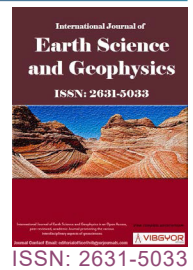


Application of Remote Sensing for the Mapping of Geomorphological Accidents of Mount Cameroon: Vectorization of the Probable Lava Flows Trajectories



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Abstract

Natural hazards are common destructive phenomena that are preventable. Mount Cameroon, an active volcano on the Cameroon Volcanic Line, has emitted innumerable lava flows since the 19th century. The flows that moved in several directions were mapped mainly by field methods. In this article, the main basic data are the SRTM map on Mount Cameroon downloaded and imported to Arcgis 10.2 for processing. Four shaded reliefs and crest lines were generated on the slopes at N000° azimuths, N090°, N180° and N270° respectively with an inclination of the sun at 45°. The generated images helped to vectorize interconnected lines of depression, drained or not and which can serve as flow under the gravity of lavas or possible lahars to towns and villages located on the slopes or at the foothill. The innovation in this work is the combination of satellite imagery with field observations to vectorize the likely trajectories of lavic flows. Thus remote sensing appears as an efficient tool for modern cartography. It was then possible, through satellite image processing, to vectorize the geomorphological lineaments that could serve as the lava flows or lahars channels on all sides of the mountain. An efficient policy to manage disasters caused by volcanism at Mount Cameroon can now be envisaged.

Keywords

Remote sensing, Mount cameroon, Lavas, Prevention

Introduction

Natural hazards are destructive phenomena which have been systematically described by scientists in order to prevent harmful consequences. Since the 19th century, numerous volcanic eruptions took place at Mount Cameroon and were characterized by the lava flows moving in various directions. Several authors [1-13] studied

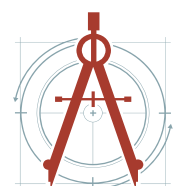
Mount Cameroon eruptions, but no detailed synthesis on the probable direction of lava flows can account for major natural disasters. Apart from technological innovations, remote sensing can be used to monitor large areas through image processing: Disaster and environmental monitoring of tailing reservoirs along the Belt and Road [14], agricultural land monitoring [15], research of archaeological sites [16], correction of color

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distortion and lower brightness of defogging image [17], structural lineament mapping [18], metals research [19] and other works. SRTM (Shuttle Radar Topography Mission) images with a 90 m resolution were processed and used [20] to determine probable lava trajectories on Mount Cameroon. But these authors compiled hazard and risk maps by combining database of DOWNFLOW simulations with the input datasets, the estimation of lava flow lengths, and the distribution of inhabited areas and

roads. Their methodology used is interesting but insufficient due to the absence of field data. In this work, we used an innovative approach combining field observations and remote sensing data.

Towns and villages (Buea, Tiko, Limbe, Ekona, Batoke, Bakingli, Idenau, Koto I, Bafia, Munyange, Bibundi) densely populated at the foot of the mountain, are probable areas subject to risk [7,10,21,22] during volcanic eruptions. It is therefore

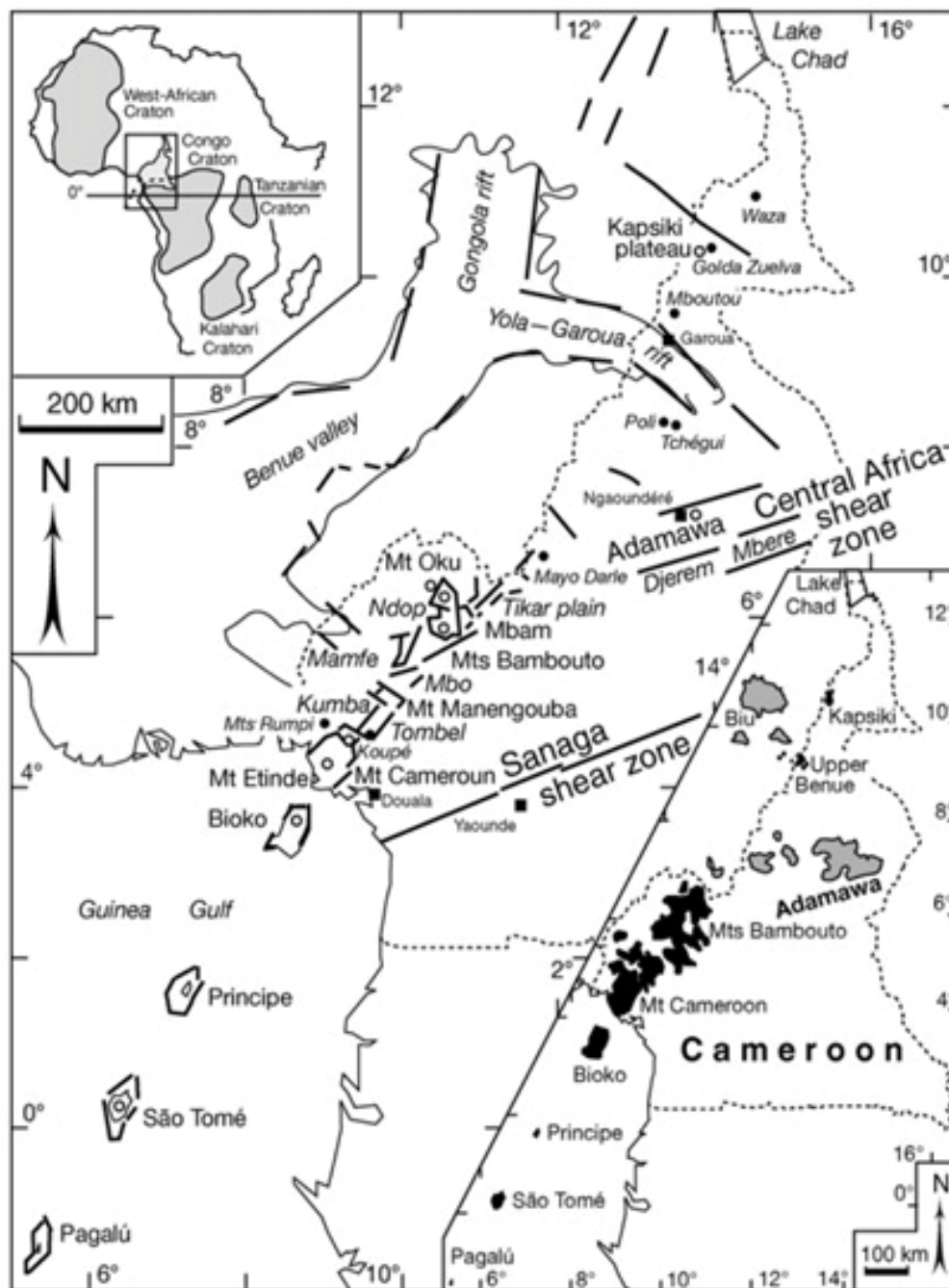


Figure 1: Cameroon hot line extending from Pagalu island to Lake Chad, between the West African and the Congo cratons (upper caption, after [23]). In the continental domain, it is a succession of horsts and grabens (in large italics) are indicated.

imperious to predict the direction of lava flows in future eruptions. The main objective of this paper is to vectorize from the processing of satellite images and maps, different geomorphological accidents recorded on the sides of Mount Cameroon in order to determine the potential directions of devastating lavas. Achieving this objective will not only find likely new lava trajectories compared to previous work, but also identify new risk areas.

Geological Setting

Mount Cameroon is an active volcano on the Cameroon hot line (Figure 1). The latter, orientated N030°E, extends from Pagalu island to Lake Chad, between the West African and Congo cratons [23]. In the oceanic domain, this hot line consists of six volcanoes, three of which are located on Bioko Island (Santa Isabel, Biao and San Carlos) and one each on Pagalu, São Tomé and Príncipe islands. The continental segment consists of seven volcanoes (Mt Etinde, Mt Cameroon, Mt Rumpi, Mt Manengouba, Mt Bambouto, Mt Mbam and Mt Oku) built on horsts alternating with grabens (Kumba, Tombel, Mbo, Ndop and Tikar) where

predominate numerous monogenic cones and more than sixty anorogenic plutonic annular complexes [24]. All the anorogenic complexes have a typical alkaline character [25] and are aged between 6 and 70 Ma [26]. Trachytes and rhyolites are generally associated with plutonic complexes except the Kokoumi massif which is a unique example which includes significant volumes of lamprophyres [27]. Several continental transverse faults oriented N070E intersect the Cameroon hot line and extend into the fracture zone in the oceanic domain [3,24,25,28-32]. Several volcanic eruptions (1909, 1922, 1954, 1959, 1982, 1999 and 2000; Figure 2) are described on Mount Cameroon (4095 m above sea level) between 1909 and 2019 [1,4,8,33-35]. These eruptions took place in separate sites thus accounting for the various directions of lava flows [34,36]. None of all these eruptions destroyed human lives despite the location of towns and villages at the foot of the mountain. This article aims at seeking, from the processing of satellite images, probable directions of lineaments that can lead future lavas and predict disasters in the case that flows run towards anthropogenic works.

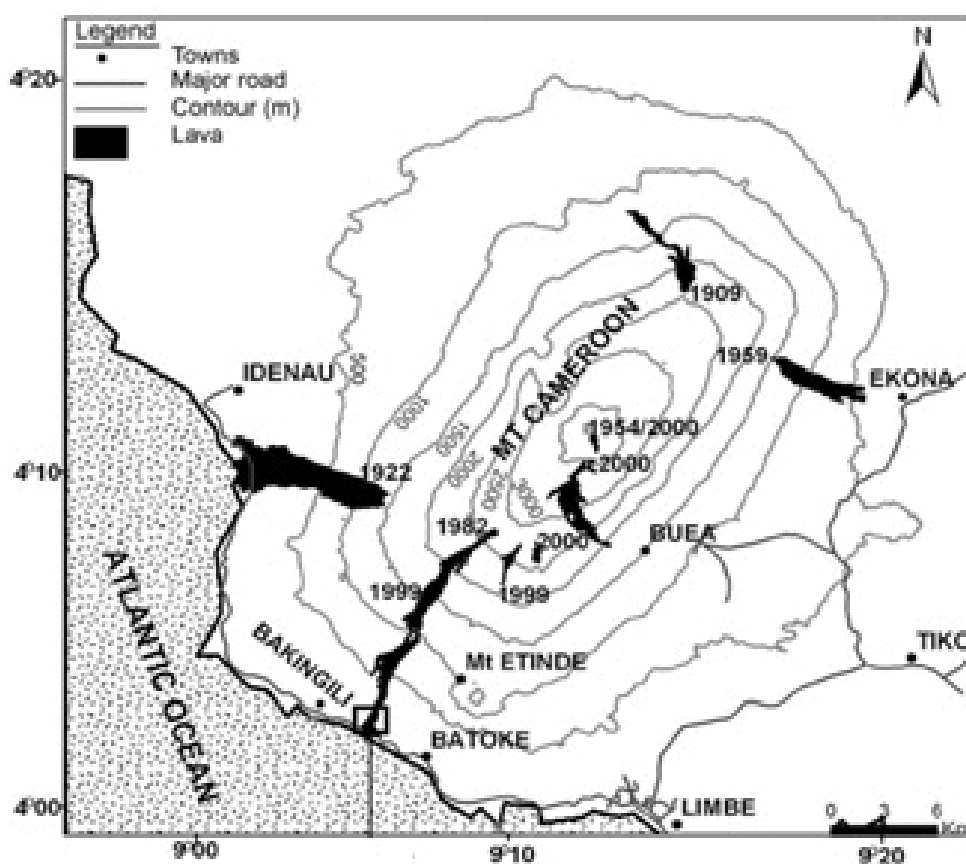


Figure 2: Location of lava flows from 1909 to 2000 [22].

Methodology

The main basic data of this article is the SRTM (90 m resolution) map on Cameroon downloaded and imported to Arcgis 10.2 for processing. From the hillshade and "slope tools of 3D Analyst Tool contained in the Arc Toolbox window, 4 emerged shaded reliefs (hillshade tool) and the crest lines (slope tool) of Mount Cameroon were generated each time in azimuths N000°, N090°, N180° and N270° respectively with an inclination of the sun at 45°. Before using 3D Analyst tools however, the georeferenced image was previously processed with an extension of type "none" and the use of nuanced relief (Z) at 16 in "layer properties". To best vectorize the lineaments, all the processed images were imported to Adobe Illustrator CS4.

As lavas can only flow mainly in depressions lines or between the ridge lines, all the interconnected depressions were digitized. A map of lineaments indicating the probable direction of lava flows was drawn on a topographic background generated from image analysis of the "Windows" window in Arcgis 10.2. Figure 3 shows a flow chart of the method.

The different images processed using the above-mentioned method are shown in Figures 4a, Figure 4b, Figure 4c, Figure 4d, Figure 5a, Figure 5b, Figure 5c and Figure 5d. The images representing the shaded relief of Mount Cameroon highlight different lineaments at the azimuths N000°, N090°, N180° and N270° respectively. To better visualize the lineaments, the crest lines were generated at

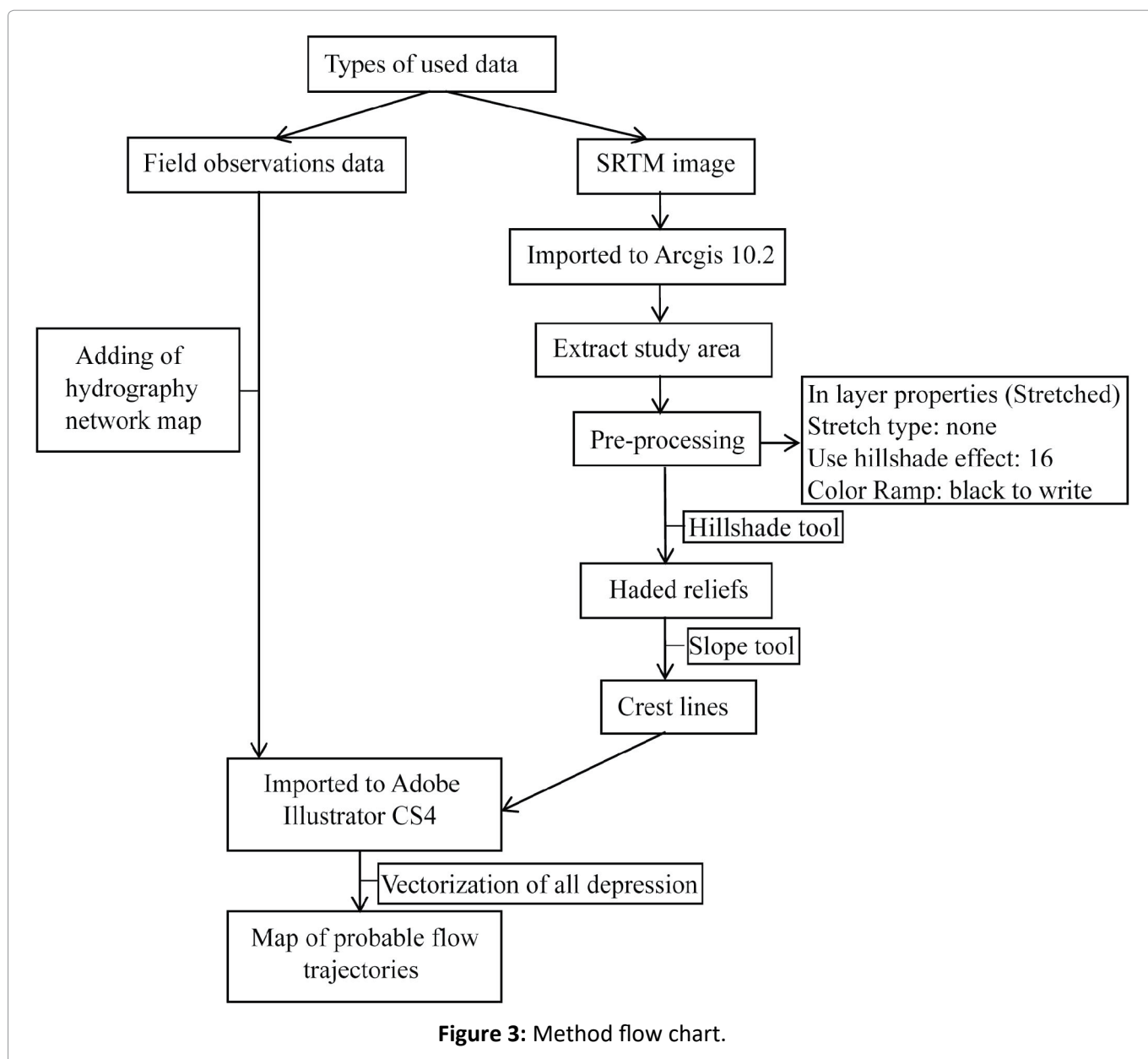


Figure 3: Method flow chart.

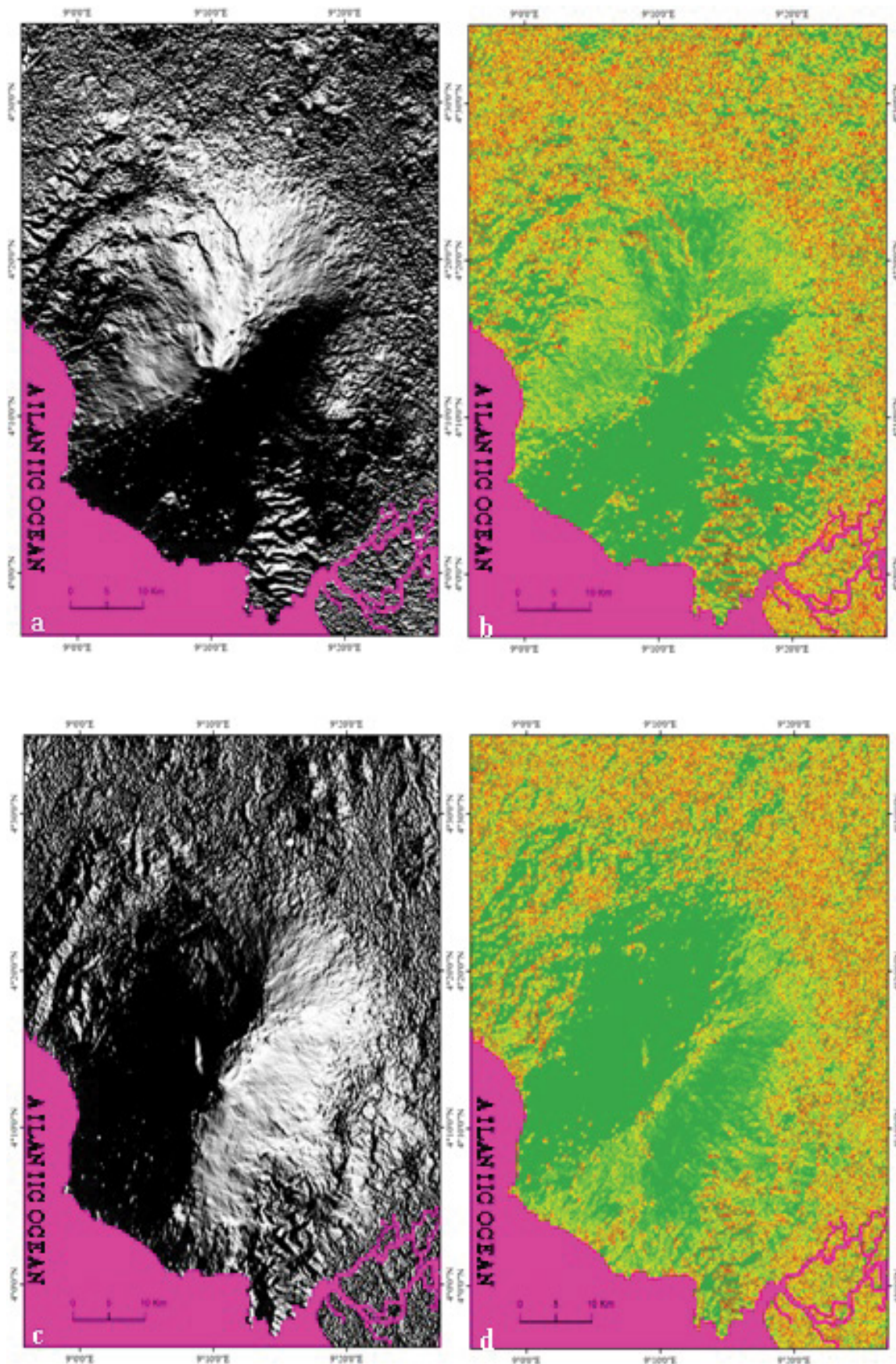


Figure 4: Maps of shaded relief and crest lines on the N and E flanks of Mount Cameroon. a) Shaded relief of the N flank; b) Crest lines of the N flank; c) Shaded relief of the E flank; d) Crest lines of the E flank.

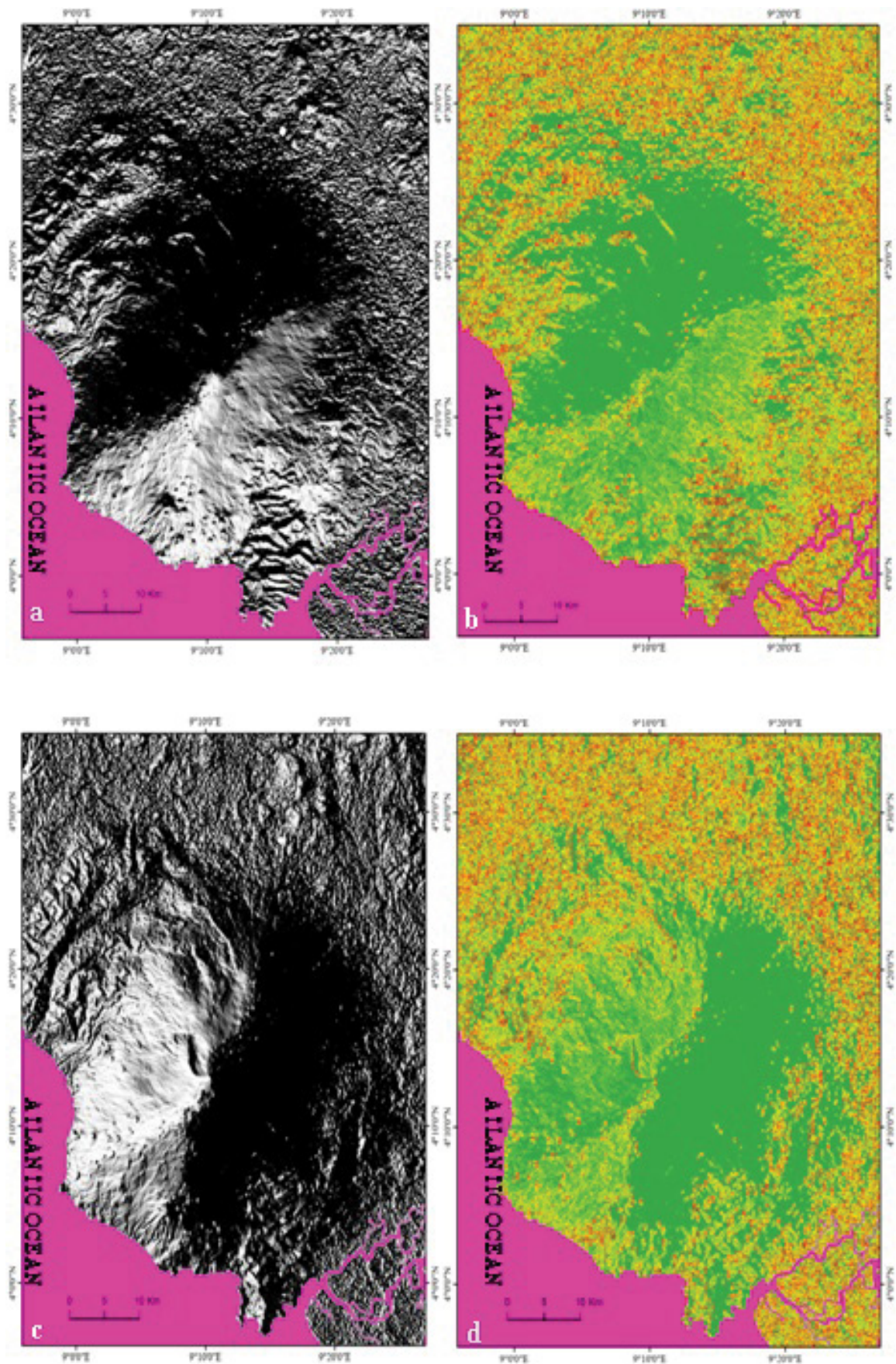


Figure 5: Maps of shaded relief and the crest lines on the S and W flanks of Mount Cameroon. a) Shaded relief of the S flank; b) Crest lines of the S flank; c) Shaded relief of the W flank; d) Ridge lines of the W flank.



Figure 6: Section of slopes at Mount Cameroon. a) Section of the W slope; b) Section of the NE slope; c) Another section of the NE slope; d) Section of the SE slope.

each azimuth. Between two consecutive ridge lines, there is naturally a depression line with more or less steep slopes. These depression lines created by the geometric arrangement of adjacent lava flows, the runoff from torrential rains and the gushing springs are drained by a river or not. Many interconnected depression lines can thus serve as a flow path for lava flows. It is also worth noting that a lava flow hardly crosses or cannot at all cross a ridge line. Mount Cameroon flanks (Figure 6a, Figure 6b, Figure 6c and Figure 6d) are characterized by a succession of hills separated by valleys with more or less straight or curved lines of depression. Several juxtaposed lava flows were observed on the flanks of Mount Cameroon (Figure 7). The processing of satellite images helps to best visualize these often drained valleys (Figure 8). Vectorized depression lines can lead lava flows to anthropic works. No interconnected lines and those limited by natural obstacles such as hills were not vectorized because they are less dangerous for the populations and human works. On a 2D topographic background, different geomorphological lineaments were

vectorized along the interconnected and generally drained depression lines (Figure 9). A 3D topographic map (Figure 10) permits to better appreciate probable courses of lavas. Figures 7, Figure 8 and Figure 9 helped to draw the final map of probable lava flow courses (Figure 11). It is worth noting on Figure 11 that the localities of Bafia, Mundongo, Munyange, Lissombe, Liwenyi, Sanje, Bomanabakweri, Idenau, Bibundi, Bakingili, Batoke, Bota, Tiko, Mutengene, Buea, Muea and Ekona would be directly threatened by lava flows. However, the movement of lava flows depends on the parameters such as fluidity, viscosity, ejection power and velocity of lavas which is also directly a function of the slope of the vacuum line. A lava flux could use a line of depression and depending on the above-mentioned parameters, to reach the populations and human works. Some past eruptions [1,37] threatened certain localities (1959 and 2000 lava flows in Ekona and Buea respectively) but were harmless. However, the 1922 flows invaded the city of Idenau and the 1999 flows destroyed plantations, farms, roads and houses [7,21,22].



Figure 7: Lava flows on the slopes of Mount Cameroon.

Discussions

Disasters caused by volcanic eruptions in the world are numerous; the prevention of various losses can be made by warning signs and the determination of the direction of lavas flow or lahar flows. The gases emitted during a volcanic eruption show no preferential direction; only the lava flows or lahars whatever their type can be vectorized if their ejection point is identified. This vectorization concerns not only volcanic rivers which drain

flanks of active volcanoes [38-43], but also all the interconnected and or undrained depressions. The Grand Carbet de la Soufrière river in Guadeloupe, eight volcanic rivers around the Montagne Pelée mass if as well as five rivers (three major and two secondary volcanic rivers) in Martinique are typical examples of non-eruptive lahars among eruptive lahars [44]. At Mount Cameroon, observed lahars are eruptive; mud flows with debris of volcanic rocks of all sizes and are characterized by a rapid

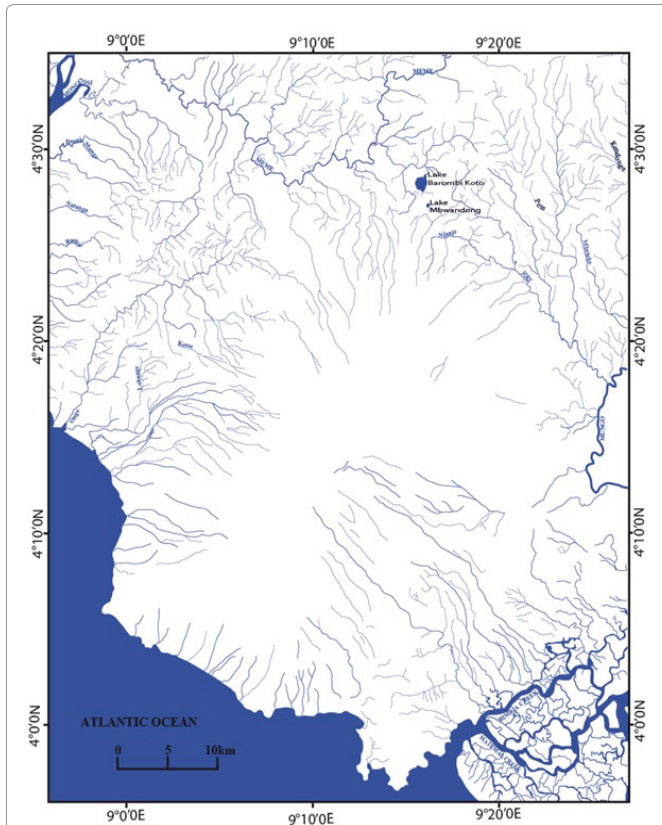


Figure 8: Mount Cameroon hydrographic network.

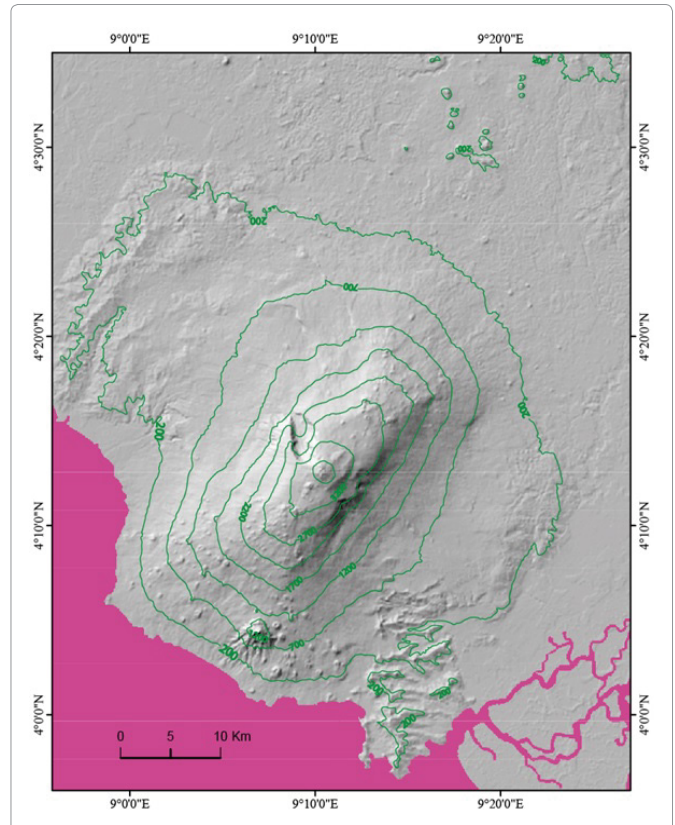


Figure 10: 3D topographic background of Mount Cameroon.

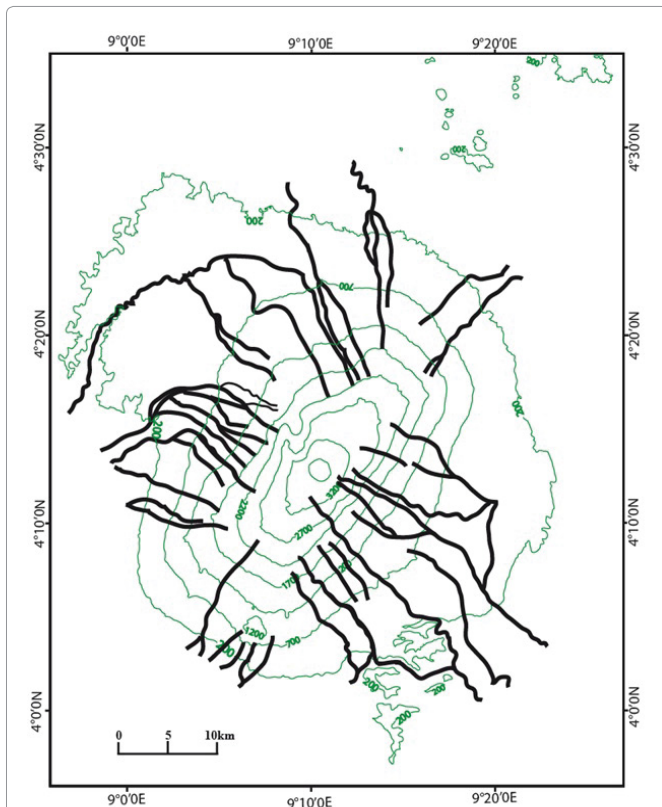


Figure 9: Map of probable flow courses on a 2 D topographic background.

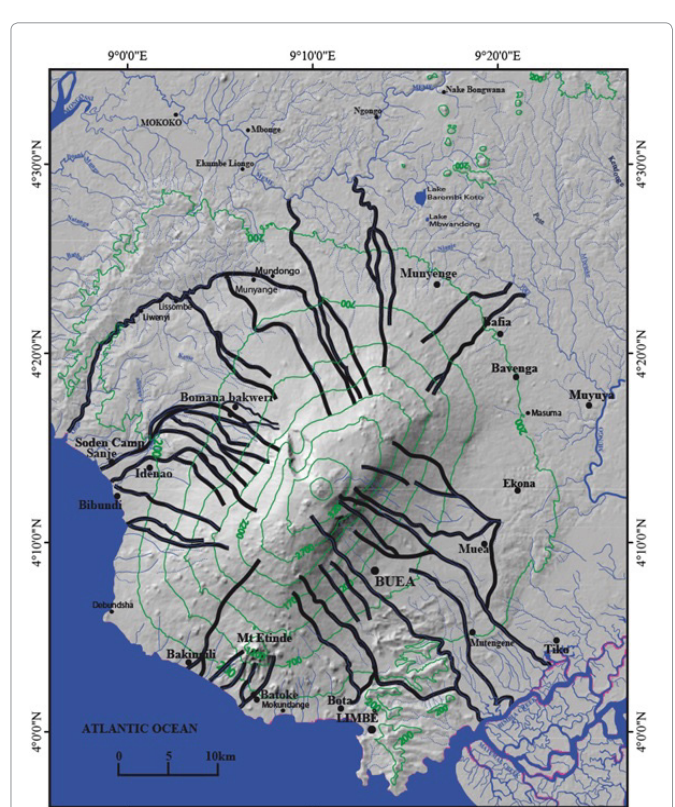


Figure 11: Map of probable flow trajectories on a 3D topographic background.

and gravitational flow [45]; the lahars generally affect the steep and poorly consolidated slopes. Between 1902 and 1929, the syn-eruptive lahars for diluting hot eruptive materials regularly used the partially buried hydrographic network on the slopes of Mount Pelée [46-49]. Thus, the 1922, 1959, 1982 and 2000 lavas which flowed towards the localities of Bibundi, Ekona, Bakingili and Buea respectively [22,25,34] using depression lines from the summit of the Mount Cameroon, could have caused huge natural disasters below. On the other hand, the city of Saint-Pierre and its inhabitants were wiped out in 1902 by heavy thunderstorm precipitation generating destructive flows in the main rivers of the volcano [48,50]. Recent Mount Cameroon lavas were more localized above 2000 m height [2] except those on the NE and SW flanks [20,37] which destroyed farms and could have killed people at Ekona and Bibundi. However, if the direction of the lava flows was mark out before the eruption, some mature crops could have been harvested, thus limiting losses. But uninformed of the direction of lava flow, the populations moved away messily from their dwellings.

The remote sensing, a tool by excellence for modern cartography, nowadays allows, through the processing of satellite images, to vectorize geomorphological lineaments that can be used to move lavas or lahars and thereby consider an efficient policy for disaster management due to volcanic eruptions. Mount Cameroon, the object of this work, is a clear example.

Conclusion

Numerous authors have highlighted recent or old lava flows at Mount Cameroon. The cartography of flows made it possible to visualize their direction as well as the levels of their stabilization on the sides of the mountain. The processing of SRTM images and the hydrographic network made it possible to highlight the interconnected depressions on all sides of Mount Cameroon. These depression lines created by the geometric arrangement of adjacent lava flows, the runoff from torrential rains and the gushing springs are drained by a river or not. The careful observation of the lava ejection area from previous work made it possible to trace via the hydrographic network and the interconnected depression lines undrained courses of flows in case of volcanic eruptions or non-eruptive lahars flow (not yet reported at Mount Cameroon).

According to these lineaments, the localities (and their surroundings) such as Buea, Tiko, Limbe, Ekona, Batoke, Bakingli, Idenau, Koto I, Bafia, Munyenge and Bibundi were detected as risk areas by previous work and this work. The new risk areas identified exclusively by SRTM image processing are Mundongo, Lissombe, Liwenyi, Bomana Bakweri, Sanje, Bota, Mutengene and Muea. Remote sensing mapping via SRTM images therefore helps to generate geomorphological lineaments that can guide lava flows or lahars and thereby considered as an efficient policy to manage volcanic eruptions related disasters or non-eruptive lahars flows on slopes of Mount Cameroon.

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