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Landslide Susceptibility Mapping and Risk Assessment on the Bamenda Mountain (Cameroon Volcanic Line)

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Abstract The Bamenda Mountain (with over 250,000 inhabitants) is one of the strato-volcanoes along the Cameroon Volcanic Line (CVL) with an accidental landscape. This area is frequently affected by landslides, which most at times result in destruction of property and loss of lives. An informative value statistical method using GIS is use to prepared a landslide susceptibility map for the Bamenda Mountain area as well as a quantitative and qualitative risk assessment. This is aimed at revealing areas where future landslide would occur and potential loss. Nine landslide controlling factors including; slope, slope orientation (aspect), curvature, stream density, proximity to roads, geomorphology, proximity to streams, geology and land use were use in the model. A total of 64 slides were inventoried in the area and use to prepare the landslide density map. The weighted informative values for the combined factor and landslide density were used to prepare the landslide susceptibility map for the area. The most significant landslide causing factors in this area are; slope, stream density and slope aspect. The susceptibility map was classified into very high (17.8%), high (25.9%), moderate (33.6%) and low (22.7%). The validated model using the success rate curve indicates that the area under curve is 0.823 and predicts landslides at 82.3% in relatively high classes. Landslide risk assessment in the area indicates 406 buildings, 2,436 people, 1,291.1km of roads, 2152 ha of farmland and an approximate USD83,540,000 worth in assets are expose to high and very high risk. This approach can be implemented in other areas along the CVL to map and assess landslide risk.

Keywords: *Bamenda Mountain, landslides, informative value, susceptibility map, risk*

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1. Introduction

Landslides occur predominantly on slopes where the soils shear stress exceeds its strength. These landslides are usually triggered by high rainfall or earthquakes. The global trend on landslide fatalities has been on the rise in the past decade. In 2015, a total of 402 lives were lost, and thousands of homes destroyed from landslide within April to November notably in Brazil, Afghanistan, Columbia, Guatemala, Nepal and China [1,7]. In 2016, the landslide fatalities increase further to 620 mortality. With the rise in global population following technological advancements, settlements along mountain slopes has increase drastically, thereby increasing the vulnerability in these zones. Landslides present a threat to life and livelihood throughout the world, ranging from minor disruption to social and economic catastrophe [38]. Though landslides have been widely studied, it still poses problems in susceptibility, risk mapping and assessment. Conversely, different types of landslide hazard mapping techniques have been developed over the last decades [6,32,43,53,59,61].

In Cameroon, landslides account for 25% of natural hazards [55] and has been on the rise in the past decade with considerable impact on human lives 128 deaths [69] environment and property [2,8,9,15,30,64]. These landslides are common along the CVL to which the Bamenda Mountain is situated. This hilly environment is prone to landslides [30]. Landslides on the Bamenda Mountain have taken a lot of lives and continue to pose a threat to the ever-increasing population. Some deadly landslide event along the CVL include: July, 2003 Magha, June 27 2001, Limbe 23 deaths, June, 1998 Melong, 11 deaths, August 1990, Dschang, 6 deaths, August 2006 Bamenda 4 deaths, 20th October 2007 Kekem 3 deaths [44].

In this paper a statistical informative value method using GIS is use to prepare a landslide susceptibility map by means of a landslide inventory-based probabilistic technique [21]. This method has proven to be very effective because it quantitatively predicts landslide susceptibility areas by means of a value, even on areas that are not yet affected by landslides. Furthermore, using spatial statistics, a risk map is prepared for the area and level of risk assessed in terms of population, buildings, cost and roads. The reason for using a GIS approach is that it is being widely used in landslide susceptibility modeling in recent years [5,24,39]. The findings in this paper could provide vital information to the Ministries of environmental protection and town planning as well as the municipal councils regarding land appropriation and occupation. The model prepared could be used by goescientists in the region and other areas as a base for landslide susceptibility mapping.

2. Study Area Profile

The Bamenda Mountain (2621 m) lies between longitude 10°10′00″E to 10°16′30″E and latitude 5°46′00″N to 5°56′30″N precisely between Mounts Bambouto (2740 m) to the SW and Mount Oku (3011 m) to the NW all of which constitute the Western Cameroon Highlands (WCH) along the CVL (Figure 1). The WCH is an almost continuous volcanic structure with no distinct limit between the mountains, having a SW-NE trend with huge volume of volcanic material extruded on Pan African granitoid [47,48,58]. The Bamenda Mountain is centrally located within the WCH and has a series of geomorphosites ranging from calderas, volcanic dykes, escarpments, plateau, domes, plains, steep slopes and valleys which serve as geosites [65]- [66]. It has two main volcanoes at Bambili and Lefo (Santa) areas which culminates at altitudes of 2621 and 2545 m a.s.l respectively. It is also characterized by two calderas; the Santa-Mbu and Lefo calderas [29]. It relief is highly accidental owing to the diversity of volcanic manifestations and products in the area. The soils are dominantly lateritic with characteristic red colour. This Mountain is well drained with streams and rivers flowing into two major drainage basins in Cameroon i.e. Sanaga and Niger basin. A series of streams and rivers which form tributaries of major rivers such as the Rivers Mezam and Naaka (Niger basin) and the Noun, Matazum and Mifi (Sanaga Basin) radiate from this Mountain. The drainage systems in this area are; trellis, radial and dendritic. The climate is of the tropical type with two distinct seasons: a long rainy season (March-October) and a short dry season (November-February) [49]. Average temperatures range from 21-25°C and rainfall of 25-1800 mm per annum. The vegetation pattern of this Mountain is mostly of the Sudan Savanah (grassland and short stunted trees) and forest type (artificial i.e. the Ngemba forest reserve and highly restricted gallery forests in valleys).

3. Methods

3.1. Susceptibility Mapping Technique

A total of 64 landslides were mapped in the area, 52 during field campaign and 12 from satellite images. The landslides conditioning factors used for mapping were constructed from different data sources such as the DEM, satellite images (Google earth and LANSAT thematic mapper), field survey and thematic maps of the area. A 90m resolution DEM was improved upon to a 10m pixel DEM raster with a higher resolution [35,36]. From the DEM landslide conditioning factors, such as: slope, slope directions and curvature were constructed using the spatial analyst tool in ArcGIS 10.2. Parameters developed from field survey, thematic maps and satellite images included: proximity to stream, stream density, and proximity to roads, land use and geology. From the google earth 2015 satellite image data was extracted in the form of kml file format and converted into shape files in the ArcGIS software for further analysis. All the landslide conditioning parameters were built with a constant cell size of 10m pixel which is essential in weighting and overlaying of the various raster data sets.

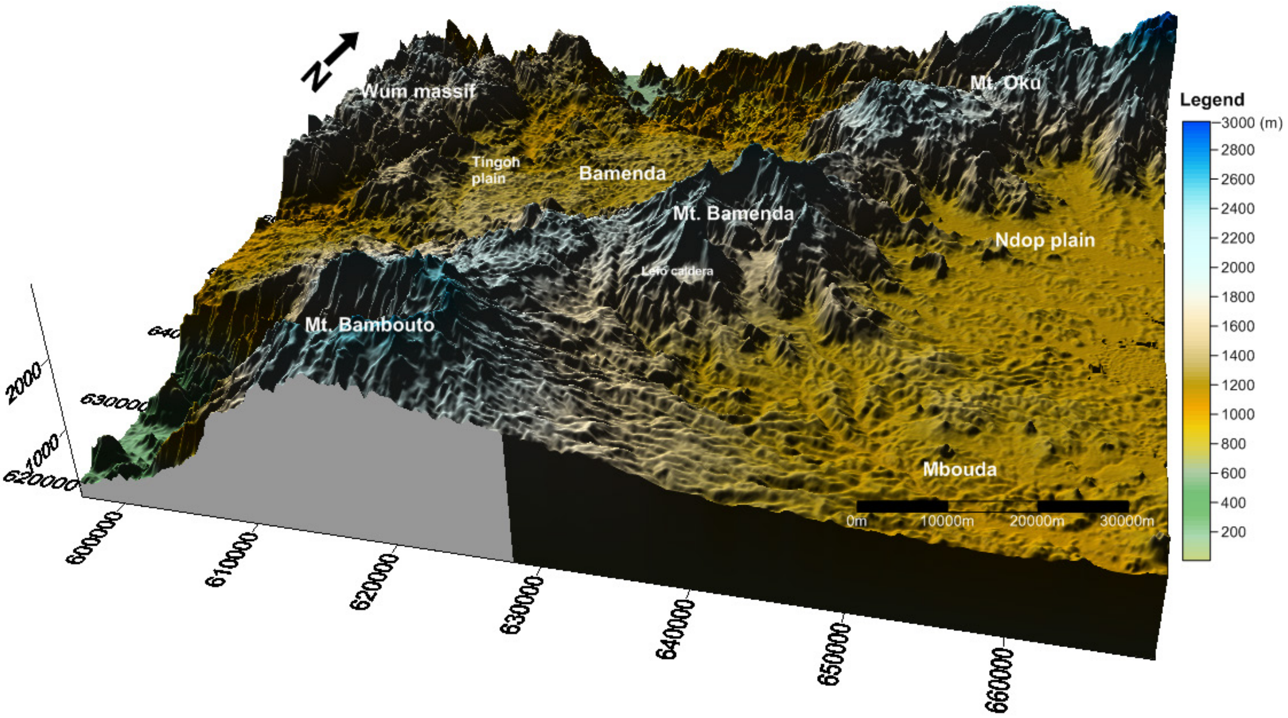

Figure 1. Location map of Mount Bamenda on the Cameroon Western Highlands (Source: SRTM data)

The informative value method which is a bivariate method use here was proposed and applied by [5,21,24,39,63] to predicts future landslide. A total of 9 landslide conditioning factors were rasterized and used to build a landslide susceptibility map for the Bamenda Mountain area. The resultant raster was then reclassified to get the pixel values of each conditioning class within the factor map. A landslide density map was also rasterized at the same pixel size of 10m. This landslide density map was then crossed with individual classes of each landslide conditioning factor *(Ncp)* [6,54] to get the combined landslide pixels of each individual class *(Nsp)*. The conditional probability *(Cp)* equation (1) (how probable a class will affect a slide) for each individual class for each factor was calculated. This was done by dividing the pixels of each individual class to the total number of pixels of that class to the total number of pixels of that class of that factor:

$$Cp = \frac{Nsp}{Ncp} \qquad (1)$$

Where Cp= conditional probability
Nsp = number of slide class pixels
Ncp= number of factor class pixels.

The prior probability *(Pp)* equation (2) (which is the probability of slide for each class to the total area of landslide in the study area) for each class was calculated from the total number of slide pixels in the area *(∑Nsp)* on the total pixels of the factor *(∑Ncp)* as follows:

$$Pp = \frac{\sum Nsp}{\sum Ncp}. \qquad (2)$$

The informative value (equation 3) for individual classes was calculated by using the natural log of the conditional probability on the prior probability as follows:

$$Inf = Log\frac{Cp}{Pp} \text{ or } \ln\frac{\frac{Nsp}{Ncp}}{\frac{\sum Nsp}{\sum Ncp}}. \qquad (3)$$

From the Informative values determined, raster maps were constructed using the lookup tool in ArcGIS. The unclassified landslide susceptibility map was gotten from the raster classification tool by summing all the weighted informative values of all the individual classes of the condition factors (Table 1).

The number of buildings, farmland and roads (elements at risk) were digitized from google earth, the number of buildings, area of farms and roads determined in ArcGIS 10.2 software using the calculate geometry tool. The classified landslide susceptibility raster map was converted to polygon using the raster to polygon tool in ArcGIS. This action enabled the percentage coverage of each class to be obtained. Using the geoprocessing tool, each susceptibility category i.e. low, moderate, high and very high was superimposed with the elements at risk (buildings, farmland and roads). This revealed the number of buildings, area of farms and lengths of roads within each category. The methodology applied is presented in Figure 2. Risk in the area was evaluated using the formula in equation 4:

$$Risk = \Sigma\left[H\Sigma(VA)\right] \qquad (4)$$

Where H= susceptibility,
V= vulnerability for element at risk,
A = amount or cost of element at risk.

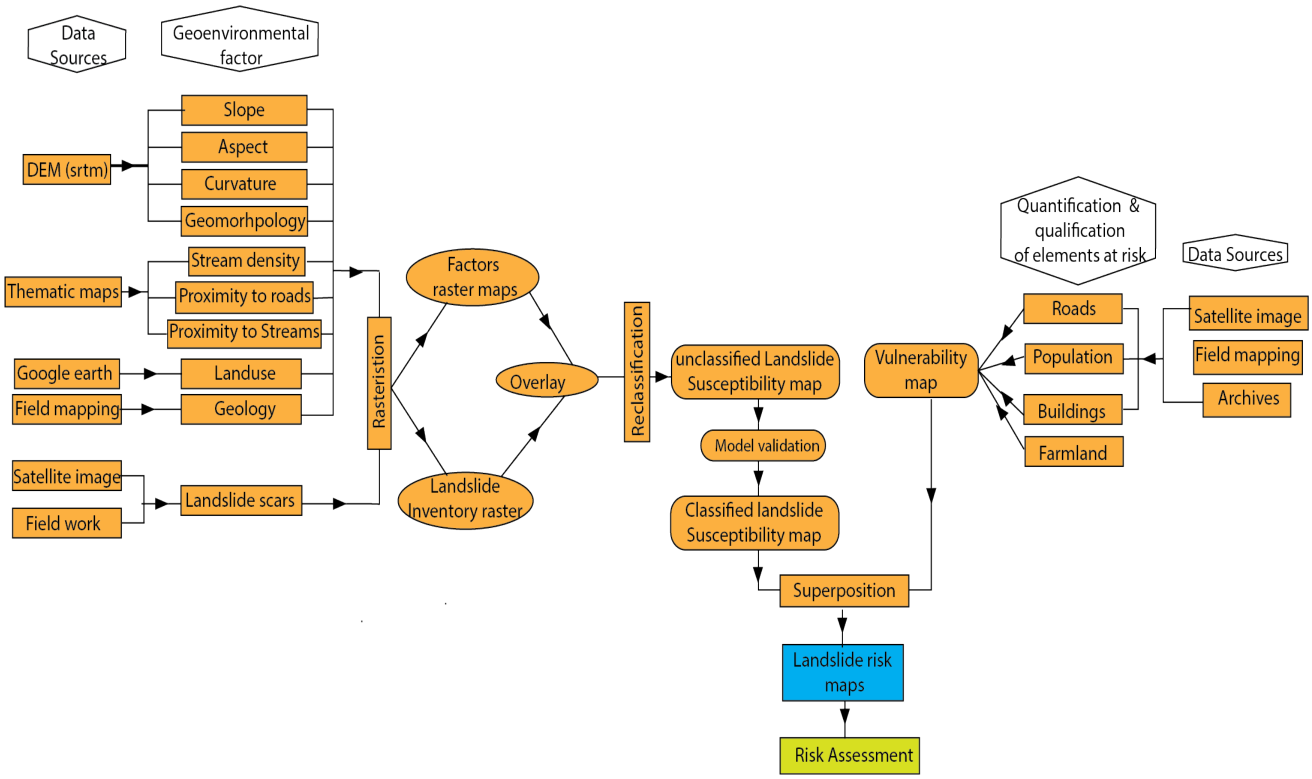

Figure 2. Landslide susceptibility mapping and risk assessment methodology

Table 1. Landslide Factors used in Susceptibility Mapping and their Parameters

Factor	Id	Class	Ncpix	Nslpix	Cp	Pp	Cp/Pp	Inf	ACC	REL
Slope	1	0 to 5	242396	34	0.00014	0.000678	0.206958	-0.68412	81	0.001
	2	5 to 10	422603	105	0.000248	0.000678	0.366594	-0.43581		
	3	10 to 15	438767	120	0.000273	0.000678	0.40353	-0.39412		
	4	15 to 20	296210	289	0.000976	0.000678	1.439551	**0.158227**		
	5	20 to 25	179462	305	0.0017	0.000678	2.507589	**0.399256**		
	6	25 to 30	106395	215	0.002021	0.000678	2.981578	**0.474446**		
	7	30 to 35	55160	90	0.001632	0.000678	2.407394	**0.381547**		
	8	>35	22188	37	0.001668	0.000678	2.460439	**0.391013**		
Aspect	1	North	171064	87	0.000509	0.000678	0.750394	-0.12471	66	0.004
	2	Northeast	175360	36	0.000205	0.000678	0.302901	-0.5187		
	3	East	214273	144	0.000672	0.000678	0.991571	-0.00368		
	4	Southeast	221354	113	0.00051	0.000678	0.753217	-0.12308		
	5	South	257611	147	0.000571	0.000678	0.841942	-0.07472		
	6	Southwest	221524	281	0.001268	0.000678	1.871606	**0.272215**		
	7	West	272955	212	0.000777	0.000678	1.145971	**0.059174**		
	8	Northwest	229040	175	0.000764	0.000678	1.127342	**0.052056**		
Curvature	1	Convex	246544	334	0.001355	0.000678	1.998854	**0.300781**	**51.8**	**0.004**
	2	Rectilinear	1195932	637	0.000533	0.000678	0.78589	-0.10464		
	3	Concave	320705	234	0.00073	0.000678	1.076562	**0.032039**		
Stream Density	1	0-1.49	240812	143	0.000594	0.000676	0.877987	-0.05651	46.25	000.8
	2	1.49-3.44	279870	110	0.000393	0.000676	0.581121	-0.23573		
	3	3.44-5.13	373049	266	0.000713	0.000676	1.054255	0.022946		
	4	5.13-6.75	334991	245	0.000731	0.000676	1.081342	**0.033963**		
	5	6.75-8.44	291966	142	0.000486	0.000676	0.719095	-0.14321		
	6	8.44-10.58	184120	201	0.001092	0.000676	1.61408	**0.207925**		
	7	10.58-16.56	62035	88	0.001419	0.000676	2.097374	**0.321676**		
Proximity to roads	0	10	48788	8	0.00016	0.000676	0.242484	-0.61532	53.03	0.002
	1	20	46988	7	0.00015	0.000676	0.220302	-0.65698		
	2	30	45290	3	0.00007	0.000676	0.097955	-1.00897		
	3	40	43126	3	0.00007	0.000676	0.10287	-0.98771		
	4	50	40844	9	0.00022	0.000676	0.325852	-0.48698		
	5	>50	1542119	1165	0.00076	0.000676	1.117158	**0.048115**		
eomorphol ogy	1	Lowlands	179146	117	0.000653	0.000676	0.96567	-0.01517	38.72	0.0001
	2	Highlands	696952	393	0.000564	0.000676	0.833757	-0.07896		
	3	Moderate highlands	890826	685	0.000769	0.000676	1.136966	**0.055748**		
Proximity to Streams	1	0 to 20	208230	158	0.000759	0.000676	1.122072	**0.050021**	**76.05**	**0.0003**
	2	20 to 40	204548	134	0.000655	0.000676	0.968761	-0.01378		
	3	40 to 80	197329	132	0.000669	0.000676	0.989213	-0.00471		
	4	80 to 100	181726	104	0.000572	0.000676	0.846298	-0.07248		
	5	100 to 120	160727	109	0.000678	0.000676	1.00287	**0.001245**		
	6	>120	137651	72	0.000523	0.000676	0.7735	-0.11154		
Geology	0	Ignimbrite	36453	21	0.000576	0.000675	0.852949	-0.06907717	100	0
	1	Granite	5269	0	0	0.000675	0	-0.00000001		
	2	Trachyte	1120956	762	0.00068	0.000675	1.006476	**0.002803216**		
	3	Rhyolite	383562	247	0.000644	0.000675	0.953451	-0.02070181		
	4	Basalt	220112	163	0.000741	0.000675	1.096429	**0.039980695**		
Land use	1	Open Savanah	639833	542	0.000847	0.000677	1.251479	**0.0974236**	**74.44**	**0.0001**
	2	Farm Land	429537	412	0.000959	0.000677	1.417058	**0.1513876**		
	3	Forest	176580	41	0.000232	0.000677	0.343031	-0.464667		
	4	Water Bodies	3906	0	0	0	0	-0.00000		
	5	Inhabited areas	515608	200	0.000388	0.000677	0.573062	-0.241799		

4. Results

4.1. Landslide Conditioning Factors

1. Slope: it has a direct effect on the shear stress of the soil. The greater the slope dipping, the greater the shear stress and the more unstable the slope [12,30,33,52,67]. The slopes ranged from 0 to 55° and were classified into 8 classes at intervals of 5° (Figure 3a). All slope classes above 35° were grouped into a single class. 63% of the areas are covered by slopes between 0 to 15°, steep slopes >35° occupy just 1% of the area. Most landslides occur in the area on slopes between 15 to 30° which occupy just 33% of the area.

2. Slope direction (Aspect): the direction to which a slope is orientated is essential in analyzing landslides [11,12,14,37,45] as it influences the slope's exposure to sunlight, drying, wind and rainfall [3,22]. The slope direction in the area ranges from 0° to 360° and were grouped into 9 classes (Figure 3b). The distribution of slope direction in this area is evenly distributed with each slope directions occupying at least 10% of the area. Conversely west facing slopes occupy up to 15% of the area.

3. Slope Curvature: the profile curvature gives the rate of change of gradient or it measures the downslope trend and identifies different breaks on the slope [51]. The convexity, concavity and linearity of different slope or the general morphology were determined using the curvature tool. A slope was considered positive when the surface is upwardly convex at that cell and was negative when it was upwardly concave, while 0 indicated a rectilinear. The curvature map was classified into three layers; concave, convex and rectilinear areas (Figure 3c). Convex slopes occupy just 14% of the area followed by concave slopes (18%). Rectilinear slopes occupy up to 68% of the area.

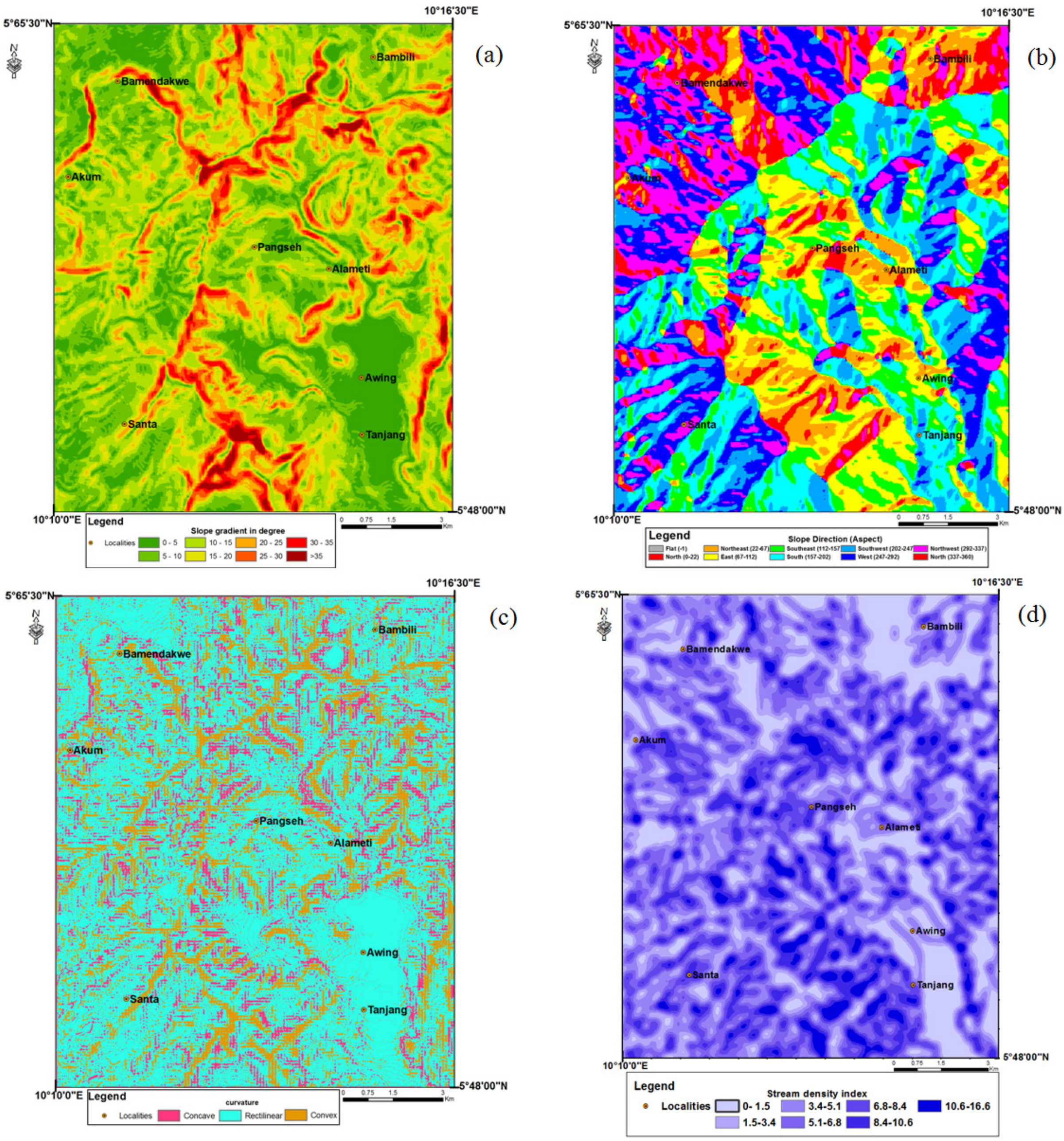

Figure 3(a-d)

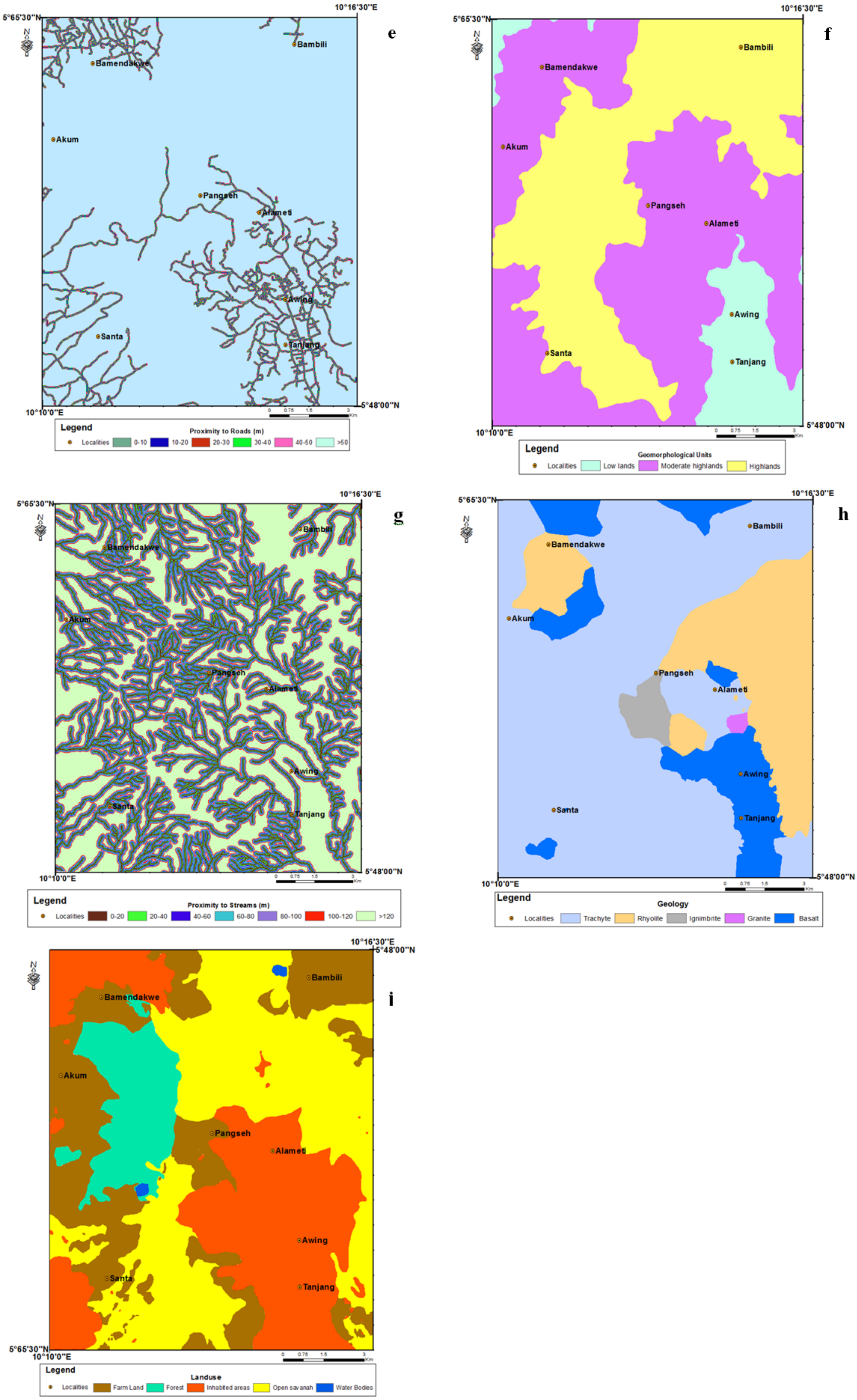

Figure 3. Landslide conditioning factors for the Bamenda Mountain area (a) Slope map (b) Slope direction (Aspect) map (c) Curvature map (d) Stream density map (e) Proximity to road map (f) Geomorphology map (g) Proximity to stream map (h) Geologic map (i) Landuse map

4. Stream Density: or wetted index is commonly used to simulate the amount of water in the soil [13,16,33]. It was used to approximate the regional distribution of ground water circulating in the study area. Stream density creates a relationship between drainage areas and slope variations within a catchment area [33]. Using all watercourses in the study area, the stream density map was computed using the non-interpolative density tool in ArcGIS. The concentration of streams and the wetted index diminish with distance. Stream density values between 0 to 11 are evenly distributed covering 10 to 21% of the area. High stream density values between 10 to 16 occupy just 3% of the area (Figure 3d).

5. Proximity to road: Roads construction in hilly areas in most cases destabilizes the slope following undercutting, overloading of displace material, and vibrations caused by vehicles [4-15]. The influence of roads was evaluated by creating multiple ring buffers around these roads with an equidistance of 10m at intervals of 10, 20, 30, 40 and 50m (Figure 3e). The distributions of values are even in distances between 0 to 50m and occupy 13% of the area while distances above 50m occupy 87% of the area.

6. Geomorphology: the geomorphological units of the area were gotten from the hypsometry. According to this, three geomorphological units were identified: lowlands (<1600m a.s.l), moderate highlands (1600-2000m a.s.l) and highlands (>2000m a.s.l) (Figure 3f). Moderate highlands occupy 50% of the area while lowlands and highland occupy 10 and 40% of the area respectively.

7. Proximity to stream: Streams have the ability to undercut and saturate its banks, thereby increasing the shear stress of the slope [15,28]. It was classified into 6 classes of 20 m interval i.e. 0-20, 20-40, 40-60, 60-80, 80-100, 100-120m and all distances above 120m were considered not having an influence on landslides. Distances >120m occupied the highest percentage (38%), while distance between 0 to 120m occupy 62% (Figure 3g).

8. Lithology: Lithology is an important conditional factor influencing the mechanisms of landslides and plays a role in the formation of superficial materials [20]. The geologic map of the area was realized from field mapping and petrographic analysis of rocks in the area. The influence of landslide varies with differences in rock type. Trachytes occupy 64%, basalt (12%), Rhyolite (22%), ignimbrite (1.7%) and granites occupy just 0.3% of the area (Figure 3h).

9. Land use types: The land use pattern has been found to have an influence on the occurrence of landslides [68], [16]. The land use pattern of the area extracted from the 2015 Google Earth image as: inhabited areas, farmland, forest, water bodies and grassland. Forest land occupies just 10% of the area while inhabited areas, open savannah and farmlands occupy 29, 36 and 25% of the area respectively (Figure 3i).

4.2. Hazards Susceptibility Classification

theres is rarely a specific reference to the classification of hazard suscpeptubilty index [35], are usually classes into 3-5 classes. The informative values of the combined parameters range from -0.2 to 1.5. This susceptibility map was classified into four classes' i.e. very high, high, moderate and low susceptibility using the natural breaks method in ArcGIS (Figure 4a). According to this, 17.8%, 25.9%, 33.6% and 22.7% of the area is expose to very high, high, moderate and low susceptibility respectively. Relatively high susceptibility (high and very high) are indicated in red and yellow and predicts up to 82.26% of landslides while relatively low susceptibility (moderate and low) are indicated in light green and green (Figure 4a).

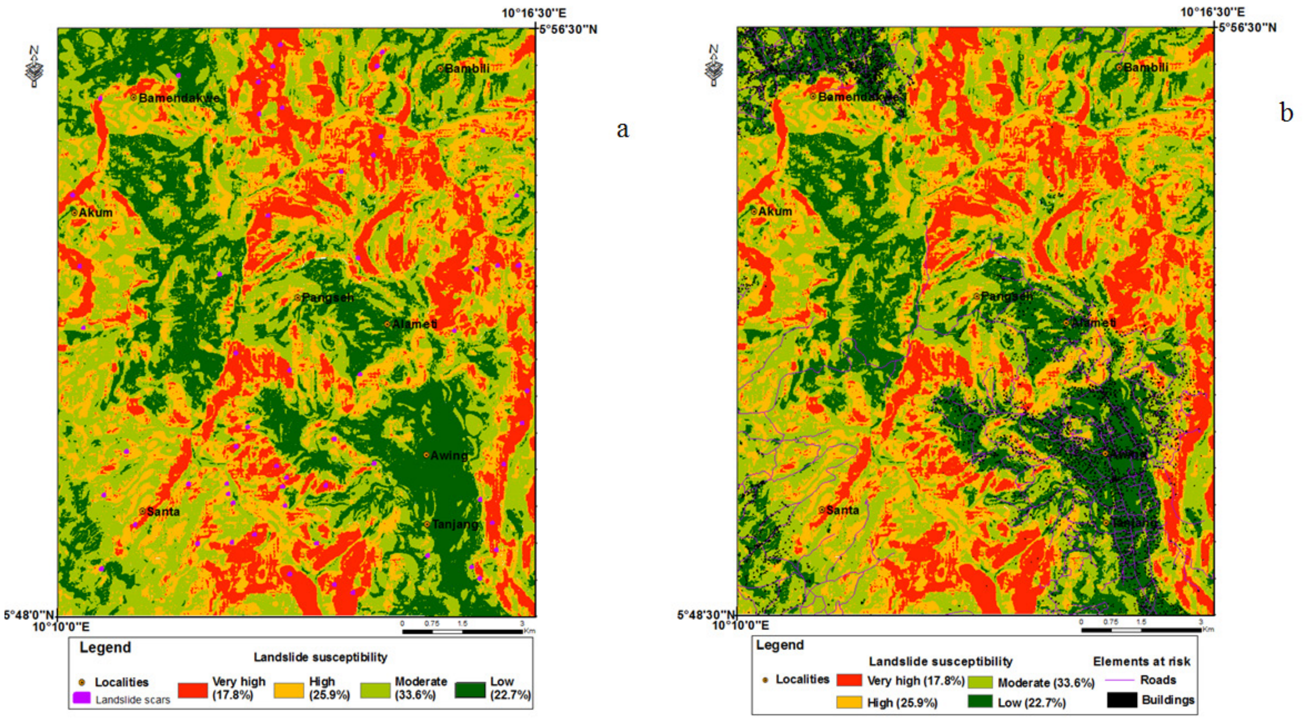

Figure 4. (a) Classified landslide susceptibility map of the Bamenda Mountain (landslide scares have been magnified) (b) Landslide risk map of the Bamenda Mountain

Table 2: Proportion of various susceptibility classes and associated distribution of landslides for all factors used in landslide susceptibility validation

Susceptibility category	% pixel in areas	Proportion of slides	Cumulative% pixel areas	Cumulative Proportion of slides
Low	22.7	3.23	22.7	3.23
Moderate	33.6	14.52	56.3	17.75
High	25.9	22.58	82.2	40.33
Very high	17.8	59.67	100	100

In this study, the susceptibility map was validated base on the "success rate curve" [59], which explains how well the model and controlling factors predict landslides. This was done by ordering the landslide index values of all the pixels in the landslide susceptibility map in percentages. The cumulative percentage of the observed landslides is plotted against the cumulative percentage area of the landslide susceptibility map (Table 2). The success rate curve for the landslide susceptibility map is shown in Figure 5. Based on the success rate graph, it shows that the first 30% of the classes with the highest value in the landslide susceptibility map can predict about 76.5% of all landslides in the area. The accuracy of the landslide susceptibility map is also determined qualitatively by the area under curve (AUC) value [50,62] which stands at 0.823 as can be considered as excellent [34] with an overall success rate of 82.3%.

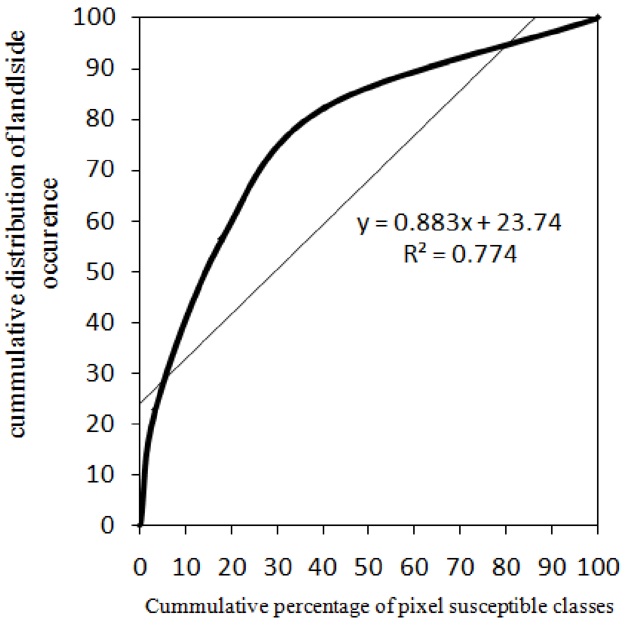

Figure 5. Success rate curve

4.3. Spatial distribution of Landslides and Significant Factors

1. Slope: it is the most significant factor regarding the occurrence of landslides with 5 significant classes (Figure 6 and Figure 7) favoring the occurrence of landslides which are classes of 15° to 20°, 20° to 25°, 25° to 30°, 30° to 35° and >35°. Less significant slopes are 0° to 5°, 5° to 10° and 10° to 15°. In this area, spatial distribution of landslides increases as the slope gradient increases from 15° to 30°. Slopes gradients of 15° to 20° and 20° to 25° have the highest distribution of landslides of 24.2% and 25.5% respectively. Slopes with 0° to 5° have the lowest distribution of landslides in the area with only 2.8%. However, the spatial distribution of landslides reduced as the slope gradient further increase.

2. Aspect: it has 3 significant classes favoring the occurrence of landslide which are the SW, W and NW facing slopes bearing 23.5%, 17.7% and 14.6% of the landslides in the area respectively. Less significant aspect classes are N, NE, E, SE and S facing slopes, with the NE facing slope being the least favorable for the occurrence of landslides (Figure 6).

3. Curvature: it has two significant classes (concave and convex slopes which occupy 18.2% and 14% of the area respectively) favoring the occurrence of landslides, with convex slopes being the most significant. Though convex slopes occupy just 13.7% of the area, it accounts for 27.9% of landslides in the area thus being the most favorable curvature class in the area. Rectilinear slopes occupy 67.8 % of the area and account for 55% of the slides and therefore have less significance to the occurrence of landslide in this area. Concave slopes occupy 18.5% of the area and account for 17.1% landslides in the area.

4. Stream Density: it has four significant landslides favoring classes which are 3.4-5.1, 5.1-6.8, 8.4-10.6 and 10.6-16.6. Stream density values with highest values have strong correlation to landslides. The highest values from 8 to 16.6 occupy 13.9% of the area and account for 24.2% of landslides in the area. Stream density has three classes which do not favor the occurrence of landslides in the area.

5. Proximity to roads: only one factor favor the occurrence of landslides in the area i.e. >50m from roads occupy 87.3% of the area and account for 97.5% of landslides in the area. Distances from 0 to 50m occupy 12.7% of the area, with low influence on the occurrence of landslides in the area accounting for only 2.5% of landslides in the area.

6. Geomorphology: it has one significant class favoring the occurrence of landslides i.e. moderate highlands occupying 50.4% of the area accounting for 57.3% landslides in the area. Lowland (10%) and highlands (40%) are less significant. Landslides are very low in lowlands compared to hilly areas; however when the slope is very high the landslide occurrence tends to reduce as the slope cannot support huge amount of soils.

7. Proximity to streams: it has three significant classes which are distances between 0-20 90-100 and >120 m. Distances close to streams of 0-20m have the highest distribution of landslides accounting for 13.2% of slides in the area. The distribution of landslide decreases from stream channels and increase from distances of 120 m and above. Distances to streams >120 m account for 40.7% landslides in the area, meaning most of the slides occur away from streams thought distances close to stream area very favorable for the occurrence of landslides.

8. Land use: this factor has two significant classes that favor landslides, which are open savannah and farmland. Less significant classes are forest inhabited area and water bodies, which do not favor the occurrence of landslides. Farmland and open savannah occupy 24.3% and 36.2 of the area and account for 34.4% and 45.3% of landslides in the area.

9. Geology: this factor has two significant classes, which are basalt and trachyte and occupy 12% and 63.5% of the area accounting for 13.3 and 63.9% of landslides in the area. Basalts have the strongest spatial distribution of landslides in the area. Rhyolite with 21.7% of the area account for 20.7% of landslide in the area the lowest are in granites and ignimbrites occupying 0.3 and 2.1% of the area with 0 and 1.7 % of the area.

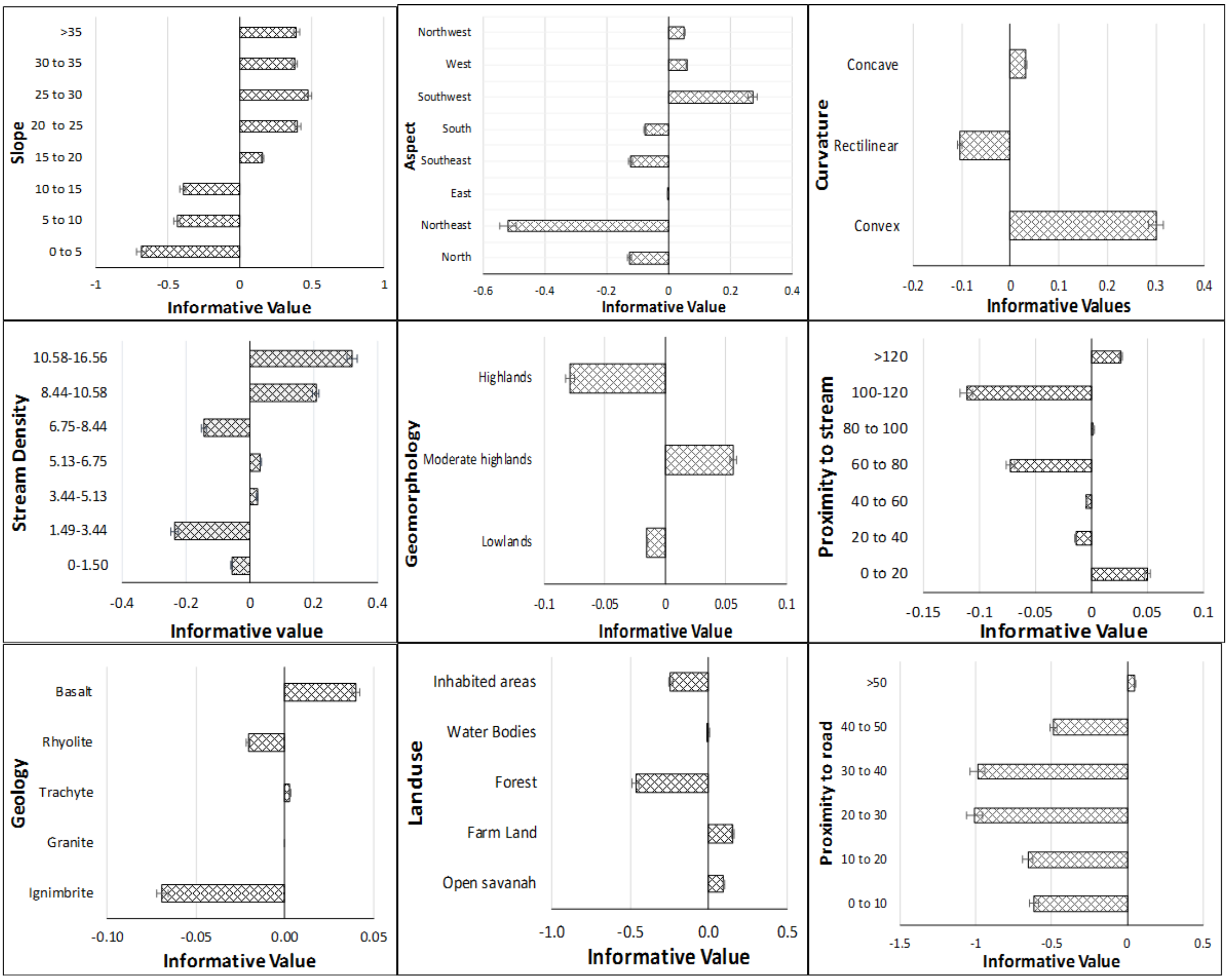

Figure 6. Landslide conditioning factors vs Informative value in the Bamenda Mountain area (Positive values indicate significant classes and negative values less significant values)

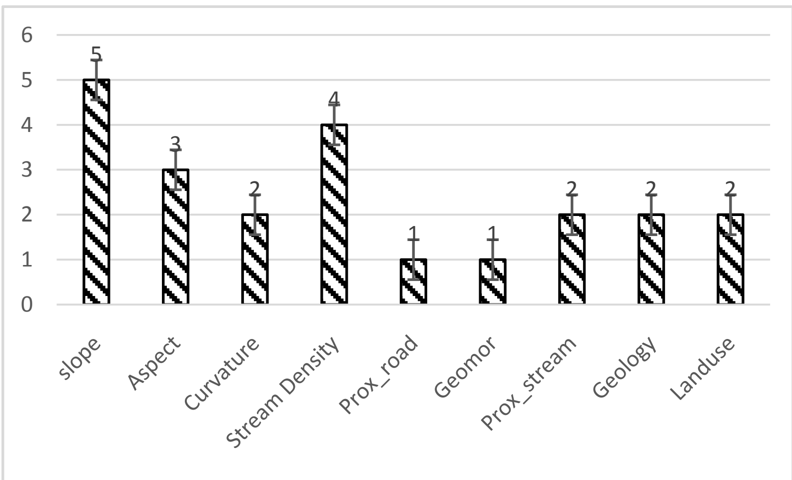

Figure 7. Standard significant factor classes affecting landslides on the Bamenda Mountain

4.4. Landslide Risk Assessment

In this study risk assessment is performed on the elements at risk which are; number of inhabitants, number of buildings, lengths of roads, farmland and cost. Assessment of the total risk was done by multiplying the hazard with the expected losses for all the different elements at risk carried out for all the landslide classes on the Bamenda Mountain following the formula based on [25,42,43,61].

The expected damage to buildings, farmland, roads, and to the population, if affected by landslides is presented in Table 3-Table 7. In the area, there are 8,354 buildings and the number of building at risk to landslides decreases as the degree of landslide susceptibility increases with just 4 and 0.8% of the building exposed to high and very high risk respectively (Table 3).

The estimated population of the area stands at 50,124 people projected from the number of building taking the average of 6 inhabitants per home [10]. 4.8% of the population is expose to high and very high risk in the area making a total of 2,436 people (2,010 expose to high risk and 426 expose to very high risk). The locality of Awing present the highest number of people exposed to high and very high landslide risk up to 1,626 people (Table 4).

The assessment potential loss in terms of cost of building and property was estimated by assuming the cost of a standard building including property which cost ≈4.5 million FCFA. Most of the people in the area are low to moderate income earners [10]. Consequently, the estimated loss of building and property stands at USD4,150,000 in high and very high risk zones (Table 5).

The total lengths of roads in the area stand at 3,960.5km. Unlike buildings, so many roads are located within high and very high landslide susceptibility zones i.e. 26.3 and 6.2km of roads respectively making a total of 32.5% of the total length of roads in the area (Table 6).

Farmlands are essential for crop production and a total of 4,070 ha of farmland are at risk. From this most of the farms are located at high and moderate landslide susceptibility zones i.e. 32.5 and 39.8% respectively. It is observed that very few farms are situated in low risk zones 7.3% and about 20% of farmlands are situated in low very high risk zones (Table 7).

Table 3. Landslide Risk Assessment in terms of Buildings

	Number of Buildings					
Susceptibility	Akum	Santa	Awing	Bamendakwe	Total	Percentage Exposure (%)
Very high	1	0	56	14	71	0.8
High	6	11	215	103	335	4.0
Moderate	35	248	869	1213	2365	28.3
Low	40	175	2892	2476	5583	66.8
Total	82	434	4032	3806	8354	

Table 4. Landslide Risk Assessment in terms of Population

	Population					
Susceptibility	Akum	Santa	Awing	Bamendakwe	Total	Percentage Exposure (%)
Very high	6	0	336	84	**426**	0.8
High	36	66	1290	618	**2,010**	4.0
Moderate	210	1488	5214	7278	**14,190**	28.3
Low	240	1050	17352	14856	**33,498**	66.8
Total	**492**	**2604**	**24192**	**22836**	**50124**	

Table 5. Landslide Risk Assessment in terms of Cost

	Cost (US dollar)					
Susceptibility	Akum	Santa	Awing	Bamendakwe	Total	PercentageExposure (%)
Very high	10,000	0	560,000	140,000	710,000	0.8
High	60,000	110,000	2150,000	1,030,000	3,350,000	4.0
Moderate	350,000	2,480,000	8,690,000	12,130,000	23,650,000	28.4
Low	400,000	1,750,000	28,920,000	24,760,000	55,830,000	66.8
Total	820,000	4,340,000	40,320,000	38,060,000	83,540,000	100

Table 6. Landslide Risk Assessment in terms of Roads

	Roads (km)					
Susceptibility	Akum	Santa	Awing	Bamendakwe	Total	Percentage Exposure (%)
Very high	0.0	37.0	206.1	2.7	245.8	6.2
High	2.9	372.2	620.0	48.1	1043.3	26.3
Moderate	1.6	425.2	1357.5	158.7	1943.0	49.1
Low	0.5	202.7	457.5	67.8	728.5	18.4
Total	5.0	1,037.1	2,641.0	277.4	3,960.5	

Table 7. Landslide Risk Assessment in terms of Farmland

	Farmland (ha)	Percentage exposure (%)
Susceptibility		
Very high	830	20.4
High	1322	32.5
Moderate	1621	39.8
Low	297	7.3
Total	4070	100%

5. Discussion

Landslides are common in mountainous regions and can also occur in lowlands. In Cameroon landslide are caused by a series of conditioning and triggering factors including geology (regolith, contrast in permeability, rigidity of the material, earthquakes, and rainfall), geomorphological (tectonics, volcanism, subsidence, erosion and groundwater extraction) and anthropogenic (deforestation, agricultural activities, mining, urbanization, slopes excavation) [4,9,15,30,56,57,66]. Landslides are frequent along the mountainous part of the country i.e. the CVL. In these areas, economic and demographic explosion led to the invasion of natural land for crop production, fuel and construction of houses as is the case on this mountain [40]. Landslide data in Cameroon remain till today very poorly recorded this is simply due to lack of means and the willingness of researchers. Consequently, most landslides remain unrecorded except in the case where lives are lost as is the case in Limbe (2001) and Wabane (2003). In the highlands of Cameroon more than 50 deadly landslides with 122 deaths have been recorded from 1954 to 2012 [4,9,46,56]. Landslides are triggered on the Bamenda mountain by extreme rainfall and human activities (roads construction and vibrations from vehicles) [5,66]. Landslide conditioning factors selected for susceptibility mapping on the Bamenda Mountain were functional and operational and were similar to those used by [4,16,30] in susceptibility mapping along the CVL. Amongst the landslide factors, slope is the most significant with the highest informative values as also indicated by [4]. However, it is observed that as the slope increases above 35 degree, the number of landslide reduces; this is probably due to soil creep which prevent huge amount of soil from accumulating on steep slopes. Proximity to roads was the most insignificant factor affecting landslides in the area even though field investigations suggest some slides do occur along roads. The other landslide conditioning factors in the area had variable impact on landslides. A similar method has been used by [4] for spatiotemporal assessment of translational and rotational landslides on the Bamenda mountain and the lowlands areas. Landslide risk assessment has some problematic aspects such as: temporal vulnerability of elements at risk, runout distance of landslides, spatial probability of landslides initiation [60]. All these factors may further increase risk intensity in an area. Landslide risk assessment focusses on the assets i.e. the elements at risk that may suffer damage from a harmful landslide. It is the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular damaging phenomenon for a given area and reference period [61]. Risk assessment is important because it can provide an insight on mitigation strategies and management methods [17,23,26,27]. Conversely to the high surface area susceptible to high and very high landslides, the risk in these areas is low. For example, very high risk occupies 17.8% of the area, but the risk percentage in this class is only 0.8%. From the validation of the model, over 82.26% of the registered landslides fall within the very high to high risk indicating the model predicts landslides well in the area. The presence of landslides on very low susceptibility zones may be as a result of magnification of landslides scares in the area or irregularities during projection. A modest number of publications on landslide risk assessment have been made [18,19,31] including a recent textbook by [42]. The landslide risk assessment method proposed by the Sub-committee on Landslide Risk Management of the Australian Geomechanics Society has been generally adopted. This classification is based on the level of quantification dividing the landslide risk assessment methods into: (1) Qualitative methods (probability and losses expressed in qualitative terms), (2) Semi-quantitative methods (indicative probability, qualitative terms), and (3) Quantitative methods (probability and losses quantified). In this work also, a quantitative and qualitative assessment of elements at risk was done. The Bamenda Mountain unlike the Bambouto caldera are both areas expose to landslide. Though more slides have occurred on the Bambouto Mountain recently, the elements at risk on the Bamenda Mountain are far beyond those of the Caldera with over 50,000 inhabitants relative to 3,000 inhabitants in the caldera. Moreover, the estimated loss in the caldera stands at USD 3,790,580 in assets [64] relative to the USD 83,540,000 on the Bamenda Mountain. Most farmlands are situated within high and moderate risk zones consequently mechanized farming will be difficult to carry out in these zones. Very few zones are situated within low susceptibility zones as these areas are preferred for settlement than farming.

6. Conclusion

This study was carried out on the Bamenda Mountain to which over 250,000 people live. Using a GIS approach and the bivariate informative value method, a landslide susceptibility map for the Bamenda Mountain was realized. 64 landslides were inventoried in the area and use in the landslide susceptibility model. Nine landslide controlling factors including; slope, slope orientation (aspect), curvature, stream density, proximity to roads, geomorphology, proximity to streams, geology and land use were used to realize the model. With the most significant landslide causing factor in the area being slope followed by stream density and aspect. This model indicated level of susceptibility as very high (17.8%), high (25.9%), moderate (33.6%) and low (22.7%). The validated model using the success rate curve indicate area under curve is 0.823 and predicts landslides at 82.26% in relatively high classes and thereby predicts landslides excellently. Quantitative and qualitative risk assessment indicate 406 buildings, 2436 people, 1,291.1 km of roads, 2,152 hectare of farmland and an approximate USD83,540,000 in assets are expose to high and very high risk on the Bamenda Mountain area.

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