REVUE HYBRIDES (RALSH)
e-ISSN 2959-8079 / ISSN-L 2959-8060

ACTES COLLOQUE
RCAC/IRADDAC, SEPT. 2024

APPLICATION OF HIERARCHICAL MULTICRITERIA TO MASS MOVEMENT SUSCEPTIBILITY ALONG THE SOUTHERN ESCARPMENT OF THE BAMILEKE PLATEAU (WEST – CAMEROON)

Application de l'Analyse Hiérarchique Multicritère à la Susceptibilité aux Mouvements de Masse le long de l'Escarpement Sud du Plateau Bamiléké (Ouest-Cameroun)

RAOUL MERLIN NDONBOU
Department of Earth Sciences, Faculty of Science, University of Dschang
ndonbouraoulmerlin@gmail.com

DAVID GUIMOLAIRE NKOUATHIO
Department of Earth Sciences, Faculty of Science, University of Dschang
nkouathio@yahoo.fr

GHISLAIN ZANGMO TEFOGOUM,
Department of Earth Sciences, Faculty of Science, University of Maroua
zangmotefogoum@gmail.com

CHRISTIAN SUH GUEDJEO
Department of Geology, Higher Teacher's Training College, University of Bamenda
guedjeochristian@yahoo.fr

KAN JEAN KOUAME
Laboratoire des Sciences et Techniques de l'Eau et de l'Environnement (LSTEE), UFR des Sciences de la Terre et des Ressources Minières, Université de Cocody
kouame_kan2001@yahoo.fr

ABSTRACT

Mass movements are natural phenomena that cause the most damage in the West Cameroon Highlands (WCH). The severity of this damage is linked to the essentially random nature of these mass movements. The Southern Escarpment of the Bamileke Plateau is a region located on the WCH and is constantly affected by mass movements. The goal is to assess the susceptibility to mass movements along the SEBP in order to circumscribe through a susceptibility map the potential areas at risk of mass movement. The methodological approach is based on the study of susceptibility factors through the application of Multicriteria Hierarchical Analysis or Analytical Hierarchy Process (AHP). A total of 10 susceptibility factors were identified, analyzed and weighted as being the factors that cause the occurrence of mass movements in the study area. Slope, soil, direction of slopes, curvature of slopes, density of watercourses, proximity to roads, geomorphology, land cover, lithology and proximity to roads. By introducing these factors into the weighting matrix, we see that the slope is the factor with the greatest weight (21.27%) of responsibility for mass movements. On the susceptibility map, 16.95% represents low susceptibility areas, 43.39% represents moderate susceptibility areas, 29.77% represents high susceptibility areas and 9.89% represents very high susceptibility areas. Some factors such as slope, soil, direction of slopes, curvature of slopes are the significant factors which have large percentages compared to other factors and are thus counted as the factors which have a strong influence on the occurrence of mass movements in the region.

Keywords: SEBP, AHP, Susceptibility Map, Susceptibility Factors

RÉSUMÉ

Les mouvements de masse sont des phénomènes naturels qui causent le plus de dégât sur les Hautes Terres de l'Ouest Cameroun. La gravité de ces dégâts est liée au caractère essentiellement aléatoire de ces mouvements de masse. L'Escarpement Sud du Plateau Bamiléké est une région situé sur les HTOC et est constamment affecté par les mouvements de masse. Le but est d'évaluer la susceptibilité aux mouvements de masse le long de l'ESPB afin de circonscrire à travers une carte de susceptibilité les potentielles zones à risque de mouvement de masse. L'approche méthodologique est basée sur l'étude des facteurs de susceptibilité à travers l'application de l'Analyse Hiérarchique Multicritère ou Analytical Hierarchy Process (AHP). Un total de 10 facteurs de susceptibilité a été identifié, analysé et pondéré comme étant les facteurs qui causent l'occurrence des mouvements de masse dans la zone d'étude. La pente, le sol, la direction des pentes, la courbure des pentes, la densité des cours d'eau, la proximité des routes, la géomorphologie, l'occupation du sol, la lithologie et la proximité des routes. En introduisant ces facteurs dans la matrice de pondération on constate que la pente est le facteur qui a le plus grand poids (21,27%) de responsabilité sur les mouvements de masse. Sur la carte de susceptibilité, 16,95% représente les zones à faibles susceptibilités, 43,39% représente les zones à susceptibilités modérées, 29,77% représente les zones à susceptibilités élevées et 9,89% représente les zones à susceptibilité très élevées. Certains facteurs comme la pente, le sol, la direction des pentes, la courbure des pentes sont les facteurs significatifs qui ont des pourcentages important par rapport aux autres facteurs et sont ainsi compté comme étant les facteurs qui ont une forte influence sur l'occurrence des mouvements de masse dans la région.

Mots-clés: ESPB, AHP, Carte de susceptibilité, Facteurs de susceptibilité

1. Introduction

Africa is a continent with a diverse human, environmental, cultural and infrastructural heritage. However, this heritage is affected by numerous economic, social, health and even environmental crises, as several countries are strongly affected by natural disasters (floods, landslides, deadly mudslides, etc.). Mass movements are among the natural phenomena that cause the most damage in Africa. They are defined as gravitational displacements of coherent land mass along the rupture surfaces, i.e. slope instability phenomena (landslides, collapses, mudslides, etc…) which, by their essentially random nature, cause significant damages that is felt on humans and their environment (Guedjeo et al., 2017). It is because of this increasing damages that the study of susceptibility to mass movements has become an important and urgent aspect in the world of scientific research in Africa and even in the world

(Thierry et al. , 2005; Maquaire et al., 2006; Malet et al., 2006; Che et al., 2011; Zangmo Tefogoum et al., 2009; Afungang, 2010; Guedjeo et al., 2013; Afungang, 2015; Zangmo Tefogoum, 2016; Aggaz and Bali, 2017; Guedjeo et al., 2017; Azarafza et al., 2018; Boyossoro et al., 2019; Nanehkaran et al., 2021; Jam et al., 2021 ; Ndonbou et al., 2022; Zangmo Tefogoum et al., 2022b; Zangméné et al., 2023; Manefouet Kentsa et al., 2023).

In Cameroon, mass movements have caused a lot of damage, and have become over the years one of the main causes of mortality (Kagou Dongmo, 2006; Zogning et al., 2007; Zangmo Tefogoum et al., 2009; Wouatong et al., 2014a; Fallou, 2019). They occur most often in the season of heavy precipitation.

The Southern Escarpment of the Bamileke Plateau (SEBP) is an area located in the Western Highlands of Cameroon (WHC), and is an important hotbed for the proliferation of mass movements due to its steep and steep landscapes (Epada et al. ., 2012; Aboubakar Balla et al., 2013; Ndonbou et al., 2022). These mass movements are further accentuated by human activity. We are witnessing an abusive exploitation of the slopes by the indigenous populations in search of fill materials. Several mining quarries arise haphazardly on the steep and unstable slopes which weaken and thus become very vulnerable to landslides (Rullen-Perchirin, 1987).

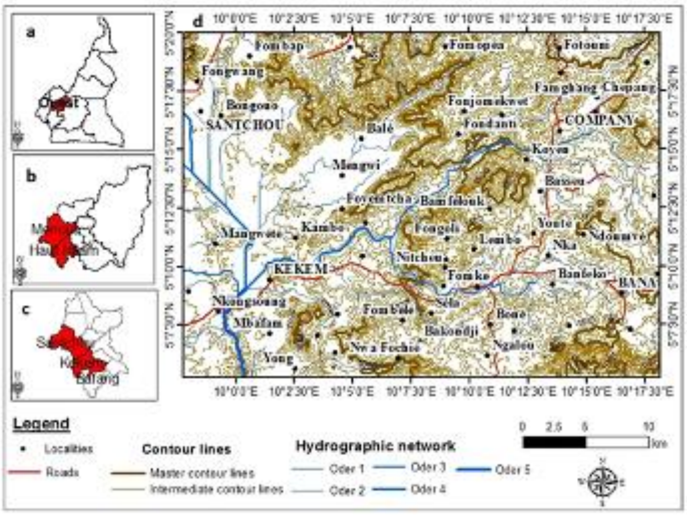
For more than 10 years, each year there has been a series of mass movements on the slopes of the localities that make up this region (Epada et al., 2012; Aboubakar Balla et al., 2013). These mass movements generally cause a lot of damages (destruction of homes, interruption of road traffic following road breaks or blockage by sliding materials, destruction of plantations, etc…). Faced with all these dangers, the populations feel threatened by the risk that persists, the agro-pastoral, cultural and infrastructural heritage also suffered from this threat. It is for this reason that it becomes important and even urgent to carry out a study on the susceptibility to these mass movements, hence the objective of this report which is to evaluate the susceptibility to mass movements along the SEBP in order to circumscribe through a susceptibility map the potential areas at risk of mass movement. The approach we are considering is an approach based on the study of susceptibility factors through the application of the Multicriteria Hierarchical Analysis or Analytical Hierarchy Process (AHP) of Saaty (1984). This method will allow us to obtain the level of responsibility of each factor in terms of percentage on the occurrence of recorded mass movements. A susceptibility map will therefore be obtained and will serve as a benchmark for decision-makers in the acquisition and redistribution of exploitable spaces.

2. Geological and Geographical Context

The study area is located in the West of Cameroon, between 5°19'58.8'' - 5°5'16.8'' North latitude and 9°57'43.2'' - 10° 18'10.8'' East longitude. (Fig. 1). It covers an area of 1006km^2, and contains three main localities namely, Santchou, Kekem and Bafang. It has an estimated population of approximately 195,181 inhabitants with a density of 815 inhabitants per km^2. The climate is of the hot and humid Cameroonian type, with a pseudo-tropical rainfall regime (Chevalier, 1993). The average annual temperature is 23.5°C, the dry season is very short and the rainy season is longer. It is traversed by a hydrographic network of the parallel to sub-dendritic type. The soils are hydromorphic, ferralitic and little evolved. Its relief is quite rugged, consisting of steep slopes, but also a relatively flat area. Speaking of the geological context, the SEBP is located on the Cameroon Volcanic Line (CVL) and is essentially made up of a granito-gneissic basement, covered in places with basalt.

Figure 1

Location map of SEPB a) Cameroon b) Western Region c) Localities in the SEBP d) SEPB



3. Methodology

In this study, a fairly simple methodology was used. (1) We previously carried out a documentary research, which allowed us to have an idea of the other works that were carried out in the study area and even in the areas more or less close to the study area and having a close similarity with the theme studied.

We have (2) carried out field campaigns that have made it possible to make an inventory of mass movements in the study area. The inventory consists of listing, following several field campaigns or from a satellite image, all the types of mass movements that affect the study area or that are likely to affect it. Then, describe them and place them on a map to bring out the mass movement density map. This is a crucial step in a mass movement susceptibility study (Abedini and Tulabi, 2018). Based on field observations and the use of previous work, we have identified the factors that influence instabilities in the area (Guedjeo et al., 2017; Azarafza et al., 2018; Boyossoro et al., 2019; Djukem Wamba , 2021; Zangmo Tefogoum et al., 2022b; Zangméné et al., 2023; Manefouet Kentsa et al., 2023). These factors were weighted using Analytical Hierarchy Process.

(3) Application Analytical Hierarchy Process (AHP). It is actually a multi-criteria decision support method integrating several criteria (Guesdon, 2011). In particular, it aims to refine the decision-making process by examining the consistency and logic of the decision-maker's preferences (Boyossoro et al., 2019). This hierarchical method is done in four steps:

-- **The first step** is the construction of the matrix and the establishment of priorities. In the case of a study like this, the matrix makes it possible to compare the hazard factors with each other. This comparison is binary and makes it possible to obtain a ranking of the factors according to their relative importance in the establishment of the mass movement (Alla Della, 2017). Table 1 below is a sketch of the pairwise comparison matrix used.

Table 1: Sketch of Saaty's pairwise comparison matrix (1984)

Factors	F_1	F_2	…	F_n
F_1	1			
F_2	■	1		
…	■	■	1	
F_n	■	■	■	1

-- **The second** step consists in determining the eigenvectors (Vp) of each criterion and their weighting coefficients (Cp) by the following formulas.

$$Vp = \sqrt[N]{W1 \times \dots\dots\dots.. \times \mathrm{WN}} \quad (1) \qquad \mathrm{Cp} = \frac{VP}{\sum VP} \quad (2)$$

N is the Number of parameters compared and WN represents the scores assigned to the criteria.

Note that the sum of the Cp of all the criteria in a matrix must be equal to 1. A high Cp will tend to increase the risk, while a low Cp will reduce the risk.

-- **The third step** is the calculation of the logical consistency. This is the approach by which the consistency of assessments is tested (Alla Della, 2017). Indeed, a reasoning is said to be coherent if its coherence index is less than or equal to 10% (Saaty, 1984). However, when it comes to comparing less than 9 elements, a tolerance threshold of 10% is set for this consistency index. Higher levels of inconsistency could be tolerated for comparisons involving more than 9 items. The coherence ratio can therefore be interpreted as the probability that the matrix is completed randomly (Saaty, 1984). This step makes it possible to know if the previously elaborated matrix follows a logic. The consistency index (CI) measures the reliability of the comparison expressed with consistent judgments (Sidi Mohamed et al., 2017). This index is found by the following formula.

$$\mathrm{CI} = \frac{(\lambda\mathrm{max} - \mathrm{N})}{(\mathrm{N} - 1)} \quad (3)$$

Where N is the factor number and λmax is a value calculated based on the average of the Saaty matrix values of the eigenvectors. In addition, the experiment established by Saaty makes it possible to define the Coherence Ratio (CR) as being the ratio of the coherence index calculated on the matrix corresponding to the judgments of the factors and the Random Index (RI) of a matrix of the same dimension. Note that the Random Index is a name established by Saaty (Sidi Mohamed et al., 2017). It is given according to the number of factors involved in the mass movement. The consistency ratio is calculated by formula 4 and measures the logical consistency of the judgments made by the decision maker on each factor. It also makes it possible to assess the consistency of judgments using the pairwise comparison method (Sidi Mohamed et al., 2017).

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \qquad (4)$$

Where RI: is the random index set according to the number of criteria listed in Table 2.

According to Saaty, if CR is greater than 0.1, there is an inconsistency in the pairwise comparisons and then the matrix resulting from the comparisons will have to be re-evaluated if it involves less than 9 elements. On the other hand, if the comparison matrix contains more than 9 elements, then it could be considered and used if its CR is greater than 0.1. Table 2 below shows the random indices according to the number of criteria.

Table 2: Random index according to the number of criteria (Saaty, 1980)

N	1	2	3	4	5	6	7	8	9	**10**	11	12
RI	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	**1,49**	1,51	1,54

-- **The fourth step** is the actual weighting of the factors or aggregation, which consists of assigning each factor it's weighting coefficient to take account of the importance given to it in the development of the hazard. In this case, the scores assigned to the classes of factors defined above are multiplied by the priority of each factor (Sidi Mohamed et al., 2017).

On this basis and that of the consistency of judgments (CR), the susceptibility index (S) to mass movements, according to the weighting coefficients is obtained by formula 5 below.

$$S = \sum_{j=1}^{n} Wj \times F \qquad (5)$$

With S: The susceptibility index,
W j: The weight of parameter j,
N: The number of parameters.

It takes the form of an equation of the type

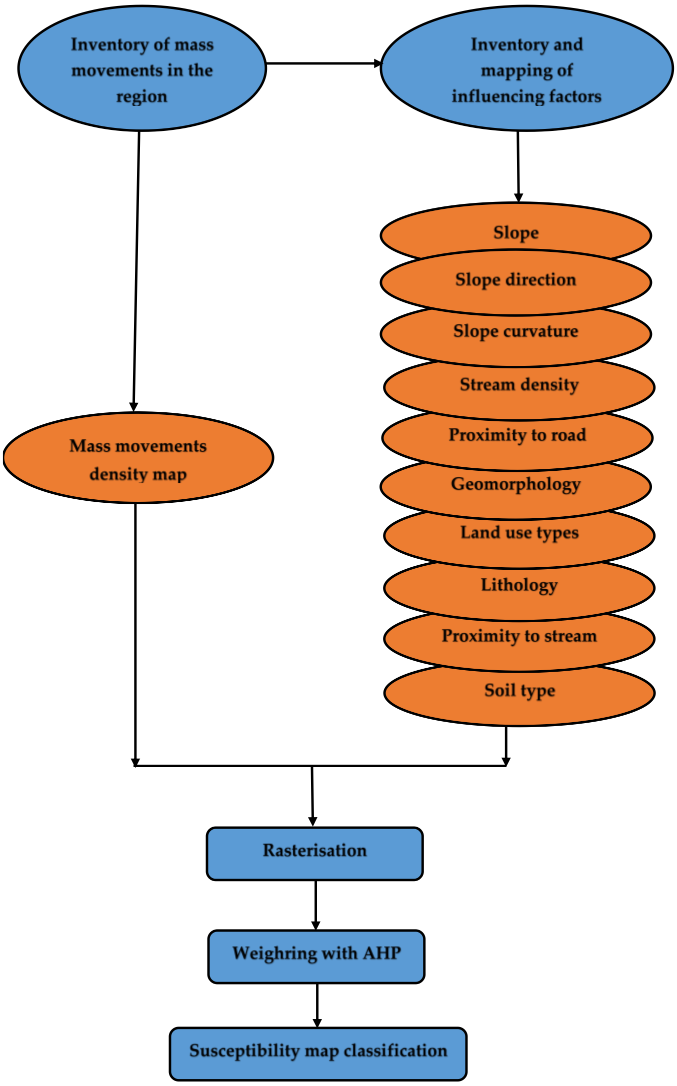
$$S = W_1F_1 + W_2F_2 + W_3F_3 + \ldots\ldots\ldots\ldots + W_nF_n \qquad (6)$$

In this equation,
S: Susceptibility Index
W: Weight of the factor on the establishment of the hazard
F: Factors

The flowchart below highlights the stages of development of the susceptibility map.

Figure 2

Outline of the mass movement susceptibility mapping procedure



4. Results

4.1. Field results : Mass movements inventory

Following the identification of mass movements by remote sensing, several field campaigns have made it possible to identify vulnerable areas as well as the types of mass movements that could affect or have already affected this area. A total of 80 sites vulnerable to mass movements have been mapped in the different localities covering the study area. Figures 3 and 4 perfectly illustrate some of these vulnerable site.

Figure 3

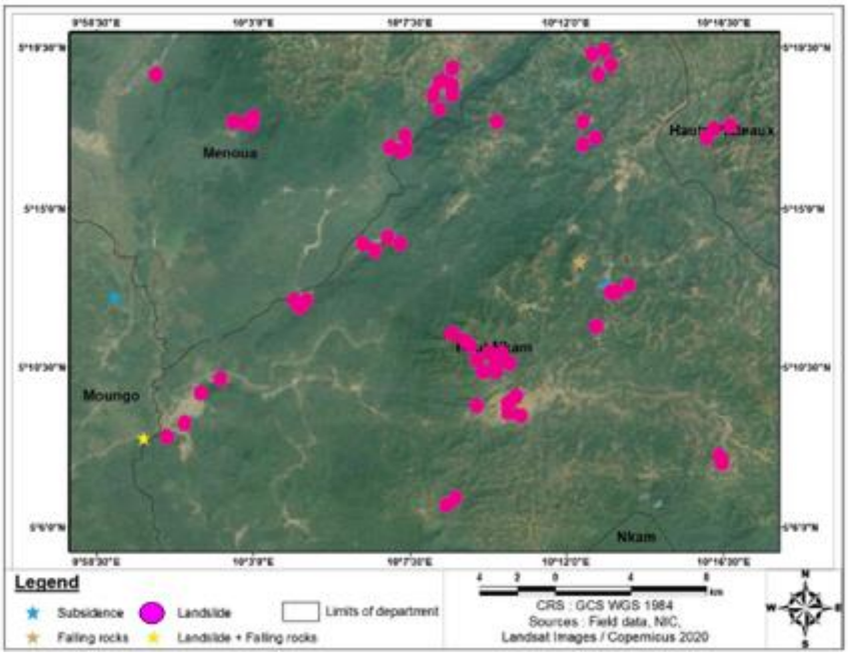
Some cases of landslides in the localities in the study area

Figure 4
Rock fall site in the locality of Basseu and Bandja

The coordinates of each site vulnerable to mass movements were plotted on a map of the study area extracted from Google Earth, making it possible to obtain the mass movement density map. Figure 3 is this density map of mass movements. It highlights the different areas affected by landslides, rock falls and subsidence.

Figure 5

Mass movement density map of the SEBP (extracted from Google Earth)



4.2. Application of Analytical Hierarchy Process on susceptibility factors

The comparison matrix is produced according to the Saaty scale of values (Tab. 3). This is a standardization table that defines the bases for assigning the different values to the mass movement factors.

Table 3: Correspondence of appreciations (Saaty, 1984)

Degree of Preferences	*Numerical Scales*	*Explanation*
Equally	1	Two activities contribute equally to the objective.
Moderately	3	Experience and judgement slightly to moderately favor one activity over another
Strongly	5	Experience and judgement strongly or essentially favor one activity over another
Very strongly	7	An activity is strongly favored over another and its dominance is showed in practice.
Extremely	9	The evidence of favoring one activity over another is of the highest degree possible of an affirmation.
Intermediate values	2, 4, 6, 8	Used to represent compromises between the preferences in weights 1, 3, 5,7 and 9
Opposite	1/2, 1/3, 1/4, 1/5,	Used for inverse comparison

	1/6, 1/7, 1/8, 1/9	

The assessments take into account the research work and the scientific culture of the researcher. With reference to his knowledge, he makes judgments about the process of mass movements. On the SEBP, in relation to the proximity of the roads, the slope is of absolute importance. It takes the value 7. Compared to the lithology, the slope has a proven importance, which gives it the value 5 and so on. It is by proceeding in this way that the importance values are assigned to the elements and this is how the pairwise comparison matrix is constructed.

By applying formula 1 and formula 2, the eigenvector values (Vp) and weighting coefficients (Cp) were determined directly in the factor matrix. The sum of the different appreciation values for each factor is therefore calculated, as well as the sum of the different values of Vp and Cp.

Table 4: Pairwise Comparison Matrix of Mass Movement Factors

Factors	**Sl**	**S**	**Sd**	**Sc**	**St**	**Pr**	**Gm**	**Lu**	**L**	**Ps**	*Vp*	*Cp*
Sl	1										2,61	0,21
S	1/2	1									2,01	0,16
Sd	1/3	1/2	1								1,66	0,13
Sc	1/2	1/3	1/2	1							1,47	0,12
St	1/3	1/2	1/4	1/2	1						1,08	0,08
Pr	1/7	1/5	1/3	1/5	1/3	1					0,93	0,07
Gm	1/2	1/2	1/5	1/3	1/2	1/5	1				0,72	0,06
Lu	1/3	1/2	1/3	1/5	1/5	1/5	1/2	1			0,56	0,04
L	1/5	1/3	1/3	1/2	1/3	1/5	1/3	1/3	1		0,45	0,04
Ps	1/2	1/3	1/3	1/5	1/3	1/7	1/4	1/5	1/3	1	1,23	0,10
amount	**4,33**	**6,19**	**8,27**	**9,93**	**12,69**	**24,87**	**19,08**	**19,53**	**28,33**	**36**	**12,72**	**1**

Factors: *(**Sl**) Slope, (**S**) Soil, (**Sd**) Slope direction, (**Sc**) Slope curvature, (**St**) Stream density, (**Pr**) proximity to road, (**Gm**) geomorphology, (**Lu**) Land use type, (**L**) lithology, (**Ps**) proximity to stream*

Based on this matrix, we determine the priority vectors of each factor. To do this, we proceed to a series of operations: the summation of each column, followed by the normalization of the matrix which consists in dividing each value of appreciation of a column by the sum of this column and finally the calculation of the average of each line, which makes it possible to obtain the priority of each factor according to the process of mass movement (Alla Della, 2017). The amount of the priorities must equal 1 or 100%.

At the end of these operations, the priority vectors of each hazard factor are determined. The priority values calculated in a spreadsheet have been grouped together in Table 5 below.

Table 5: Values of the different weights assigned to each factor

Factors	*Weight (%)*	***Factors***	*Weight (%)*
Sl	21,27	***Pr***	10,80
S	15,76	***Gm***	6,73
Sd	12,85	***Lu***	5,63
Sc	11,58	***L***	3,82
St	8,33	***Ps***	3,23

These values obtained (Tab. 5) actually explain that in the process of movements on the SEBP, the slope has a responsibility of 21.27%, the ground has a responsibility of 15.76%, the direction of the slopes has a responsibility of 12.85%, curvature of slopes has a responsibility of 11.58%, density of streams has a responsibility of 8.33%, proximity to roads has a responsibility of 10.80%, geomorphology has a responsibility of 6.73%, land cover has a responsibility of 5.63%, lithology has a responsibility of 3.83% and proximity to watercourses is 3.23%.

4.2.1. Logical Consistency Check

The notion of consistency in Saaty's (1984) pairwise comparison is based on respecting the transitivity of our judgment. The pairwise comparison of the criteria applied for our case study, as well as the calculations relating to the various parameters gave the following results: λmax = 12.13, coherence index CI = 0.23, random index RI = 1.49 (Tab. 2); coherence ratio CR = 0.15< 0.1. This CR value is simply explained by the fact that our analysis involves 10 criteria.

4.2.2. Aggregation

It consists of multiplying each factor layer by its respective weighting coefficient, and then adding these results to produce a suitability index, for each site, located on a scale of 0 to 10 (Sidi Mohamed et al., 2017). The sum of the weights is equal to 1 or 100%. Once the decision factor layers were assessed, we then combined them by a weighted linear combination to create a suitability index illustrated by equation (7) (Yoon and Hwang, 1995).

$$S=0,21Sl+0,16S+0,13Sd+0,12Sc+0,08St+0,11Pr+0,07Gm+0,06Lu+0,04L+0,03Ps \quad \textbf{(7)}$$

Generally, this equation is called the suitability index, but in the specific case of this study, it represents the index of susceptibility (S) to mass movements in the study area.

4.2.3. Mapping of susceptibility factors

Factors influencing instabilities in the study area were individually mapped.

Figure 6

Map of slopes in the SEBP

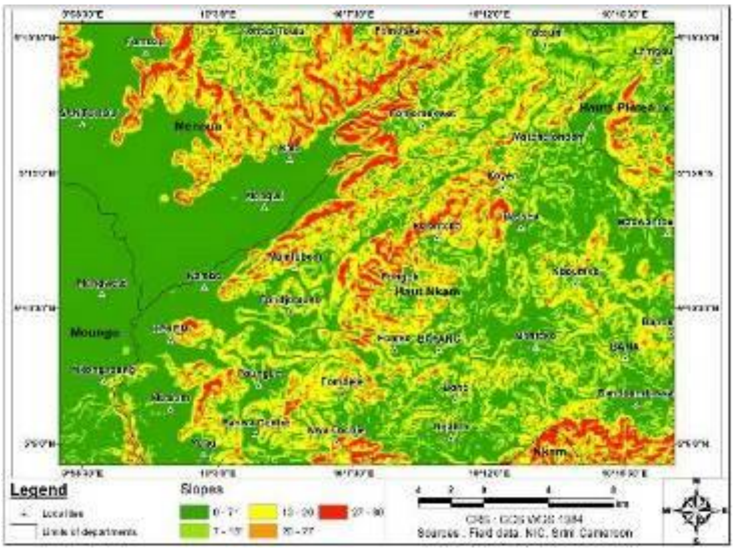


Figure 7
Slope direction map of the SEBP

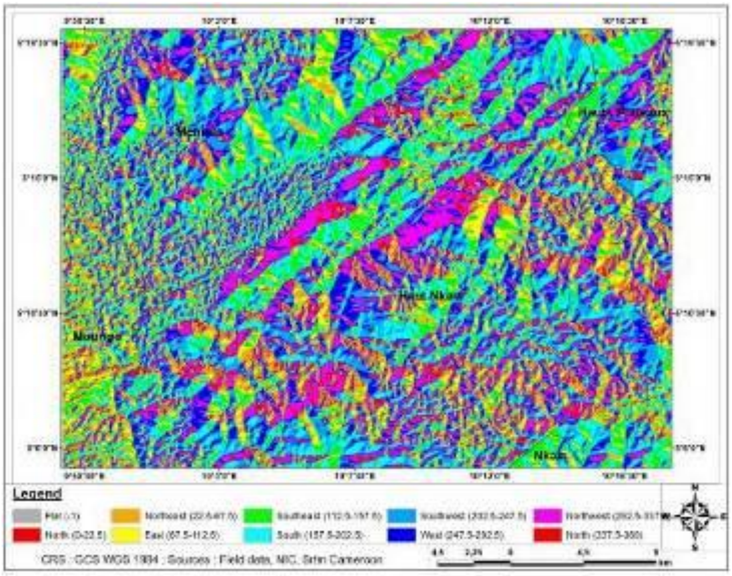
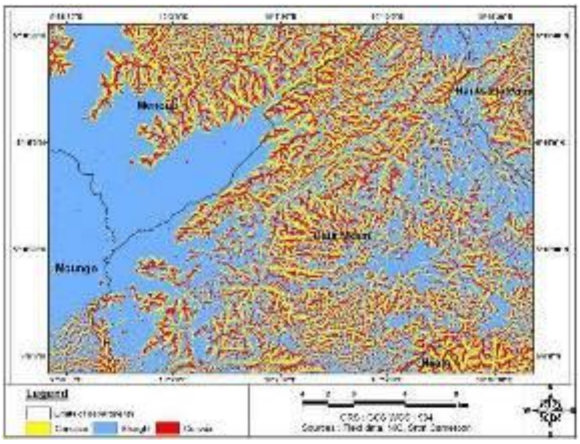


Figure 9
Soil map of the SEBP

Figure 8
Map of slope curvature of the SEBP



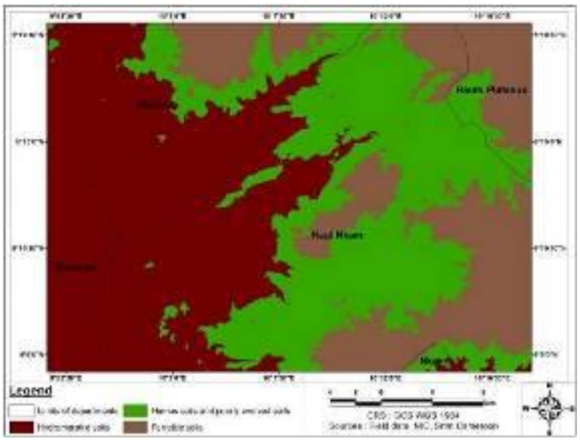


Figure 10
Geological map of the SEBP modified after Dumort, 1968; Tcheumenak Kouemo et al., 2014 ; Kwékam et al., 2013

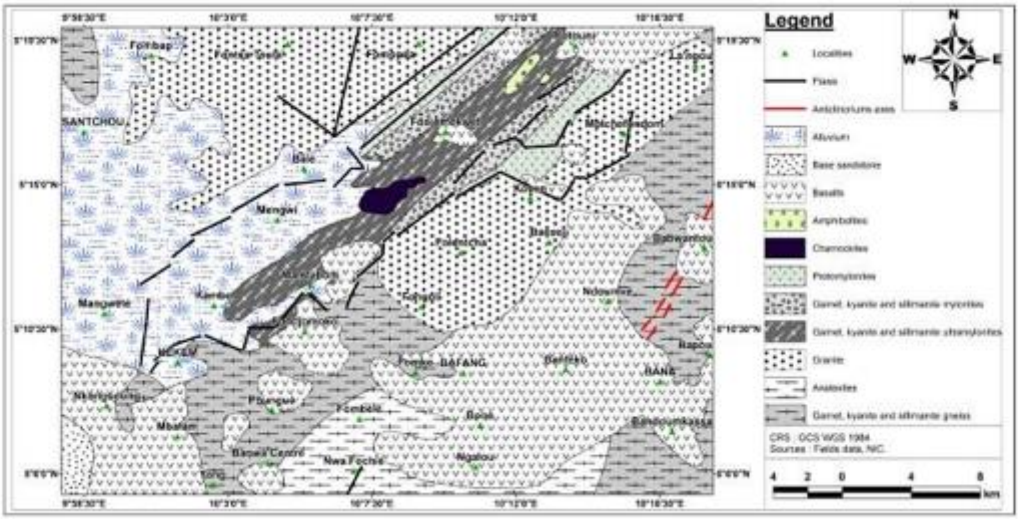
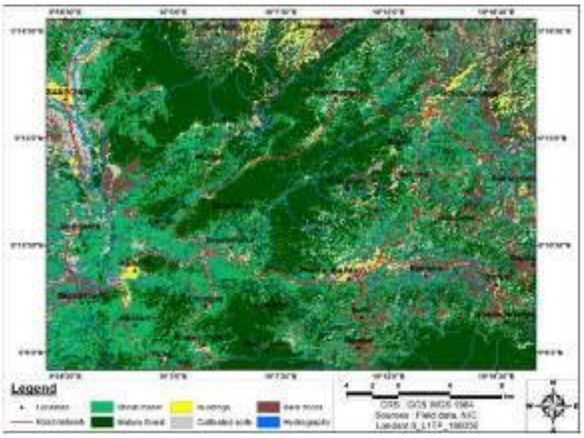


Figure 11
Land use map of the SEBP

Figure 12
Geomorphological map of the SEBP



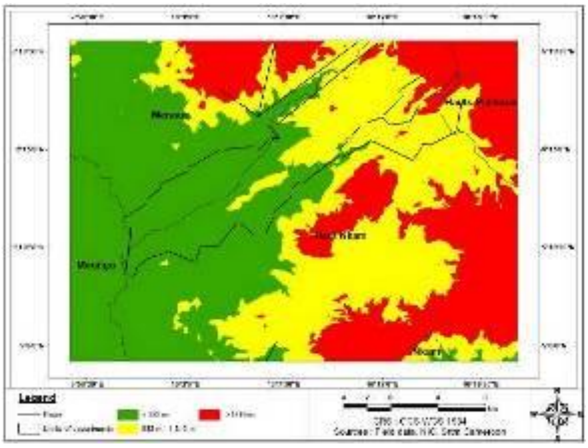


Figure 13
River density map of the SEBP

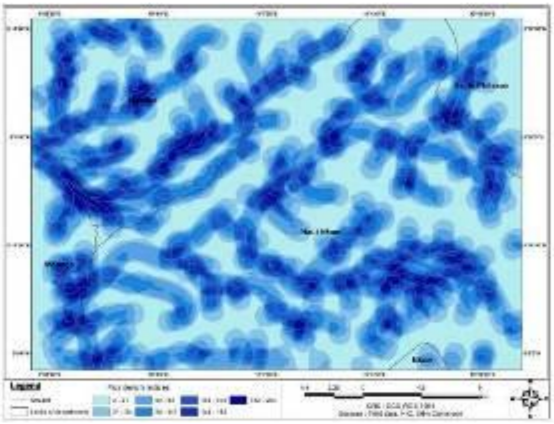


Figure 14
Proximity map of water courses in the SEBP

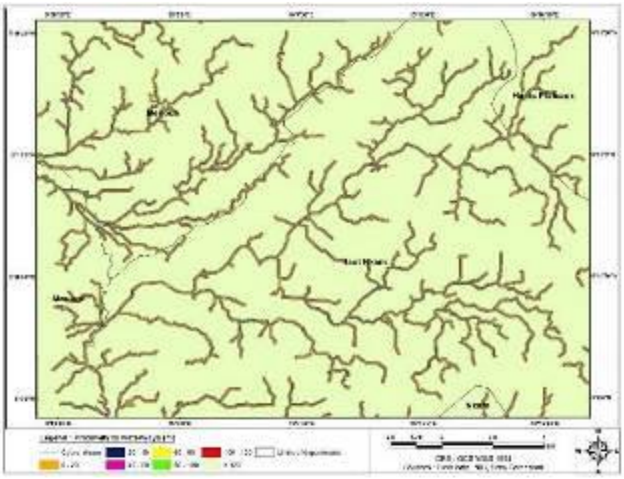
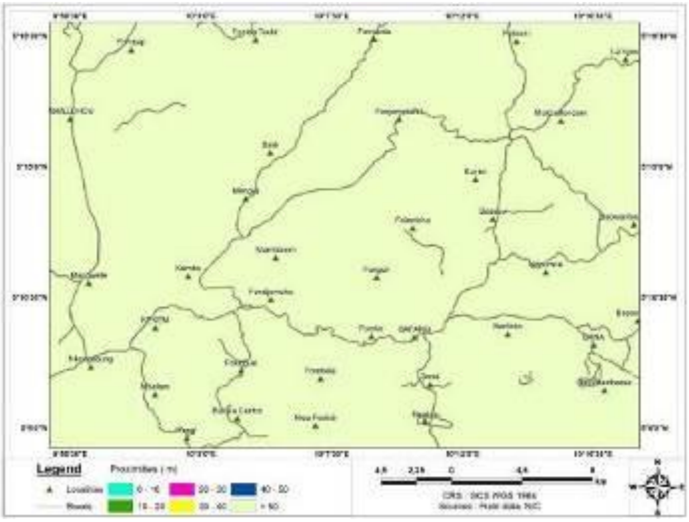


Figure 15
Road proximity map of the SEBP



4.3. Assessment of susceptibility to mass movements

The susceptibility assessment is the last step of the modelling. It is done by producing a map of susceptibility to mass movements. Following the classification, the susceptibility map (Fig.16) shows four classes which reflect four levels of susceptibility distributed over the SEBP. It is defined as follows: zones with low susceptibilities, zones with moderate susceptibilities, zones with high susceptibilities and zones with very high susceptibilities. The susceptibility indices are attributes linked to the different levels of susceptibility and which are created in the database during the combination in the GIS. Therefore, the higher the susceptibility index, the more the area is susceptible to mass movements (Boyossoro et al., 2019).

Figure 16

Mass movement susceptibility map of the SEBP

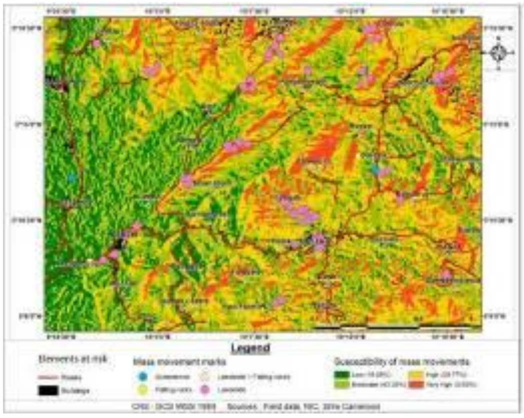
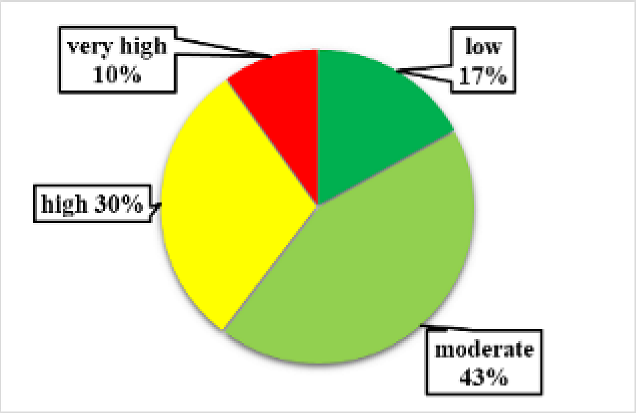


Figure 17

Graph of distribution of the different levels of susceptibility



The susceptibility map is defined as follows: low susceptibility zones, moderate susceptibility zones, high susceptibility zones and very high susceptibility zones. This map should integrate the spatial dimension and the probability of occurrence of mass movements in a given period of time. Although these elements are assumed to be independent (Guzzetti, 2005). These susceptibility classes are defined by susceptibility indices ranging from 0.099 to 0.627 (Tab. 6).

Table 6: Repartition of susceptibility indices

CLASSES	SUSCEPTIBILITY INDICES	PERCENTAGES (%)
LOW	0.099-0.265	16.95
MODERATE	0.265-0.364	43.39
HIGH	0.364-0.463	29.77
VERY HIGH	0.463-0.627	9.89

5. Discussion

Mass movements are natural phenomena with a random character. These mass movements are always strongly influenced by factors that predispose to risk (Maquaire et al., 2006; Che et al., 2008; Zangmo Tefogoum et al., 2009; Afungang, 2010; Guedjeo et al., 2013; Zangmo Tefogoum, 2016; Aggaz and Bali, 2017; Guedjeo et al., 2017; Azarafza et al., 2018; Boyossoro et al., 2019; Djukem Wamba, 2021; Nanehkaran et al., 2021; Jam et al., 2021; Ndonbou et al., 2022; Zangmo Tefogoum et al., 2022b; Zangméné et al., 2023; Manefouet Kentsa et al., 2023). On SEBP, 10 factors were assessed as having a significant impact on the occurrence of mass movements in the study area. These factors were weighted using the AHP. This factor weighting method has proven itself and has already been implemented by several authors (Catena, 2011; Renard and Chapon, 2011; Guesdon, 2011, Park et al., 2013; Kavzoglu et al., 2014; Sidi Mohamed et al., 2017; Alla Della, 2017; Boyossoro et al., 2019; Vojtekova and Vojtek, 2020; Nanda et al., 2021) whether in the assessment of environmental impacts, or in the study of mass movements. These authors had satisfactory results using AHP in solving a specific problem. The main advantage of this method is that it makes the decisions taken in the choice of factors that influence mass movements in a given region objective, by assigning to each factor a weight which is its percentage of responsibility linked to the hazard.

By applying the AHP on the susceptibility factors along the SEBP, it is now known that the slope has a responsibility of 21.27%, the ground has a responsibility of 15.76%, the direction of the slopes has a responsibility of 12.85%, the curvature of the slopes has a responsibility of 11.58%, the density of the streams with a responsibility of 8.33%, the proximity of the roads has a responsibility of 10.80%, the geomorphology has a responsibility of 6.73% land use has a responsibility of 5.63%, lithology has a responsibility of 3.83% and proximity to watercourses is 3.23%. These values mean that on SEBP, the factors do not act to the same degree in setting the occurrence of movements. Each factor has its own percentage of responsibility. Factors like slope and soil have the highest percentages (21.27% and 15.76% respectively for slope and soil). These percentages can be explained by the fact that the mass movements mainly develop on slopes and the materials mobilized are soil materials. Proximity to watercourses and lithology have low percentages (3.83% and 3.23% respectively) due to the fact that in the study area, just 2 sites are at risk of rock fall and only 1 site was affected by a landslide along a watercourse. Compared to the work of Boyossoro et al. (2019) on mass movements in the Man's region in Ivory Coast, where the slope also has the largest weight (36%), the largest eigenvector (Vp=2.15) and the largest coefficient weighting (Cp=0.27). As for the work and Nanda et al. (2021) on landslides along the national road 1D from Sonamarg to Kargil (North-West Himalayas), we also observe that the slope has the large eigenvector (Vp= 2.21) and the greatest weighting coefficient (Cp=0.11). This similarity with the values obtained on the SEBP is linked to the fact that the slope in general is the factor that most influences mass movements.

In light of the above, the conditioning factors can be subdivided into 3 groups according to their percentages. The first consists of 4 factors namely the Slope, the Soil, the Slope direction and the Slope curvature this group of factors is called significant factors, that is to say the factors which have a strong influence on the occurrence of mass movements in the region. The second group consists of geomorphology, Land use type, lithology, and proximity to stream, these are insignificant factors which have a lesser influence on the recorded instabilities and the third group consists of intermediate factors, namely the stream density, and the proximity to road. Their implications are medium in the occurrence of mass movements in the study area. This classification is similar to that obtained by Zangméné et al., 2023 in the Bafoussam-Dschang area (West-Cameroon) and by Boyossoro et al., 2019 in the Man's region in Ivory Coast.

This factor weighting method of Saaty (1984) used to assign a weight to instability factors is a method that is not very common among mass movement risk assessment methods in Cameroon, especially on CVL and on WCH more specifically, with the exception of the work of Zangméné et al., 2023, many other researchers should be interested in it because this method is easy to implement and presents satisfactory results.

6. Conclusion

The objective of this study is to analyze the factors of susceptibility which are at the origin of the occurrence of mass movements along the SEBP. From multiple field campaigns carried out and also by exploiting satellite images, it can be seen that the study area is strongly threatened by mass movements. These mass movements are influenced by many factors such as the slope, the ground, and the direction of the slopes, the curvature of the slopes, the density of the rivers, the proximity of the roads, the geomorphology, and the occupation of the land, lithology and proximity to roads. The Analytical Hierarchy Process of Saaty (1984) made it possible to analyze and assign a weight to these conditioning factors. It is therefore known that the slope is the factor that has the greatest weight (21.27%), that is to say the factor that has the greatest responsibility for the occurrence of mass movements in the region. In the case of this study, the slope, the ground, the direction of the slopes, and the curvature of the slopes are the significant factors which have significant percentages compared to the other factors and are thus counted as being the factors which have a strong influence on the occurrence of mass movements in the region. Geomorphology, land use, lithology and proximity to roads are insignificant factors, that is to say, they have less influence on the instabilities recorded in the study area. The susceptibility map obtained made it possible to define the different risk zones, namely: low susceptibility zones, moderate susceptibility zones, high susceptibility zones and very high susceptibility zones. This analysis made it possible to apply the AHP on the 10 factors that cause instabilities along the SEBP.

7. References

Abedini, M., Tulabi, S. (2018). Assessing LNRF, FR, and AHP models in landslide susceptibility mapping index: a comparative study of Nojian watershed in Lorestan province, Iran. *Environmental Earth Sciences 77(11), 1-13p.*

Aboubakar, B., Kagou Dongmo, A., Nkouathio, D.G., Ngapgue, F. (2013). Instabilité des terrains dans les Haute Terres de l'Ouest Cameroun: Caractérisation géologique et géotechnique du glissement de terrain de Kékem. *Bulletin de l'Institut Scientifique, Rabat, Section Sciences de la terre, 20, (35), 39-51p.*

Aggaz, H., et Bali M. (2017). Cartographie Géotechnique, des Risques de Glissements de terrain de la ville de Bejaia (ALGERIE). *Memoire fin d'etude master 2 Université A. MIRA Bejaia.*

ALLA Della, A. (2017). Multi-criterion analysis and cartography of areas sensitive to soil erosion in tropical urban environments: an example of Anyama (Northern Nuburb of Abidjan). *Int. J. Adv. Res. 5(10), 1908-1921p.*

Azarafza, M., Ghazifard, A., Akgün, H., Asghari-Kaljahi, E. (2018). Landslide susceptibilityassessment of South Pars Special Zone, southwest Iran. *Environmental Earth Sciences, 77(24), 805p.*

Boyossoro, H. K., Kan, J. K., Sika, B., Gabriel, E. A., Vami, H. N., B., Assa, Y. (2019). Utilisation des SIS et de la télédétection pour la Cartographie de la susceptibilité auxmouvements d'instabilité de versant dans l'Ouest Montagneux de la Côte d'Ivoire. *Revue Française de photogrammétrie et de Télédétection. 1 (221) 321p.*

Catena (2011). A GIS-based comparative study of frequency ratio, analytical hierarchy process, bivariate statistics and logistics regression methods for landslide susceptibilitymapping in Trabzon, NE Turkey. *85, (3), 274-287p.*

Che, V. B., Kervyn, M., Ernst, G., Trefois, P., Ayonghe, S., Jacobs, P., Suh, C. E. (2011). Systematic documentation of landslide events in Limbe area (Mt Cameroon Volcano, SW Cameroon): geometry, controlling, and triggering factors. *NaturalHazards, 59(1), 47-74p.*

Chevalier, (1993). Cartographie et évolution de la plaine de Mbo (Ouest-Cameroun) *UDS.DEFORD. Dschang. 36p.*

Dumort, J.C. (1968). Carte géologique de la reconnaissance de la république fédérale du Cameroun *feuille N° : NB 32 SE 028.*

Epada, P., Ganno, S., Tabod, C. T. (2012). Geophysical and Geotechnical Investigations of a Landslide in Kekem Area, Western Cameroon. Geophysical and Geotechnical Investigations of a Landslide in Kekem Area, Western Cameroon. *International Journal of Geosciences, 3, 780 789p.*

Fallou, (2019). Cameroun: reprise des fouilles sur le site du glissement de terrain à Bafoussam. Vonews Afrique, *www.vonews.net (access on November 4th, 2019).*

Guedjeo, C. S., Kagou Dongmo, A., Wotchoko, P., Nkouathio, D. G., Chenyi, M. L., Wilson, B., Kamgang, K.V. (2017). Landslide Susceptibility Mapping and Risk Assessment on the Bamenda Mountain Cameroon Volcanic Line. *Journal of Geosciences and Geomatic, 5 (4), 173-185p.*

Guesdon, G. (2011). Méthodes et outils. Aide multicritère à la décision Comparaison de Saaty. *Faculté des sciences et de génie Université Laval 24p.*

Guzzetti, F. (2005). Landslide hazard and risk assessment: *PhD thesis, University of Rheinischen FriedrichWilhelms, Bonn-Italy, 389p.*

Jam, AS, Mostaffaie, J., Sarfaraz F., Shafar S., Akhtari R. (2021). GIS-based landslide susceptibility mapping using hybrid MCD M models. *Natural Hazards,*

Kagou Dongmo, A. (2006). Le Mont Manengouba: Évolution volcanique, caractères magmatologiques et risques naturels; comparaison avec les monts Bambouto et Bamenda (Ligne du Cameroun). *Thèse Doct. État, Univ. Yaoundé I, 230p.*

Kavzoglu, T., Sahin, E. K. Colkesen I., (2014). Landslide susceptibility mapping using GIS-based multi-criteria decision analysis, support vector machines, and logistic regression.*Landslides 11(3), 425-439p.*

Kwékam, M., Affaton, P., Bruguier, O., Liégeois, J.P., Hartmann, G., Njonfang, E. (2013). The Pan African Kekem gabbro-norite (West-Cameroon), U-Pb zircon age, geochemistry and Sr Nd isotopes: Geodynamical implication for the evolution of the Central African fold belt. *Journal of African Earth Sciences 84, 70-88p.*

Malet, J.-P., Van Asch, Th. W. J., Van Beek, R., Maquaire, O. (2005). Forecasting the behaviour of complex landslides with a spatially distributed hydrological model. *Natural Hazards and Earth System ScieTnces, 5, 1-15p.*

Manefouet Kentsa, B. I. Rugendabanga, C. C. Barhadosanya, L. C´., Buzera, K. C. Foko Tamba, C (2023). Landslide susceptibility assessment by mapping and diachronic analysis: Case of Bushwira (Democratic Republic of Congo*).Journal homepage: www.sciencedirect.com/journal/quaternary-science-advances*

Maquaire, O., Yannick T., Jean-Philippe M., Anne, P. (2006). Évaluation et cartographie par SIG du risque 'glissement de terrain'. Application aux Alpes du Sud. *Interactions Nature-Société Analyse et Modèles.*

Nanda, M. A., Zahoor, H. L., Pervez, A., Kanth T. A. (2021). Landslide Susceptibility Zonation along National Highway 1D from Sonamarg to Kargil, North Western Himalaya. *Jour. Geol. Soc. India. 11(12). 8p*

Nanehkaran, Y A., Mao, Y., Azarafza, M., Kockar, MK, Zhu, HH. (2021). Fuzzy-based multiple decision method for landslide susceptibility and hazard assessment: A case study of Tabriz, Iran. *Geomechanics and Engineering 24(5), 407-418p.*

Ndonbou, R.M., Nkouathio, D.G., Zangmo, Tefogoum G., Guedjeo, C.S., Tematio, P., DjukemFenguia, S.N., (2022). Mass movements susceptibility analysis along the Southern Escarpment of the Bamileke Plateaus (Western Cameroon Highlands) using a GISa based analytical approach. J. *Environ. Earth Sci. 81, 154. https://doi.org/ 10.1007/s12665 022 10240-z.*

Park, S., Choi, C., Kim, B., Kim, J. (2013). Landslide susceptibility mapping using frequency ratio, analytic hierarchy process, logistic regression, and artificial neural network methods at the Inje area, Korea. *Environmental Earth Sciences 68(5) ,1443-1464p.*

Renard, F., Chapon, P-M. (2010). Une méthode d'évaluation de la vulnérabilité urbaine appliquée àl'agglomération lyonnaise. *Belin L'Espace géographique. 1, (39) 35-50p.*

Rullen-Perchirin. (1987). Les mouvements de masse dans le bassin-versant du Rhumel constantinois: essai méthodologique. *Travaux de l'Institut de Géographie de Reims Année 69, (72), 151171p.*

Saaty, T. L. (1980). The Analytic Hierarchy Process. *McGraw-Hill, New York, USA 17p.*

Saaty, T.L. (1984). Décider face à la complexité: une approche analytique multicritère d'aide à la décision. *Collection université entreprise, entreprise moderne d'édition, Paris. 367p.*

Sidi Mohamed, E. A., Mohamed, R., Mourad, B., Abdelwahed, E. I. (2017). Intégration du SIG et de l'analyse hiérarchique multicritère pour l'aide dans la planification urbaine : étude de cas de la province de Khemisset, Maroc. *Papeles de Geografía, 63, 71 90p.*

Tcheumenak Kouémo, J., Njanko, T., Kwekam, M., Naba, S., Bella Nke, B.E., Yakeu Sandjo, A.F., Fozing E. M., Njonfang E. (2014). Kinematic evolution of the

Fodjomekwet Fotouni Shear Zone (West-Cameroon): Implications for emplacement of the Fomopéa and Bandja plutons. *Journal of African Earth Sciences 99, 261-275p.*

Thierry, P., Stieltjes, L., Kouokam, E., Nguéya, P., Salley, P. M. (2008). Multi-hazard risk mapping and assessment on an active volcano: the GRINP project at Mount Cameroon. *Natural Hazards, 45(3), 429-456p.*

Vojteková, J., Vojtek, M. (2020). Assessment of landslide susceptibility at a local spatial scale applying the multi- criteria analysis and GIS: a case study from Slovakia. *Geomatics, Natural Hazards and Risk 11(1): 131- 772p.*

Wouatong, A. S. L., Tchungouelieu, W. H., Ngapgue, F., Katte, V., Beyala, V. K. K. (2014b). Mineralogical and geotechnical characteristics of the loose weathered trachytes of Fongo-Tongo (West-Cameroon). *International Journal of Applied, 47p.*

Yoon, K. P. Hwang, C. L. (1995). Prise de décision à plusieurs attributs : Une introduction publication sage

Zangmene, F. L., Nsangou Ngapna, M. Balla Ateba, M. C., Mboudou, G M M Wabo Defo, P. L. Tetang Kouo R, Kagou Dongmo A, Owona S. (2023). Landslide susceptibilityzonation using the analytical hierarchy process (AHP) in the Bafoussam Dschang region (West Cameroon). *Advances in Space Research xxx (xxxx) xxx*

Zangmo Tefogoum G Amza Mfossi Merlin Gounti´e Dedzo David Guimolaire Nkouathio Armand Kagou Dongmo, Marcelin Bikoro Bi Alou (2022b). Factors affecting mass movement hazards in and around Djound´e (Far North Region, Cameroon). *Geomorphology journal homepage: www.journals.elsevier.com/geomorphology*

Zoning, A., Ngouanet, C., Tiofack, O. (2007). The catastrophic geomorphological processes in humid tropical Africa: A case study of the recent landslide disasters in Cameroon. *Sedimentary Geology, 199, 13p.*