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Contribution of GIS to the mapping of landslide risk areas in the city of Bafoussam GIS and landslide management

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ABSTRACT

Context and Background:

Landslide risk prevention remains a major global concern. They are part of the natural disasters to which most countries are exposed. They thus constitute a brake on development and endanger the populations. The city of Bafoussam, because of its relief, its rainfall, the nature of its soils and the density of land use and the population actions, is therefore a real case study.

Goal and objectives:

This work allowed the characterization and mapping of landslide risk areas and the evaluation of their accessibility in the city of Bafoussam. The objectives are to produce a map of landslide risk areas and their accessibility through a GIS analysis and to make a global analysis of the hazards (slopes, nature of the soils, abundance of precipitation, land use) that can be at the origin of landslides in order to inform on landslide control.

The Methodology:

The methodological approach use was based on the integration in a geographic information system (GIS) of data interpreted from satellite images, pedology, climatic data and the digital elevation model (DEM). On the basis of multi-criteria analysis, the main factors of landslide risk were considered: relief, rainfall, occupation and nature of soils.

Results:

The multi-criteria spatial analysis carried out in a GIS allowed the elaboration of hazard maps as well as the map of landslide risk areas. This map includes five classes: areas with very low landslide risk (18.36%), areas with low landslide risk (34.33%), areas with moderate landslide risk (26.36%), areas with high landslide risk (16.67%) and areas with very high landslide risk (4.28%). A buffer zone around road traffic routes allowed us to obtain the accessible areas for the last four classes. Thus, we have the following accessibility rates: 10.57% for low landslide risk areas, 11.36% for moderate landslide risk areas, 11.29% for high landslide risk areas and 18.19% for very high landslide risk areas.

This rate represents for each area, the percentage of the accessible surface. The results of our work can be used not only for landslide risk prevention but also for potential crisis management.

Keywords:

landslide, GIS, risk areas, multicriteria analysis, prevention

1. INTRODUCTION

A landslide is a rapid discontinuous downward displacement of an earth mass along a failure surface under the influence of gravity (Taleb, 2019). It is a phenomenon of seismic, geological, and geophysical origin resulting in the displacement of a continuous, planar, or curved slope (Payne et al., 2009). The consequences on human lives and activities resulting from landslides are so significant that it is difficult to accurately inventory them (Schuster & Fleming, 1986; Gokceoglu et al., 2005; Highland & Bobrowsky, 2008; Desodt et al., 2017). The degree of risk of a terrain to landslides generally corresponds to the combination of topography, lithology, and physical occupation of the land under study (Desodt et al., 2017).

The risk factors influencing landslides are always difficult to quantify, which makes the elaboration of risk maps even more tedious (Schuster & Fleming, 1986, Lin, 2003). In sub-Saharan Africa and in Cameroon in particular, landslides are common, even if it is difficult in the present state to anticipate these phenomena, it is nevertheless possible to limit their consequences in human and material terms. This requires good decision making, which imposes a good localization of the zones at risk. As these areas are generally occupied by populations, the planning of the places and the good access roads will have a certain impact on the consequences of the natural disasters which are likely to occur there.

Geographic Information Systems (GIS) are proving to be an essential tool for the study of landslides. Many software (Arcgis, QGIS, etc.) are developed to meet the needs of engineers, practitioners, geographers, etc. In landslides, GIS allows to elaborate Digital Terrain Models (DTM) in order to model the hazard and the vulnerability, which allows to easily identify the landslide-prone areas.

The resulting map is of socio-economic and safety interest (Saley et al., 2005). This work can thus be used as a decision-making tool for the issuance of land-use or urban planning permits (building permits, siting permits, etc.) and can also serve as a support not only for the prevention of landslide risks but also as a guide for rescue workers in the event of a disaster.

A good knowledge of the elements that contribute to landslides is an imperative for good decision making. This knowledge is fundamental for the implementation of measures and devices intended to prevent or limit the damage caused by different kinds of landslides.

How to facilitate the decision making regarding the occupation of the city by taking into account the accessibility to the areas at risk, in order to avoid the heavy consequences related to landslides?

The objective of our work is to associate multi-criteria analysis with a GIS database to produce a map of landslide risk areas in the city of Bafoussam. Indeed, the global study of the hazards (slopes, nature of soils, abundance of rainfall, land use) that can be the cause of landslides, highlights GIS tools in the fight against landslides.

2. STUDY METHODOLOGY

2.1 Description of the study area

Bafoussam is a city, located at an altitude of 1450 m above sea level, between the 5th degree 28 north latitude and the 10th degree 25 east longitude (Tangmouo et al., 2020). It consists of 3 communes namely Bafoussam1, Bafoussam 2 and Bafoussam 3.It is bounded to the north by the commune of Kouoptamo, to the south by the commune of pete-Bandjoun and Poumougne, to the east by the commune of Foumbot, and to the west by the commune of Penka Michel and the commune of Batcham (PCD.,2011). Figure 1 shows the geographic location of Bafoussam.

The relief of Bafoussam has flat areas and hills that favor water erosion and create landslides in places. The city has a climate of the Caméronian type of altitude. Annual rainfall varies between 1600 and 2000 mm, with August being the wettest month. On the whole, the soil of Bafoussam is essentially made up of metamorphic rocks, covered in places by volcanic ash; in certain districts (Ndiembou, Banengo), there are red lateritic, ferralitic soils; hydromorphic soils are found in the shallows and on the edges of waterways. The growth of the population leads to anarchic occupation of the city and especially of the areas at risk.

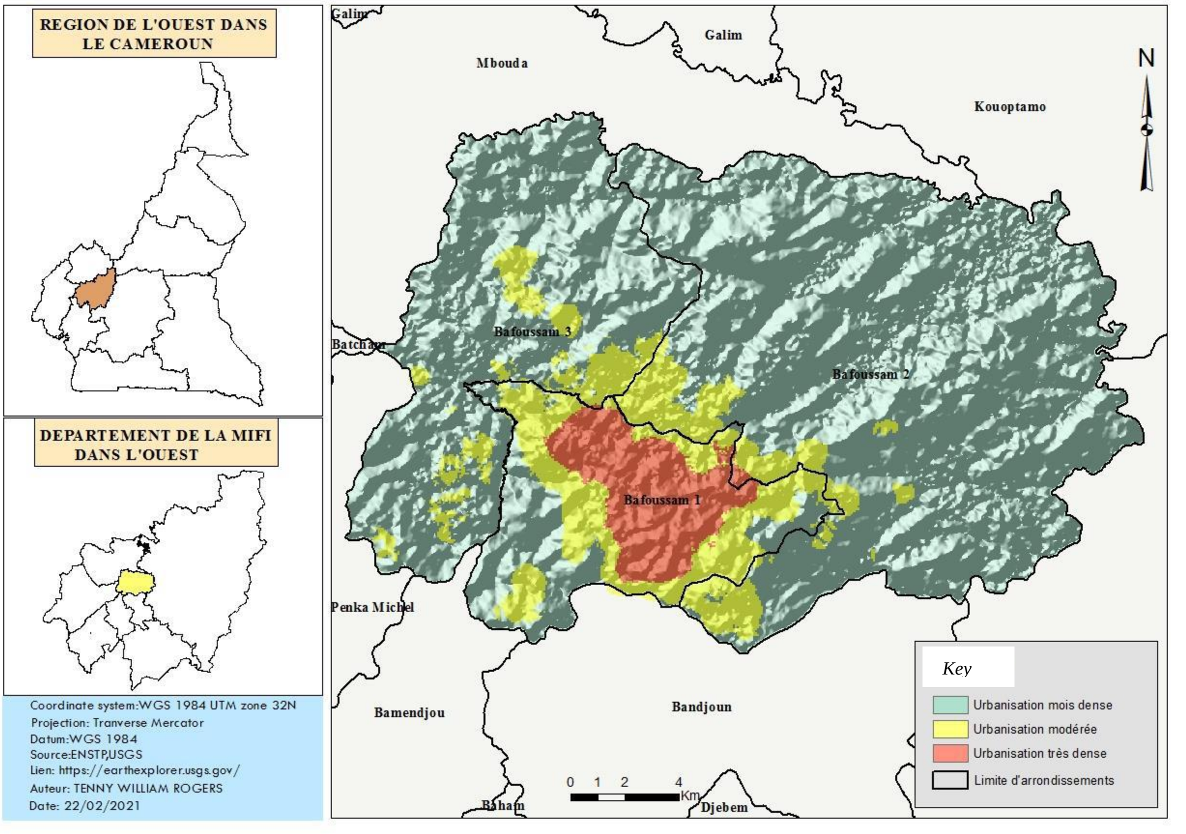

Figure 1 : **Location of the study area**

2.2 Methodology

The methods used for the landslide assessment can be statistic, spatial, heuristic or deterministic. The statistical models have the advantages to be easily applicable at the municipal scale unlike the deterministic models which require detailed knowledge regarding the unstable slope characteristics (e.g shear resistance parameters, unstable soil thickness); and to be objective, unlike the heuristic models which are subjective and the quality of which depends on the experience of the expert, especially for the attribution of weighted values. Spatial data help understand and quantify impacted areas and the land uses affected.

This study used a methodology on the coupled use of remote sensing and Geographic Information Systems (GIS), for landslide risk assessment, relying on the concepts of landslide hazard and vulnerability in the city of Bafoussam. The aim is to delimit the perimeters of areas at risk and to identify those that are accessible or difficult to access.

The first methods for assessing landslide susceptibility were introduced by Radbruch (1976), Brabb (1972) Dobrovolny (1977) based on the spatial distribution of factors related to the instability process of areas without temporal involvement (Pourghasemi et al., 2012). These models were based on the equality distribution of the most important studied parameters such as slope stability and soil geology (Guzzetti et al.,1999).

Hierarchical multicriteria analysis was developed in statistics by Saaty L. (1980). In the study of phenomena, it allows to group all the factors influencing this phenomenon, then to classify them and to weight them according to their relative importance. As GIS and image processing software we used QGIS 2.8.

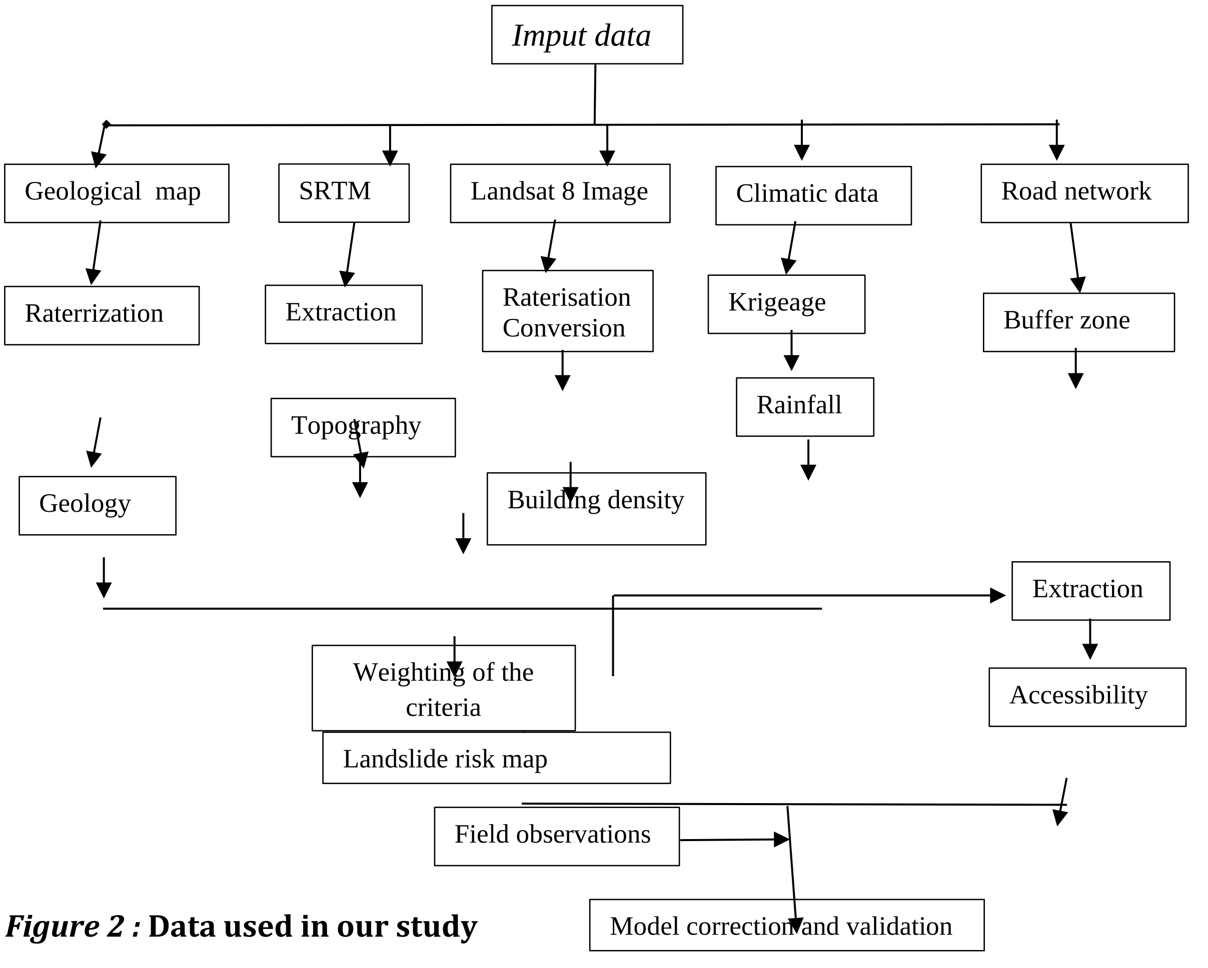

Figure 2 : **Data used in our study**

3. RESULTS

3.1. Landslides and their causes in Bafoussam

The landslide corresponds to the displacement of a mass of loose or rocky land along a failure surface (flat, circular or any) (Cerema., 2016). It is a phenomenon of seismic, geological and geophysical origin where a mass of earth descends on a slope, in other words a more or less continuous, more or less flat or curved slide plane (Payne et al., 2009). The causes are generally related to rainfall, slope, agriculture and the level of exposure of the soil.

The slope, the nature of the soil and the abundance of rainfall are the main natural factors causing landslides (Saha., 2014). The city of Bafoussam abounds with nearly 15% of slopes at high risk with annual rainfall varying between 1600 and 2000 mm. The months of July and August are the rainiest (800-1000mm) and constitute the propitious period for landslides. The latter triggers, on favorable slopes, the setting in motion of important masses of land in landslides. With soils that have absorbed huge amounts of water, reach their saturation point and trigger mudflows.

The most felt case is that of the Gouache IV district where, on the night of October 28, 2019, around 21h30mn, a landslide caused the death of 47 people with numerous material damages (*Cameroon Tribune, 28 oct. 2019*).

Agriculture, one of the driving forces, is also widespread. Bafoussam has an essentially agricultural population with activities increasingly accentuated on the steep slopes and therefore firewood is the main means for cooking. These actions are not without consequences on the vegetation cover and

also lead to soil exposure. The high demographic pressure of the 1980s and 2000s has caused the installation of certain populations on steep slopes.
These settlements are made by filling in and excavating to create housing estates.

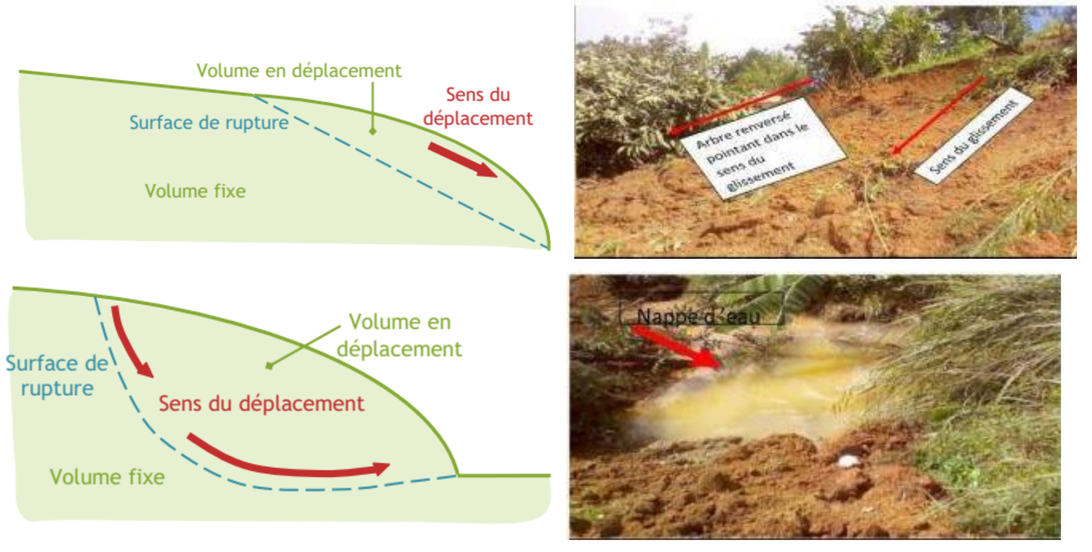

Figure 3 : Planar slip (a) and circular slip (b source: Tsoata , Happy(2019)

In Bafoussam, landslides can be observed both in plan and circular. This is the case of the one that occurred in the Gouache IV neighborhood. Observations made at the landslide site show that the landslide was both translational, as the landslide surface is identifiable by the planimetry and inclination of the slope, and rotational. This is reinforced by the trees pointing downslope. The width of the detachment niche was approximately 40 m.

The land slide was also rotational, as trees pointing up the slope were encountered in places. Also, spoon-shaped surfaces of discontinuities were present (Tangmouo et al.,2020).

3.2. Population exposure to risk zones in Bafoussam

Neighborhoods such as Tanguissa (tougang ville), and Gouache, although located in landslide risk zones, are overpopulated and the layout of the houses does not respect any urbanization norms. Houses are dispersed and close to each other without any structure like in the rural agrarian space. The first consequence is the reduction of access to these popular areas with dirt roads in poor condition (1), exposition of household to water diseases (2) and flood (3) which is likely to compromise rescue operations in case of disaster.

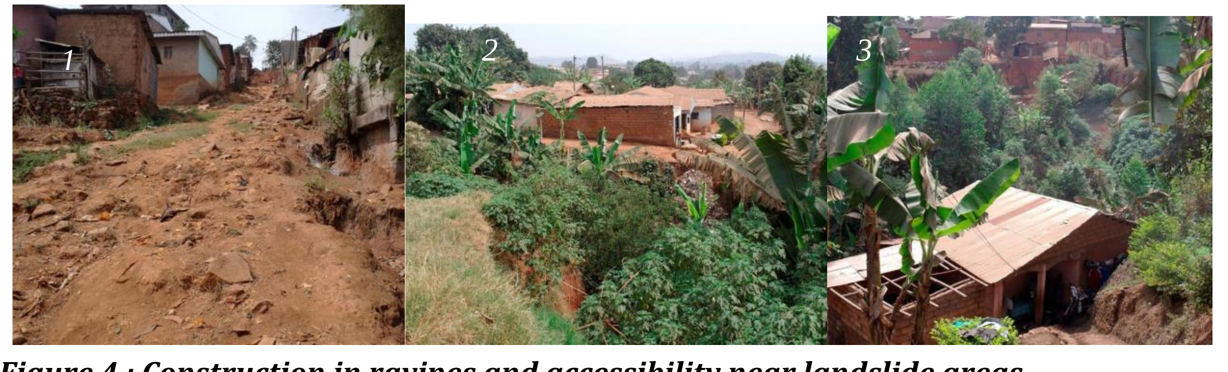

Figure 4 : Construction in ravines and accessibility near landslide areas

In Tougang city, a landslide engulfed two (2) houses and caused significant material damage; there was no loss of life because the authorities had warned the occupants of the area before the landslide according to the testimony of local residents. Unfortunately, we note that after the landslide, although aware of the danger that this area represents, the populations have occupied them again (1). This is the observation made for the majority of the dangerous areas of the city.

4. Evaluation of landslide risk areas in Bafoussam

4.1 Mapping of topographic and geological factors

The method we have chosen (multi-criteria analysis) to analyze our problem requires us to construct the different hierarchical levels and their criteria per level.

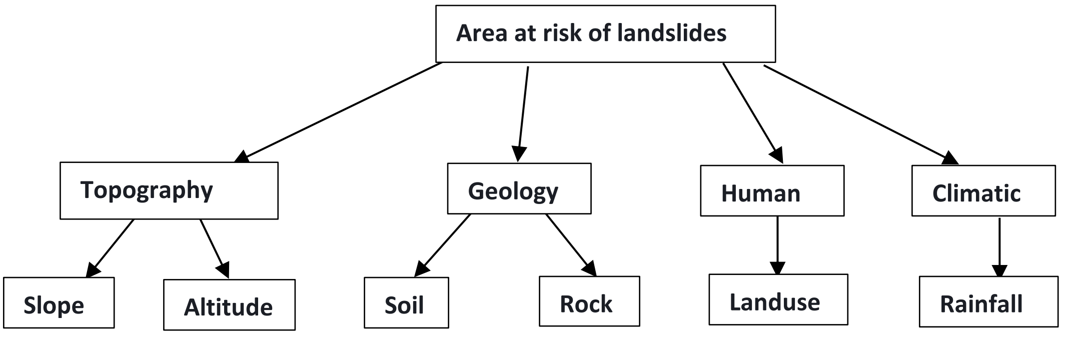

Figure 5 : Hierarchical structuring of land slide

In this part, we will map the topographic and geological hazards, because for the anthropic and climatic hazards, we will use respectively the density map of the buildings and the isohyets made in the previous chapter.

The general principle of calculating susceptibility is the weighted sum of several classified parameters of the territory. Our maps will result from a crossing of the maps that we made in the previous chapter; and the formula of crossing is the following:

$$D_i = \sum_{j=1}^{j=n} (W_j . R_j) \quad (1)$$

Di: global susceptibility index of a map unit; Wj: weighting factor of parameter j; Rj: index of parameter j; n: number of parameters taken into account.

Before performing the cross-referencing, it is necessary to convert into raster files all the maps that are not, reclassify them, and weight them; after all these steps, we will apply the above formula using the raster calculator of the ArcGIS software to obtain the desired maps.

For the weighting of the criteria, we will base ourselves on the non-exhaustive predisposition factors of the Gouache landslide.

Rainfall was chosen as the most important element, followed by the slope gradient and then the altitude. Soil type comes fourth, followed by rock type, and in sixth place we have land use (density of buildings).

4.2 Mapping the topographic factor

The map we are looking for is the result of crossing the slope map and the altitude map according to formula (1); it is therefore necessary to proceed with the weighting of these criteria.

4.2.1 Weighting of the criteria

For the weighting of the criteria, the criteria weighting table was used. The sub-criteria slopes and altitudes which allowed to obtain the topographic map by the determination of the binary comparison matrix which allowed to note a strong importance of the slopes compared to the altitudes (table 1)

Criteria	Slope	Altitude
Slope	1	5
Altitude	0,2	1
Total	1,2	6

***Table 1 :* Comparaison Matrix**

4.2.2 Reclassification of the maps

Here, we have to classify the pixel values in order to facilitate the calculations. The process leading to the reclassification is given in figure 6.

This process will be the same for the heights and all raster files requiring reclassification in the rest of our work.

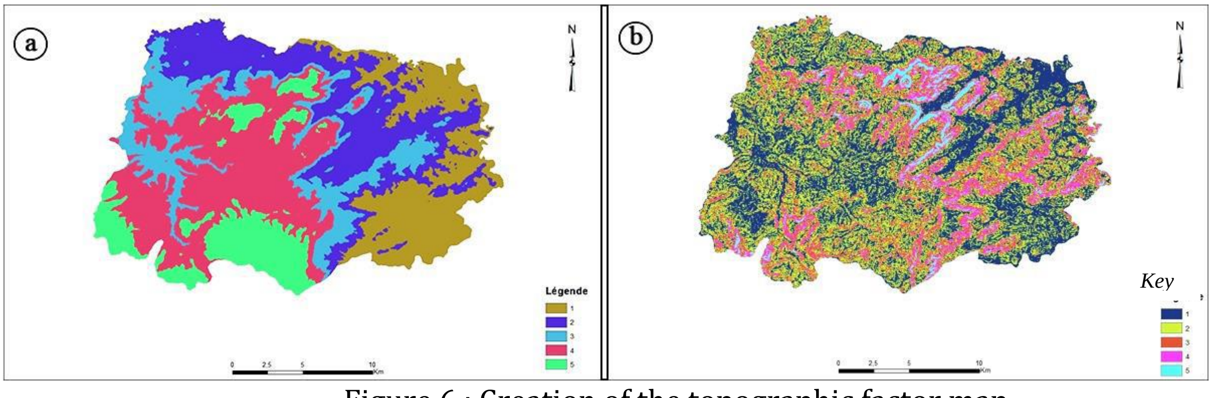

Figure 6 : Creation of the topographic factor map

The topographic factor map results from the intersection of these two maps, by applying the formula (4) in the raster calculator of the QGIS software.

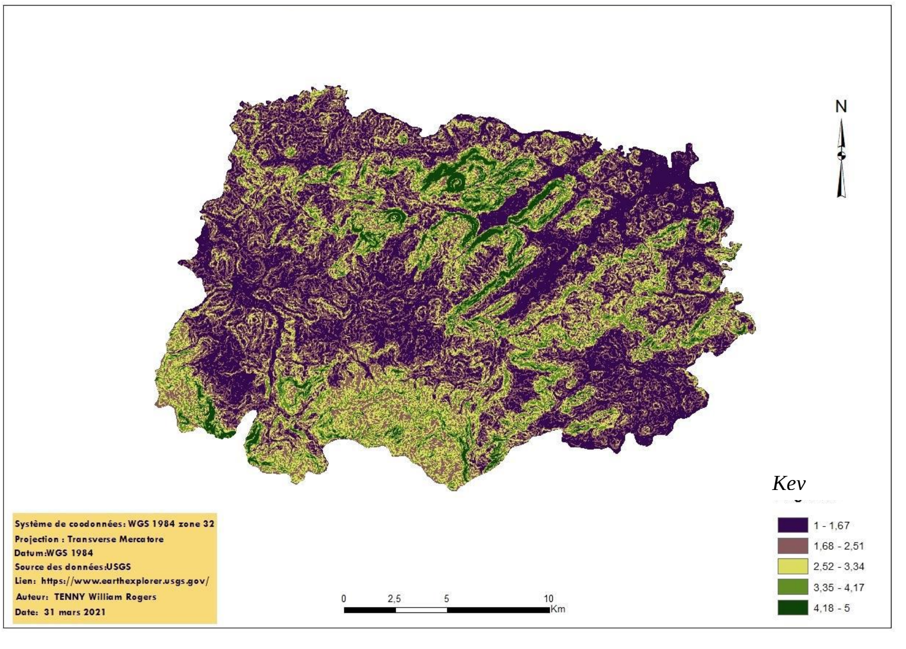

Figure 7 : Topographic Map of Bafoussam

4.3 Mapping of the geological factor

This map is the result of crossing the soil type map and the rock type map according to formula (4). To do this, we follow the same steps as above.

4.3.1. Weighting of the criteria

For the topographic criterion, the subcriteria are soil types and rock types. The first step consists in the determination of the binary comparison matrix.

We consider an average importance of soil types in relation to rock types; the resulting matrix is represented by Table 2.

Critères	Slope	Altitude
Soil type	1	4
Rocks type	0,25	1
Total	1,25	5

Table 2 : **Binary comparison matrix**

The next step was the normalization of the matrix. The normalized comparison matrix was obtained (Table 3).

Critère	Slope	Altitude	Total
Soil type	0,80	0,80	1,60
Rocks type	0,20	0,20	0,40

Table 3: Normalized comparison matrix

Determination of the weight of the criteria

By applying formula (1), the values in Table 4 were obtained

Critères	Weight of the criteria
Soil type	0,80
Rocks type	0,20

***Tableau 4*: Weight of the criteria**

4.3.2 Reclassification of the maps

For a better appreciation of the risk areas, the soil and rock type layers have been converted to raster for reclassification (figure 8).

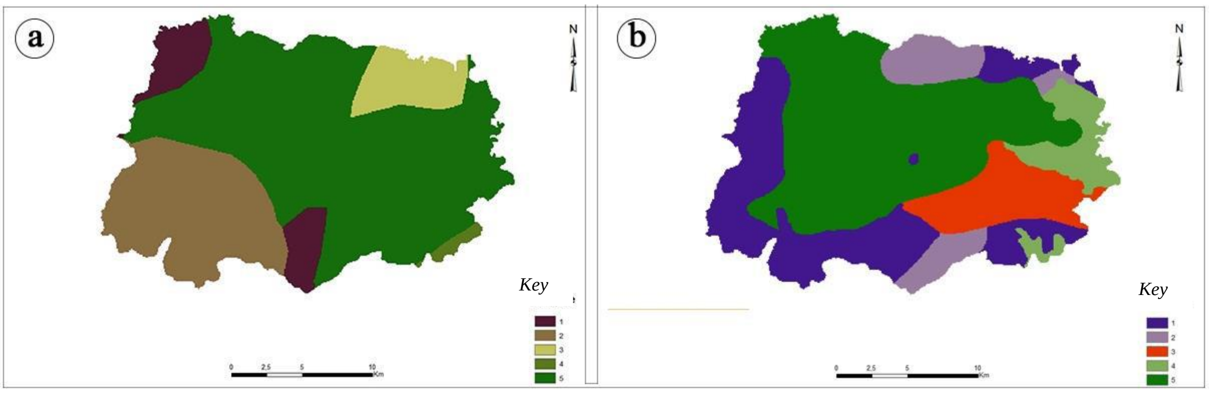

Figure 8 : **Map of soil types(a) and rock types(b) after reclassification**

4.3.3 **Creation of the geological factor map**

The map we are looking for is the result of crossing the two maps of soil and rock types (figure 9).

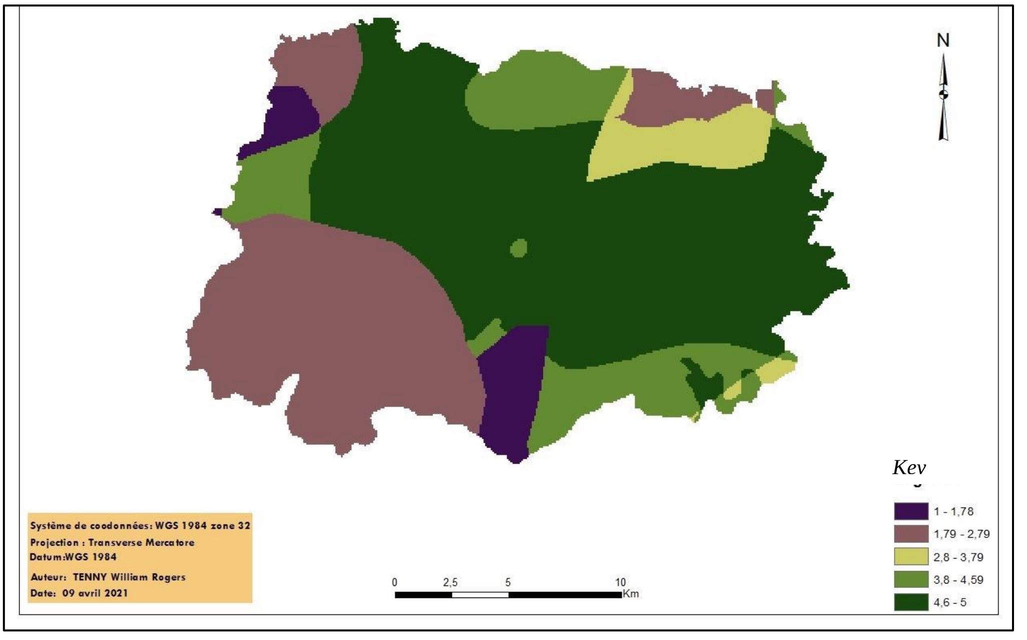

Figure 9 : Classified soil type in the study area

This map allowed us to create our landslide risk map.

4.4. Mapping of landslide risk areas

It has been elaborated with the weighting of topographic, geological, climatic (rainfall) and anthropic (density of buildings) factors.

4.4.1 Weighting of criteria

The considerations made allow us to have the matrices given in Tables 5 and 6 as well as the selection criteria (Table 7).

Criteria	Climatic	Topographic	Geologic	Human
Climatic	1,00	2,00	2,00	4,00
Topographic	0,50	1,00	5,00	5,00
Geologic	0,50	0,20	1,00	2,00
Human	0,25	0,20	0,50	1,00
Total	2,25	3,40	8,50	12,00

***Tableau 5*: Comparison matrix**

Criteria	Climatic	Topographic	Geologic	Human	Total
Climatic	0,44	0,59	0,24	0,33	1,6
Topographic	0,22	0,29	0,59	0,42	1,52
Geologic	0,22	0,06	0,12	0,17	0,57
Human	0,11	0,06	0,06	0,08	0,31

***Tableau 6 :* Normalized comparison matrix**

Criteria	Weight of the criteria
Climatic	0,40
Topographic	0,38
Geologic	0,14
Human	0,08

Tableau 7 : Weight of the criteria

4.4.2 Evaluation of the consistency of judgments

To evaluate the consistency of the judgments, each column of the unnormalized comparison matrix is multiplied by the weight of the associated criterion, and we obtain the matrix in Table 8.

Criteria	Climatique	Topographique	Geology	Human	Total
Climatic	0,40	0,76	0,28	0,31	1,75
Topographic	0,20	0,38	0,71	0,39	1,68
Geologic	0,20	0,08	0,14	0,16	0,58
Human	0,10	0,08	0,07	0,08	0,33

Tableau 8: Intermediate matrix

Evaluations of the consistency between the sum of the lines obtained and the weight of the line criterion; the results obtained are given in table 9.

Criteria	Criteria weight
Climatic	4,38
Topographic	4,42
Geologic	4,14
Human	4,13
Average consistency	4,27

***Tableau 9*: Coherence**

The application of the mathematical formulas (3) and (2) gave us the following results:

Coherence index: 0.089

Coherence ratio: 0.09

0.09 < 0.1 so the arbitrarily chosen comparison matrix makes sense.

Before proceeding to the realization of our risk zone map, we have to convert the density map of the buildings and the rainfall map into a raster file, then make a reclassification of it.

4.4.3 Reclassification of the building density and rainfall maps

To perform this task, the same procedure as for the previous maps was followed.

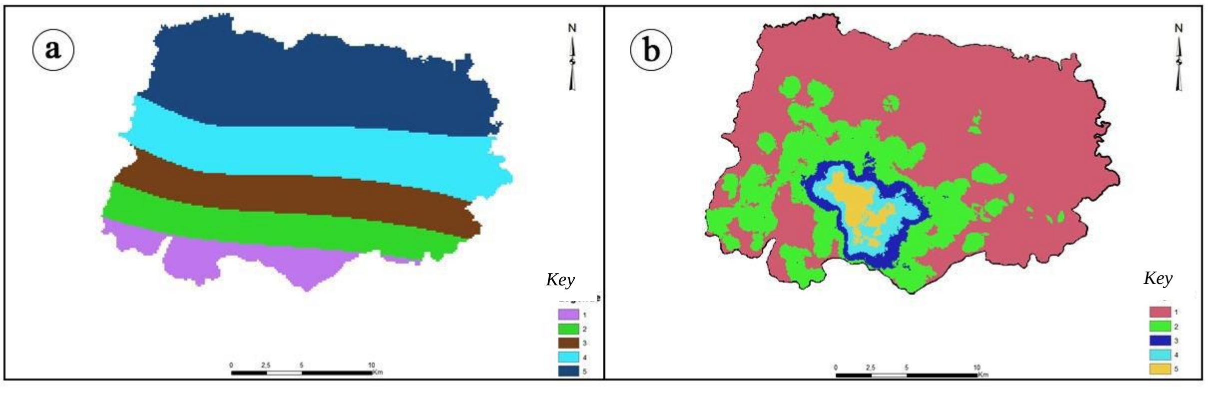

Figure 10 : Map of rainfall (a) and building density (b) after reclassification

4.4.4 Map of landslide risk areas

This map is obtained by crossing the maps obtained by the application according to their weight obtained in the taleau . This operation is done by applying the formula (4)

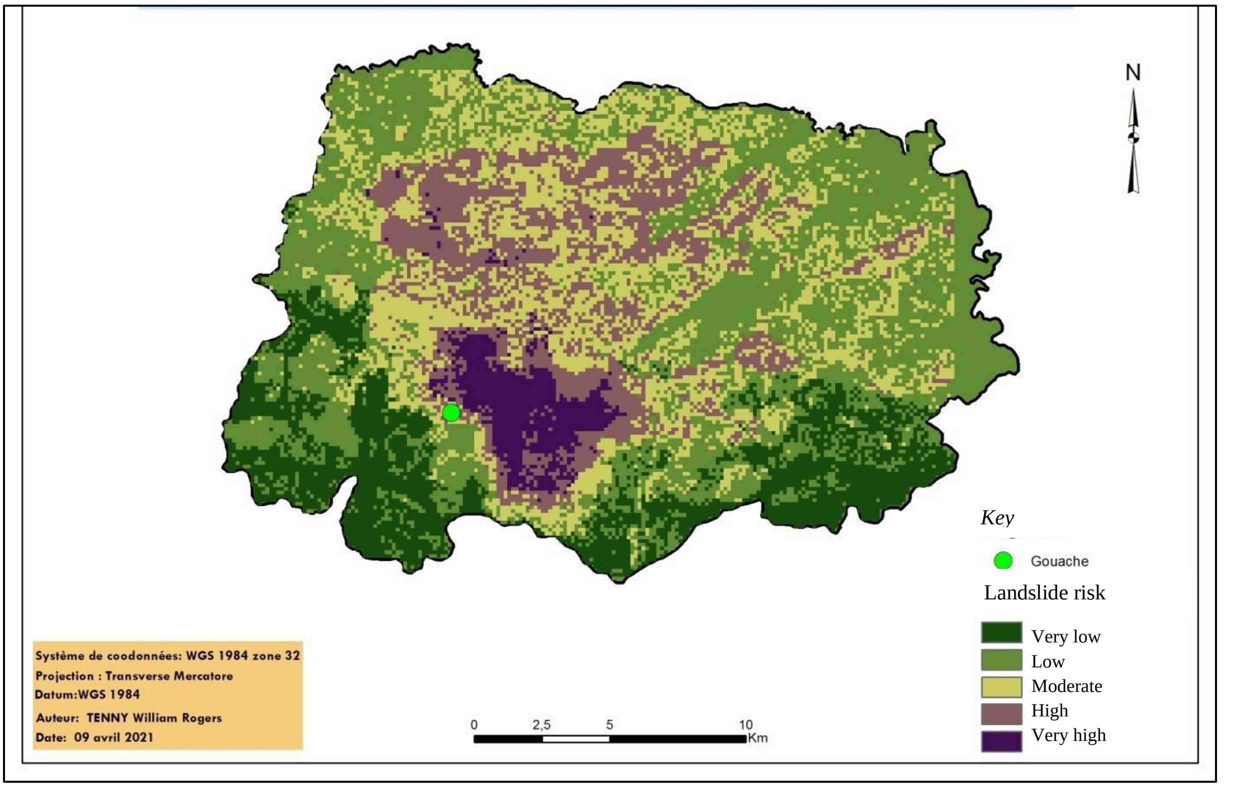

Figure 11 : Map of landslide risk areas in the city of Bafoussam

Having identified the areas at risk of landslides we can evaluate their accessibility.

4.4.5 Evaluation of the accessibility of landslide risk areas

A field trip allowed us to note that the zones located at an average distance of 100 m on both sides of the roads are accessible to the emergency vehicles, (they are vehicles of firemen having 10m of length, 2,4m of width, 3,10m of height and weighing approximately 16 tons). It is on the basis of this observation that we are going to evaluate the accessibility of the zones at risk.

The first step will be to create a buffer zone of 100m on both sides of its axes. The second step will be to extract our risk areas by category and calculate their surfaces and in this case, only the areas of low, moderate, strong and very strong risk will be taken into account. In the third step, we will use the buffer zone created to extract the accessible areas for each category and finally, we will calculate the percentage of the accessible areas.

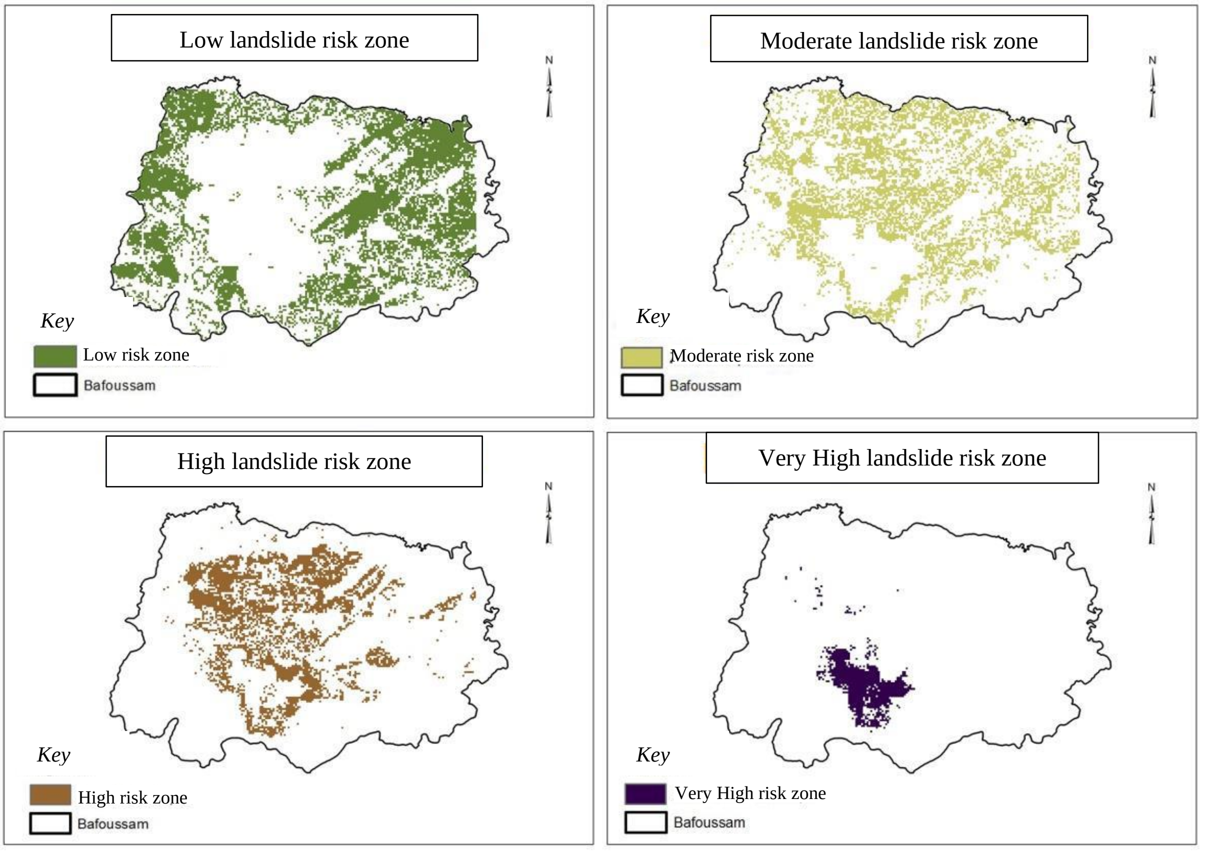

Figure 12 : **Map of Risk Zones**

The properties of these maps indicate that a pixel has a side length of 4.33 m; from this value, taking into account that a pixel is square, we can obtain its surface area, which is 18.77 m², and by multiplying the surface area obtained by the number of pixels in the layer, we have the surface area of the layer. This canvas allowed us to have the values of table 10.

Landslide risk areas	Area (en km2)
Low risk area	137,63
Moderate risk area	106,59
High risk area	67,06
Very high risk area	17,44
Total	328,74

Tableau 10: Area at risk

4.4.6 Extraction of accessible areas and calculation of the accessibility rate per area.

The tool " extraction by mask of the software " ArcGIS allowed to isolate the accessible zones. It is a question of using the buffer zone to delimit the zones sought.

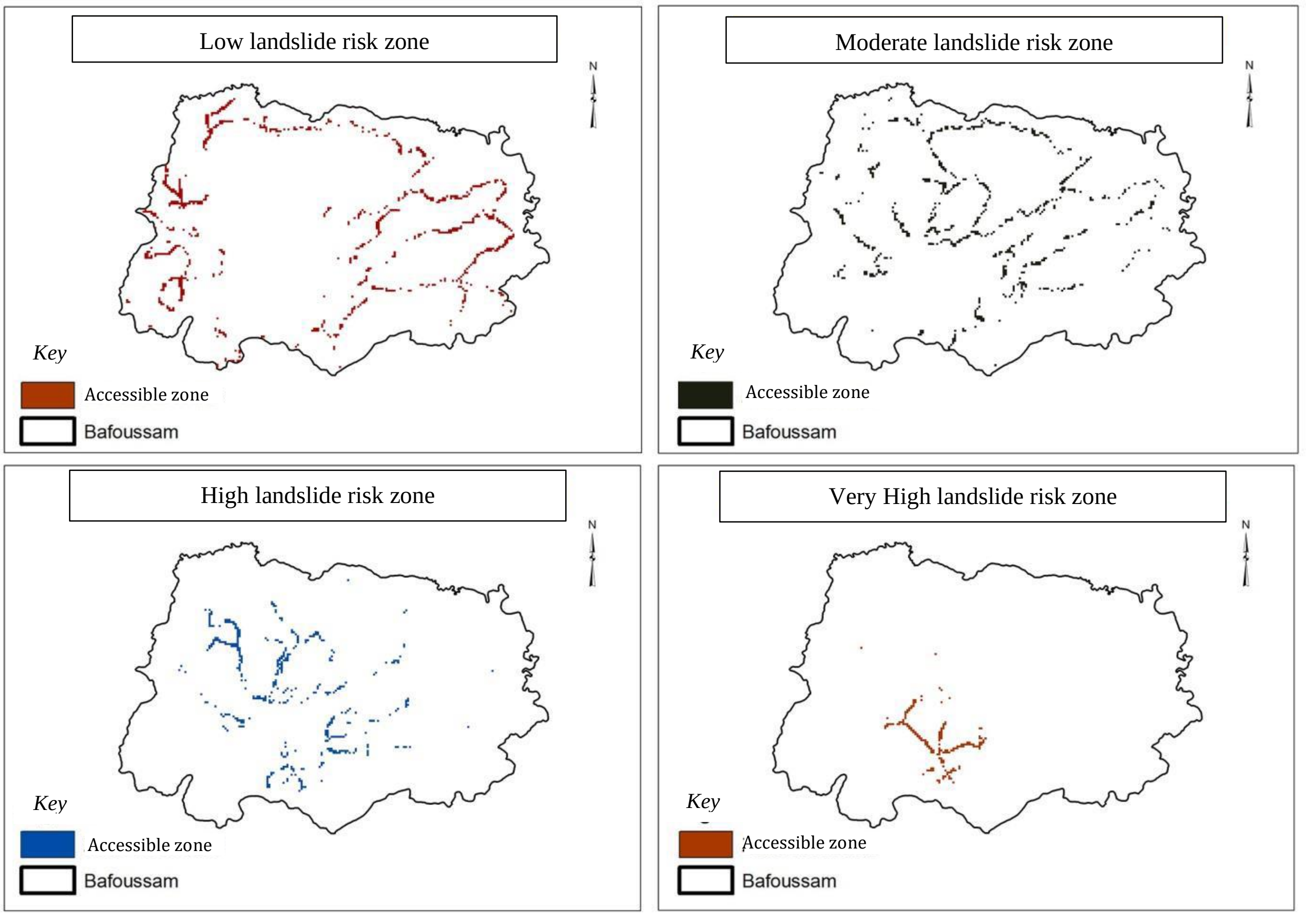

Figure 13 : Accessible area in Bafoussam

The surface areas of these zones are given in Table 11.

Landslide risk areas	Surfaces accessible (en km2)
Low risk area	14,55
Moderate risk area	12,11
High risk area	7,56
Very high-risk area	3,17
Total	37,40

Tableau 11: Areas of accessible areas

The formula that will allow us to calculate the accessibility rate is the following:
Accessibility rate = Accessible area of the zone × 100/ Total area of the zone (5)

Landslide risk areas	Accessibility rate in %
Low risk area	10,57
Moderate risk area	11,36
High risk area	11,29
Very high risk area	18,19

***Tableau 12 :* Surface des zones à risque**

5. DISCUSSION AND VALIDATION OF RESULTS

5.1 Validation of results

The step of verification of the results is essential in any scientific study. It consisted in comparing the results of the theoretical work with those of the practical work (real observations and field surveys). For this purpose, direct observations, GPS surveys and field surveys were conducted in several randomly selected sites in the city. The data were organized in the table 13.

Name (quarter)	Latitude (°)	Longitude (°)	Theoretical Nature of the Risk
BAMENDZI	5,459193	10,427569	High
BANENGO	5,458182	10,413944	High
TAMDJA	5,468457	10,418809	High
LAFE II	5,504993	10,398185	High
KENA 2	5,514936	10,364935	Moderate
TYO VILLE	5,497711	10,403287	Moderate
GOUACHE 2	5,490162	10,398696	Very High
KOPTCHOU	5,487598	10,429082	Very High
KAMKOP 7	5,482674	10,425851	Very High
DJELENG I A	5,482038	10,412080	Very High
TOUGANG II	5,490249	10,415230	Very High

***Tableau 13*: Geographical coordinates of the audit sites**

5.2 Discussion

The methodological approach on which the mapping of landslide risk areas in the city of Bafoussam and the assessment of their accessibility was based has the advantage of using multi-source data in synergy. Indeed, satellite imagery coupled with data obtained in the field have made it possible to define and spatialize the landslide factors as well as to analyze the vulnerability of the study site. The reliability of such a map is therefore linked to the input parameters, notably the DEMs (digital elevation model) and the data provided by the urban community of Bafoussam.

The results obtained were divided into 5 zones according to their risk level; the interest in subdividing the zones into different risk levels (zoning) lies in the fact that the rigors of decision-making will be based on the risk level of the delimited zones.

5.3 Validation of results

Thus, for low and very low risk areas, no recommendation is made for human settlements. For moderate risk and accessible areas, human settlements are possible, but some vigilance is required for medium scale works. For high risk and accessible areas, human settlement is slightly discouraged and constant vigilance must be exercised in the event of human settlement, particularly during the rainy season. Concerning the zones with a very high risk, the establishment of dwellings is strongly discouraged in any season, on the other hand, other human activities can be practiced there such as agriculture under a constant monitoring of the triggering parameter of rainfall.

6. CONCLUSION

The objective of this chapter was to draw a map of landslide risk areas and to evaluate their accessibility. It was found that the city of Bafoussam is made up of 34.33% of low-risk landslide areas, 26.36% of moderate risk landslide areas, 16.67% of high-risk landslide areas, and 4.28% of very high-risk landslide areas. We also showed that only 11.38% of these risk areas are accessible by rescue vehicles; This would have a considerable impact on the reaction capacity of the rescue workers and consequently an increase in human and material losses in case of disaster. Points at different risk levels were taken randomly and a field check was performed. The model was found to be correct, however, recommendations were made to improve the accuracy of the results.

The main objective of this study was to map the areas according to their landslide risk and to evaluate their accessibility in the city of Bafoussam. To achieve this, after presenting what can be defined as a landslide with its multiple causes, factors and manifestations, it was necessary to make a multi-criteria analysis to better define the choice of this site. It was necessary to define maps of landslide risk factors, and their intersection gave us the map of landslide risk areas in the city of Bafoussam. Five zones were identified and classified successively according to those with a very low risk, a low risk, a moderate risk, a high risk, and a very high risk. With regard to accessibility, we generated a buffer zone on each side of the roads from the Bafoussam road file. This buffer zone represents the accessible surface and allowed us to extract the accessible zones. The area of each zone was calculated, which allowed us to find the percentage of accessible areas. These results were verified on site by a randomly selected point test, and proved to be conclusive. However, recommendations were made regarding the nature of the data used, which can be greatly improved, thus increasing the accuracy of the results.

In the future, this work could be completed by the development of a software that will allow the automatic update of the data used in this work and that would facilitate the access and the use of the information that it will generate.

7. AKNOWLEDGEMENT

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8. CONTRIBUTIONS OF THE AUTHORS

This work is the result of a research work of Master in Topography and which a current problem in Cameroon that Mr. Tenny has kindly presented. Our contribution overall was the technical supervision at the laboratory of applied geomatics at the University of Yaoundé I and at the School of Geology and Mining (where I work) with support from the researcher on the concepts and methodology used for implementation. Mr. Tenny had to use the tools available in the two host institutions to develop the thesis under the supervision of his academic supervisor.

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10. KEY TERMS AND DEFINITIONS

Landslide : is the displacement of a mass of loose or rocky soil along a failure surface (flat, circular or otherwise)

Landslide risk assessment model : refers to a perceived potential hazard in a given social, economic and cultural context. This notion is very close to that of uncertainty and is expressed by the product of a hazard and a vulnerability.

Hazard : a threatening phenomenon of natural and/or anthropic origin, likely to affect a given area, in particular by the nature and value of the exposed elements that this area supports (people, goods, activities ....). It is characterized by its nature, its identity, its probability of occurrence and its frequency when it can be estimated.

Vulnerability : It is the set of conditions and processes resulting from physical, social, economic and environmental factors, which increase the sensitivity of a community, a region, a nation to the effects of hazards.