted from the panchromatic band with the LINE module of PCI Geomatica, and then exported (vector format) to QGIS for validation. However, the function includes several parameters that must be added simultaneously without possibility to visualize the impact of each of them separately [39,40,50,51]. Lineaments that have been repeated more than once are eliminated to avoid repeating segments in the summary map. After processing, the best parameter values established 3274 lineaments (Figure 7b). As shown in Figure 8, it can be seen that the maximum number of main lineaments after treatment are oriented NE-SW. The second major lineament trends in the study area are NNE-SSW and NE-SW respectively.

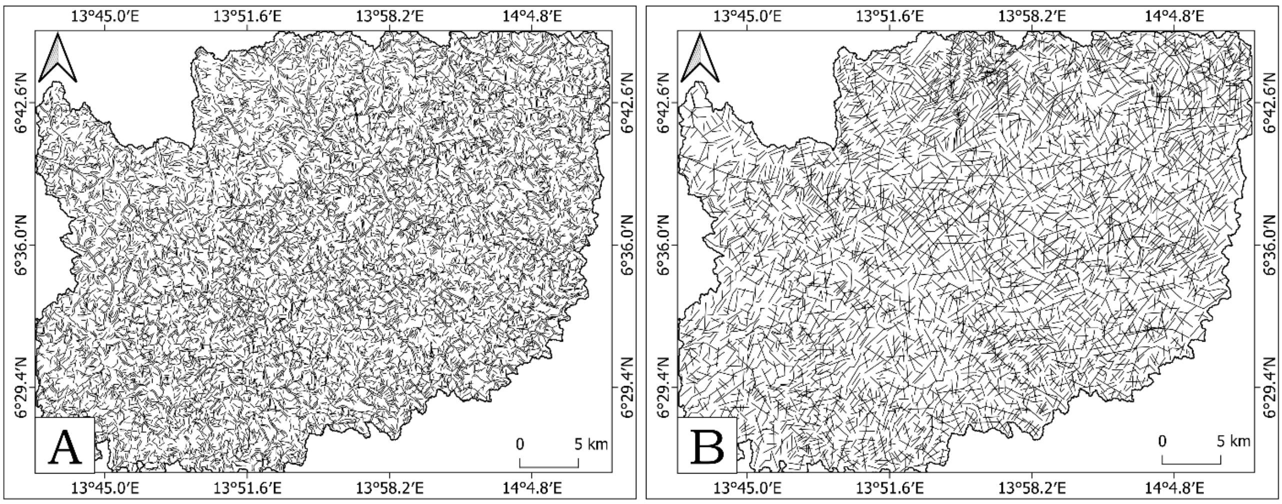

Figure 7. Automatic extraction lineament map (A) after superimposition of the four filters. (B) Lineaments obtained after validation obtained from the filtered Landsat 8 OLI/TIR images

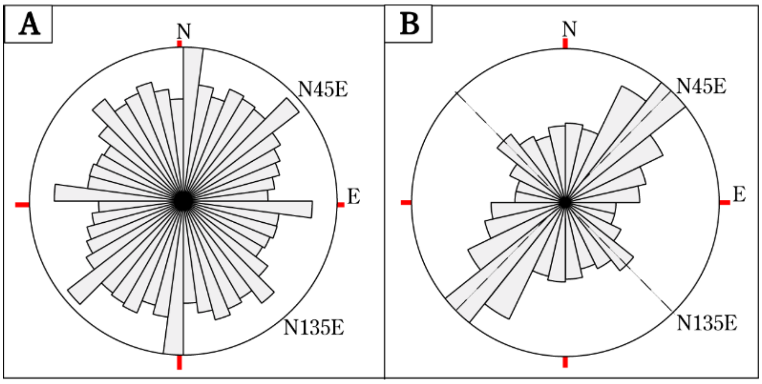

Figure 8. Rose diagram of lineaments (A) before and (B) after treatment

A remotely sensed lineaments map (Figure 9) was produced depending on directional filters and edge enhancement. This map presented the lineaments detected and ascribed to potential faulting in the present work. There is a general compromise between the macro-scale, fractures and the faults (Figure 10) previously mapped by geological survey in Figure 12.

Fields observations and measurements (Figure 10) made it possible to better understand and put into perspective the linear directions revealed during the processing of satellite images. We discovered from this fieldwork that there are several directions of the structures observed on the rock outcrops:

(1) The sinistral and dextral "slip fault" oriented between ENE-WSW and E-W; (2) The veins have a disparate orientation (from N-S to E-W); (3) The faults have one main orientation (NNW-SSE).

The orientations of lineaments ENE-WSW and SSE-NNW were generated using rose diagrams (Figure 11) and trends observed on the structural map field features and the lineament map could be recognized in these diagrams, showing strongly major trend in NE-SW and ENE-WSW.

The precision of lineament map is calculated using ArcGIS overlay technique that determines where the lineaments and faults are matched [52].

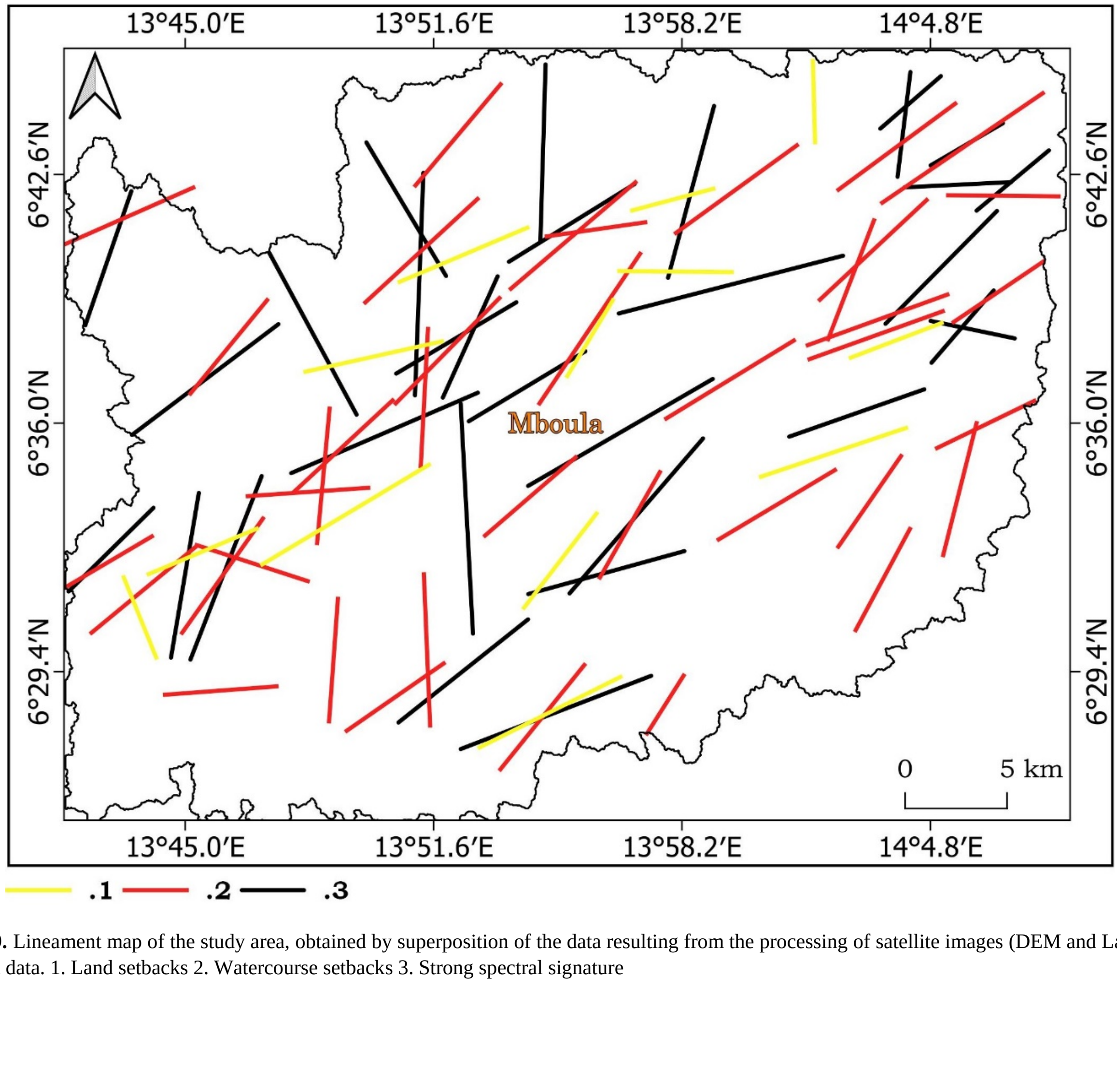

Figure 9. Lineament map of the study area, obtained by superposition of the data resulting from the processing of satellite images (DEM and Landsat_8) and field data. 1. Land setbacks 2. Watercourse setbacks 3. Strong spectral signature

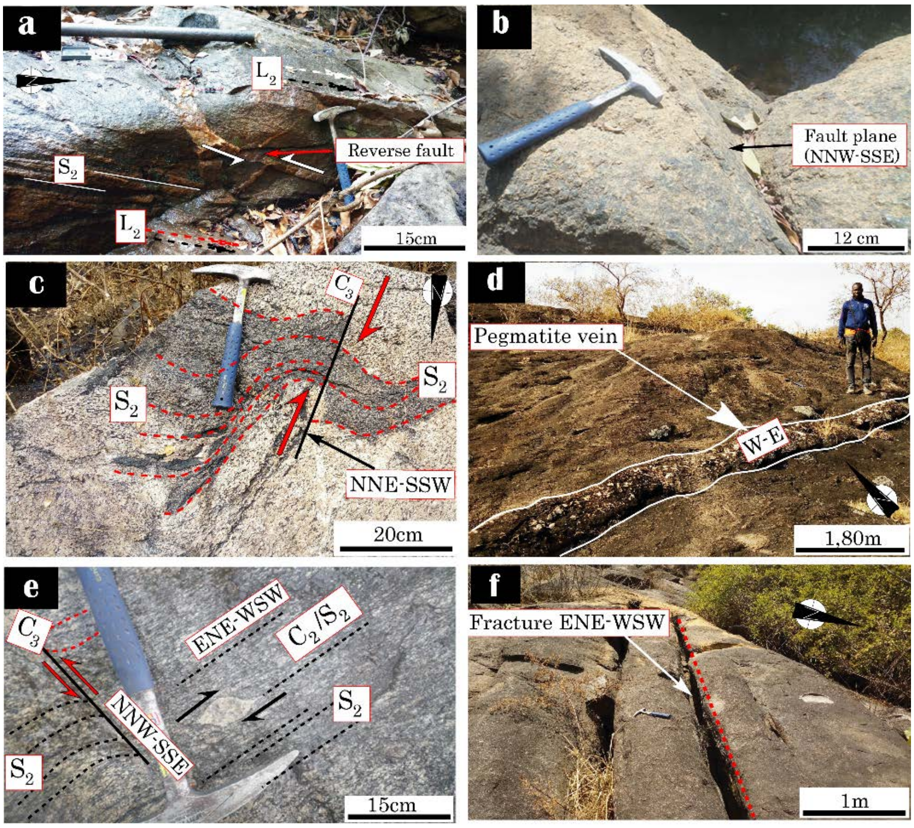

Figure 10. Main structures observed in the field: (a) fault plane filled by a microgranite; (b) normal fault plane filled by a quartzo-feldspathic vein in the stream bed of the Dorguene; (c) C_3 shear affecting an amphibolite vein in the amphibole granite; (d) W-E oriented pegmatite vein in the Gomtalla syenite; (e) C_2/S_2 composite shear, the symmetrical boudin of the stretched-tailed quartzo-feldspathic level is noted; (f) parallel fracture planes followed by the Gambaka stream.

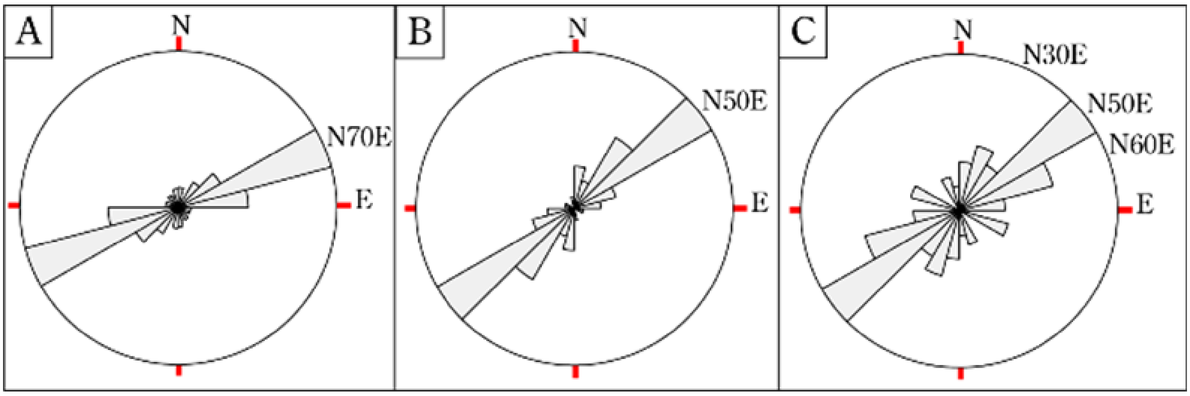

Figure 11. Rose diagram of (a) faults measured in the field, (b) faults observed at stream level and (c) high spectral area

The output of these operations produced two types of lines.

- Non-matching lineaments: these are the lineaments that do not match with any fault line;

- Lines correspond to lineaments and existing fault lines.

4.4. Geomorphological Units

The DEM (Figure 13) from the Alos Palsar sensor made it possible to draw up a geomorphological map of the study area (Figure 14). An analysis of this map highlights four geomorphological units: hill top, mountains, plateaus and alluvial plains.

- Hill top outcroups in the south-east and north-west, in an isolated manner and as intrusions along the NE-SW direction. This allignment is parallel to the Djerem flow direction which is orientated either towards the NW or SE direction or towards the north or south direction. This unit has altitudes of ≈1100m and have a NE-SW orientation which covers about 5% of the study area;

- Mountains are located in the SE part of the study area. This relief is made up of iron mounds developed on the metamorphic and granitic basement. It covers about 10% of the study area with altitudes of about 900m. They have a NE-SW direction made up of flat to round top hills;

- The plateau constitutes about 77% of the main relief shapes. It represents a geographical area where the watercourses are boxed in, as opposed to the plains where the watercourses flow on the surface. It covers areas with altitudes varying around 700 to 900 m. Radar images made it possible to better map the sub-basins that constitute it. The thalweg lines carried by it are generally oriented NW-SE to ENE-WSW;

- The alluvial plain is made up of more or less large and rounded pebbles. The rose diagram distribution of this plain indicates an orientation between NE and NW-SE. The deep character of the alluvial plain in the flow channel which hosts the hydrographic network seems to indicate the major role of runoff water in the degradation of rocks [42]. It covers almost 8% of the surface of the study area.

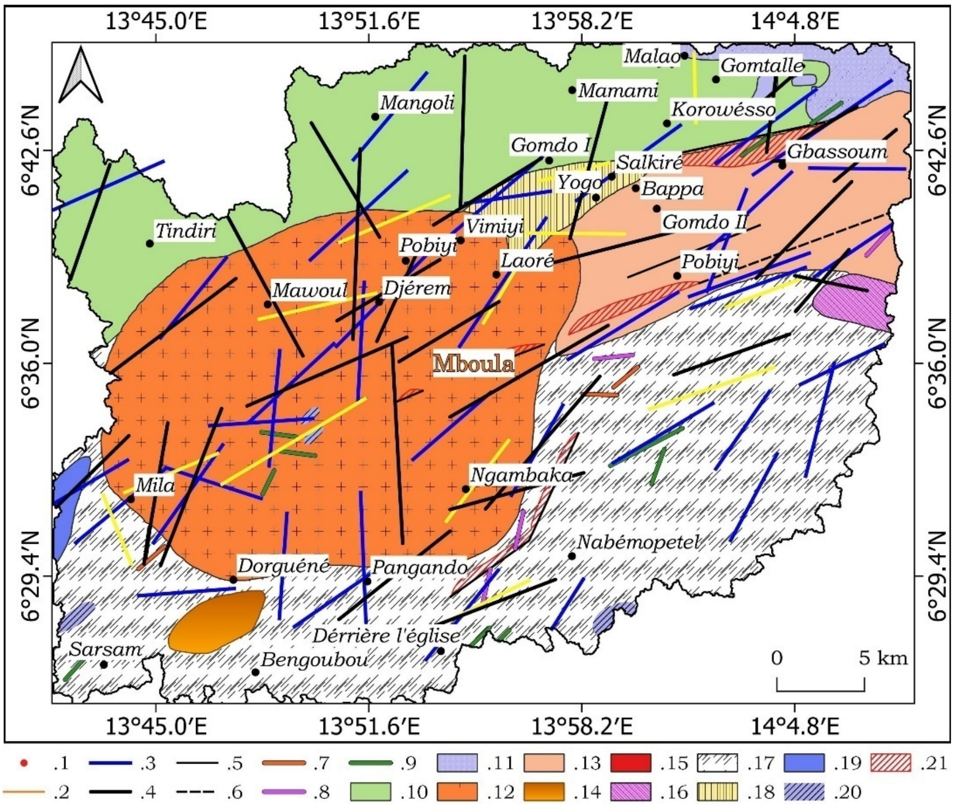

Figure 12. Comparison of lithological data [8], tectonics and lineaments: (1) Locality; (2) Ground setbacks; (3) Watercourse setbacks; (4) Strong spectral signature; (5) fault; (6) Supposed fault; (7) Pegmatite vein; (8) Quartz vein; (9) granite vein; (10) Sandstone series; (11) Basalt; (12) Biotite and amphibole granite; (13) Granite Chlorite; (14) Granite) biotite and garnet; (15) Granite Biotite; (16) Orthogneiss; (17) Biotite and amphibole migmatite; (18) Migmatite biotite; (19) Biotite and amphibole gneiss; (20) Ampphibolite; (21) Mylonithe

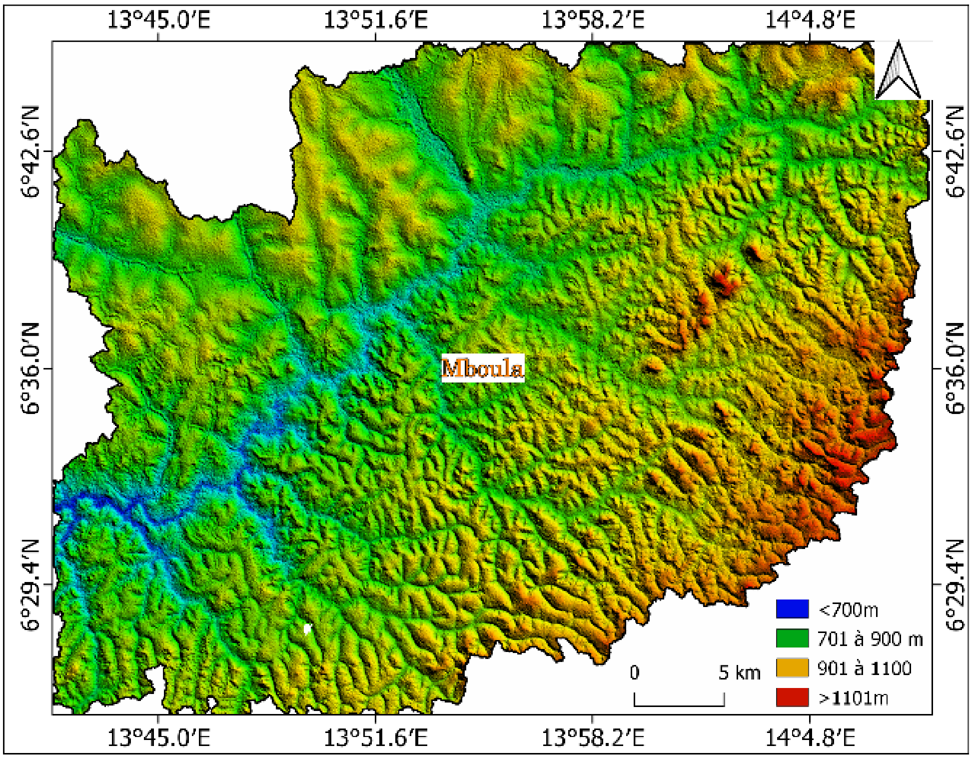

Figure 13. Digital elevation model of the study area

4.5. Relationship between Tectonics, Geomorphology and Lithology

By superimposing the tectonic map on the geomorphological and lithological map, the coincidence is unequivocal (Figure 15). Analysis of the tectonic, geomorphological and topographic map shows that the main directions of flow of the Djérem River are guided by fractures and by alluvial formations. Referring to the geological reconnaissance map of [8] (Figure 15), we noticed that the hill tops are occupied by biotite and amphibole migmatites, chlorite granites and sometimes by gneisses.

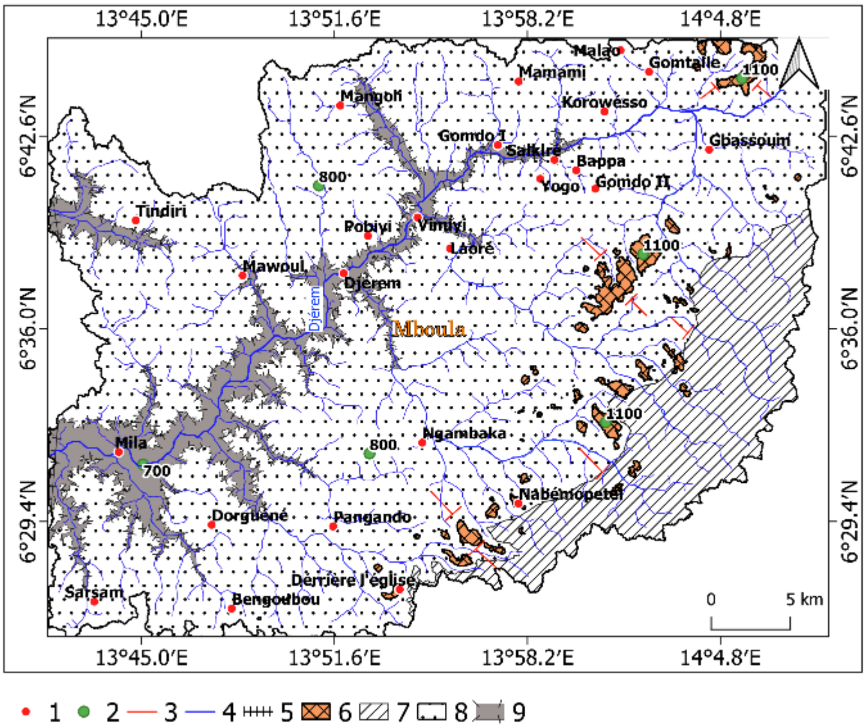

Figure 14. Geomorphological map of the Mboula watershed (Note the alignment of the summits follow the NE axis). (1) Locality; (2) point dimension; (3) rocky slope; (4) stream; (5) bank embankment; summit of collione; (7) mountain; (8) tray; (9) alluvial plain

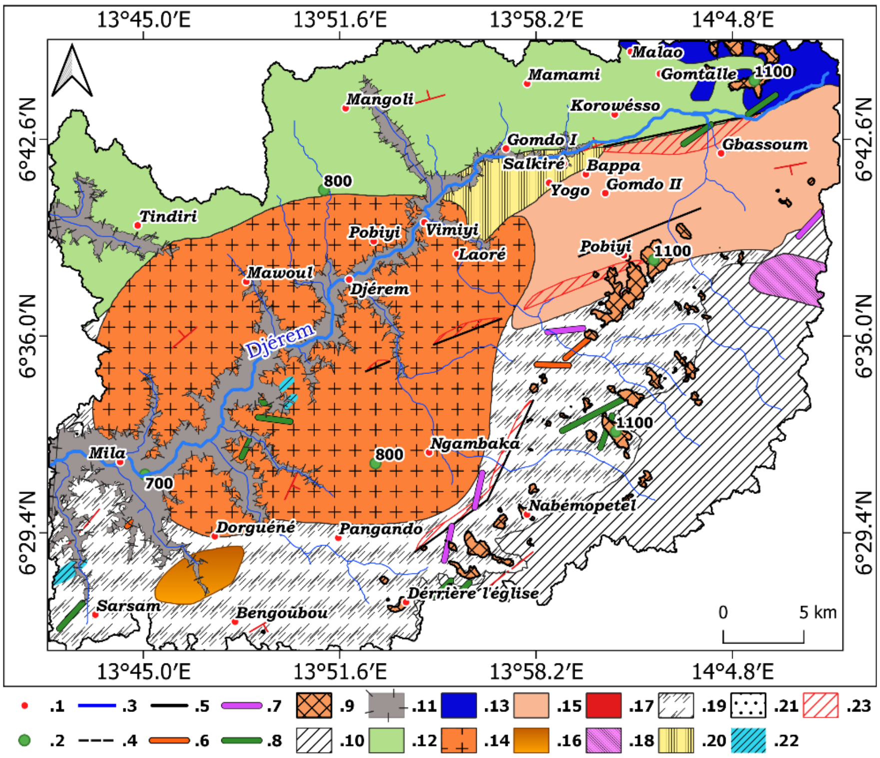

Figure 15. Map showing the relationship between tectonics, geomorphology and lithology. (1) Locality; (2) point dimension; (3) watercourse; (4) supposed fault; (5) fault; (6) granite vein; (7) pegmatite vein; (8) quartz vein; (9) hilltop; (10) mountain; (11) alluvial plain; (12) sandstone; (13) basalt; (14) biotite granite; (15) chlorite granite; (16) biotite and garnet granite; (17) biotite and amphibole granite; (18) orthogneiss; (19) biotite and amphibole migmatite; (20) biotite migmatite; (21) biotite and amphibole gneiss; (22) amphibolite; (23) mylonite

On the other hand, the low altitude zones (from upstream to downstream) are occupied by biotite amphibole gneisses, biotite migmatites, biotite amphibole granites, basalts and formation of the sandstone series. These formations are found in the different orographic sets and are also well represented in the dendritic hydrographic network domain with angular and parallel tendencies. The two northern and southern limit of the chlorite granites of Gbassoum and Bappa coincide with the ENE-WSW fault materialized by mylonites and followed by the Djérem stream.

5. Discussion

The morphotectonic evolution of the Mboula area has been constrained through the coupling of two types of investigations: geomorphology on DEM and field data crossed through a GIS. The results obtained show that the study area consists of NE-SW stretching fold with asymmetric flanks, mountains, plateau and plain. The hydrographic network goes from dendritic to sub-dendritic. The study basin is a vast depression full of eroded valley and bordered by a plateau. The peculiarity of the relief is therefore highlighted by tectonic lines. The paths of rivers and sources follow the directions of fracture networks. In addition, the relationships between the type of basement rocks and topography have been demonstrated by [53,54]. The relationship between tectonic lines, topography and hydrography is very close. The faults and the entities they delimit have an NE-SW orientation, which corresponds to the CCSZ. The topographic therefore seems to have been influenced by the ductile deformation related to the CCSZ and the lithology.

The morphology and spatial arrangement of the four geomorphological units on one hand, and the faults on the other hand, indicate that the study area is a grabben / collapse wall that would have set in place the major faults. The hydrographic network is guided by the tectonic lines. This highlights the tectonic from hydrographic network. It appears that geomorphological units are attributable to geology factors. Like the CCSZ, it has been reactivated several times over [9,28,38,55]. This zone would represent the border between the North paleo-active margin [56,57,58,59] and the South paleo-intracontinental domain [60,61]. The CCSZ will have controlled the establishment of intrusions and regional geomorphology.

In the Aptian, the separation of the African and South American cratons is probably achieved by a selective reactivation of the pre-existing fractures inherited from the Pan-African orogeny, one of the privileged networks of which consists of faults oriented NNE-SSW to ENE-WSW [1,49,62,63,64] to which our massif belongs. In addition, the establishment of the volcanic line from Cameroon to the Upper Cretaceous also contributed to the replay of post-Pan-African faults [65]. The morphology and the structure of the area of Mboula therefore seem to have been imprinted by this shear corridor formed by the Adamawa faults.

The numerous sinistral trend structures recorded within E-W veins can be easily explained using the Riedel shear model of [34] in which E-W fractures and veining and NNW-SSE to ENE-WSW tension gashes are contemporaneous of early sinistral evolution of a NE-SW fault (Figure 10).

The evolution of the CCSZ seems to have influenced its emplacement mechanism of the Mboula granitic pluton. Based on lineament analysis of satellite images and the overall distribution of lineations of the Mboula granitic pluton (Figure 4, Figure 7, Figure 9 and Figure 10), has been interpreted as resulting from the influence of the activation of the CCSZ. Field observations and satellite images data as well as the gentle fold shape of the pluton, seems to indicate that the emplacement late stages of the Mboula granites (at 607 Ma) [26] was influenced by the late dextral evolution of the CCSZ (Figure 10c).

6. Conclusion

This study is part of a geomorphological and linear analysis on satellite images of a portion of the CCSZ through the combination of two types of investigations: geomorphology on DEM and field data crossed through using GIS. The methodology adopted consisted in using the preprocessing technique, maps derived from DEMs and directional filters on Landsat 8, Alos Palsar and terrain data images. The results obtained show that the geomorphological system of Mboula includes four geomorphological units: hill tops, mountain, plateau and alluvial plain. The formation of these geomorphological units would have been influenced by lithology, CCSZ and local faults reactivated during the post-orogenic phases, and during the formation of the basins of the Cameroonian margin, imprinting on the basin its current morphology.

Acknowledgments

This manuscript is a part of the PhD thesis of the first author supervised by the Universities of Ngaoundéré (Cameroon). The first author sincerely appreciate Dourwe Maurice of the University of Ngaoundéré for his contribution in the training of Remote Sensing and GIS. We also thank the anonymous reviewers for their critical comments on this manuscript.

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