



Full Length Research Paper

Natural hazards along the Bamenda escarpment and its environs: The case of landslide, rock fall and flood risks (Cameroon volcanic line, North-West Region)

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Bamenda town is situated on the North Northwest slope of the Bamenda Volcano (2621m) which is a stratovolcano situated along the Cameroon Volcanic Line precisely between Mount Bambouto (2740m) and Mount Oku (3011m). The general morphology shows the presence of an escarpment of about 150m high, which separates Bamenda town into Up Station and Down Town areas. Rapid population increase in the town of Bamenda (500,000 inhabitants) has pushed the inhabitants to settle along the slopes of the Bamenda Mountain and close to river channels thereby exposing themselves to landslide, rock fall and flood hazards, with negative environmental and socioeconomic impacts. These hazards usually occur during the rainy season and are provoked by natural and anthropogenic factors. The area consists of volcanic (ignimbrites, trachytes and dolerites) and plutonic (granites and gneisses) rocks. Geotechnical analysis of the soils shows that the soils have low bulk density (1.32-1.59), low specific density (2.20-2.58); high porosity (47.92-64.28 %); water content exceeds 35.2%, and predominance of fine grain particles. Atterberg limits indicate that the soils are plastic in nature. Cohesion is low (2.60-7.20 kPa) the angle of internal friction values vary from 25.5° to 28°. These parameters indicate that the soils are predisposed to landslides. The model employed in realizing the risk maps uses parameters such as; slope, type of material, nature of river, the presence of rocks and/or escarpment and influence of geotechnical parameters. The obtained risk maps indicate settlement areas at risk. This approach can assist in town planning, risk mitigation, environmental and civil protection.

Keywords: hazards, floods, rock fall, landslide, escarpment, risk maps and Bamenda volcano.

INTRODUCTION

Bamenda is situated between longitude 10°08' to 10°12' E and latitude 5°55' to 6°00' N. Figure 1 is the Digital Elevation Model showing the location of Bamenda and general morphology of the Bamenda highland of Cameroon. Bamenda covers a surface area of 71.23

square kilometres. The morphology of Bamenda is characterised by a gentle sloping Up station area separated from an undulating to flat Down Town area by an escarpment which is about 7 km long with trend N37° and about 150 m high (Figure 2). The slopes along the escarpment are more than 35° (Figure 3). The climate is the humid tropical highland type characterized by two seasons a rainy season and a dry season. The vegetation is characterised by short

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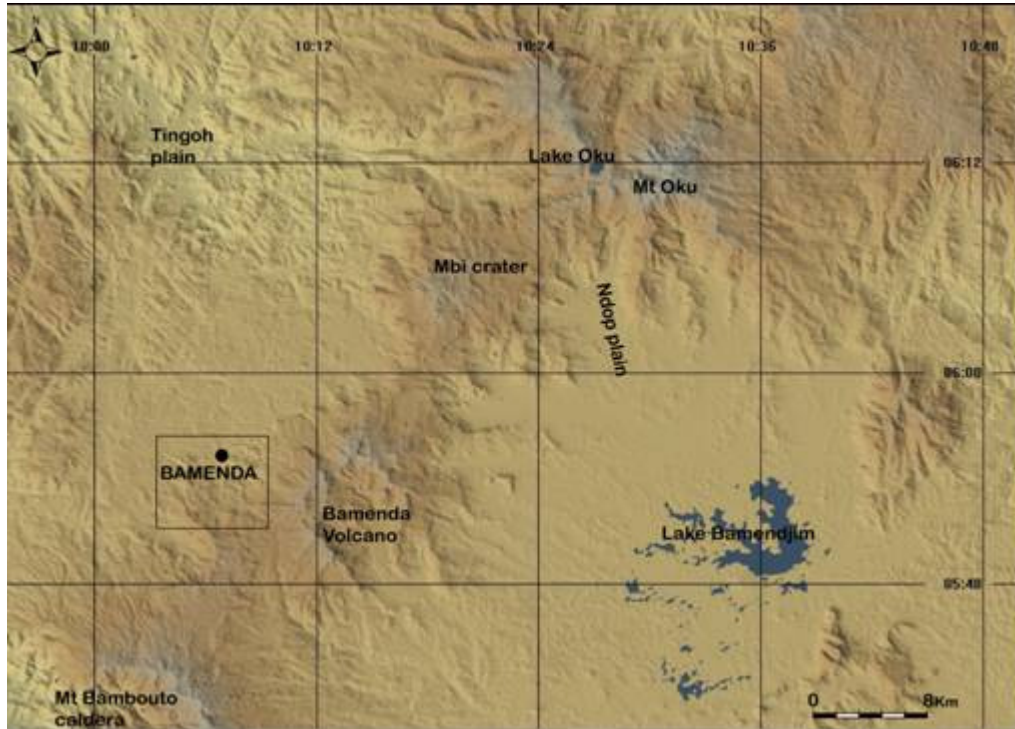


Figure 1. Digital Elevation Model (DEM) showing the location of Bamenda and the general morphology of the Bamenda highlands of Cameroon.

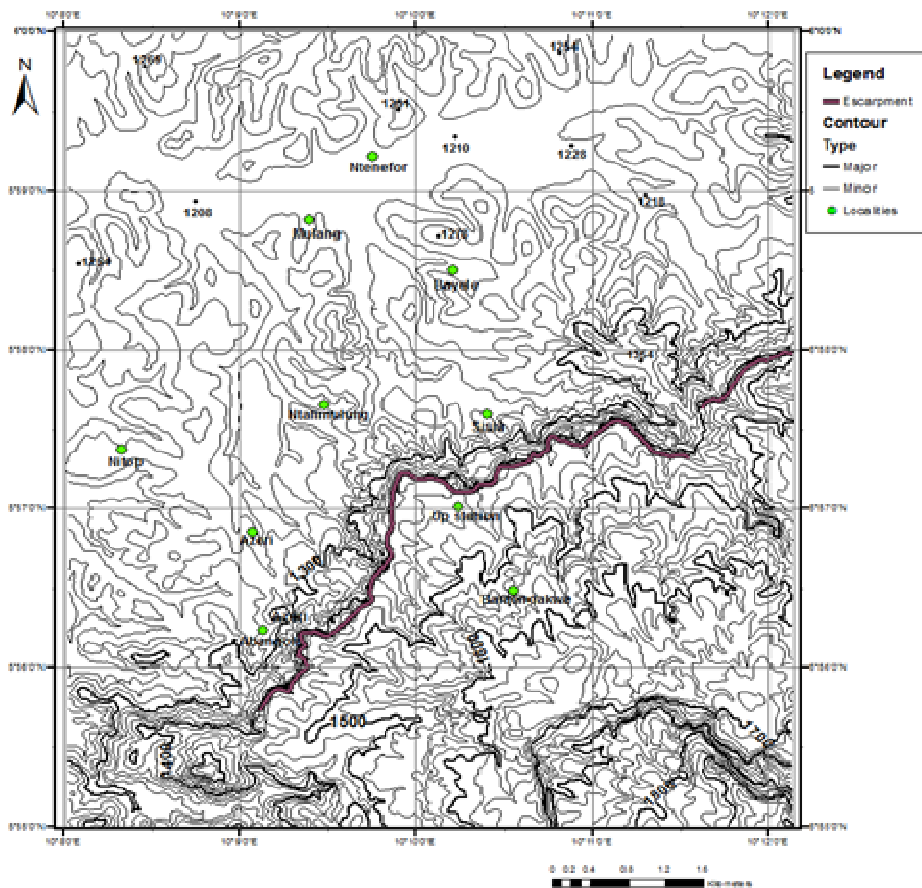


Figure 2. Topographic map of Bamenda

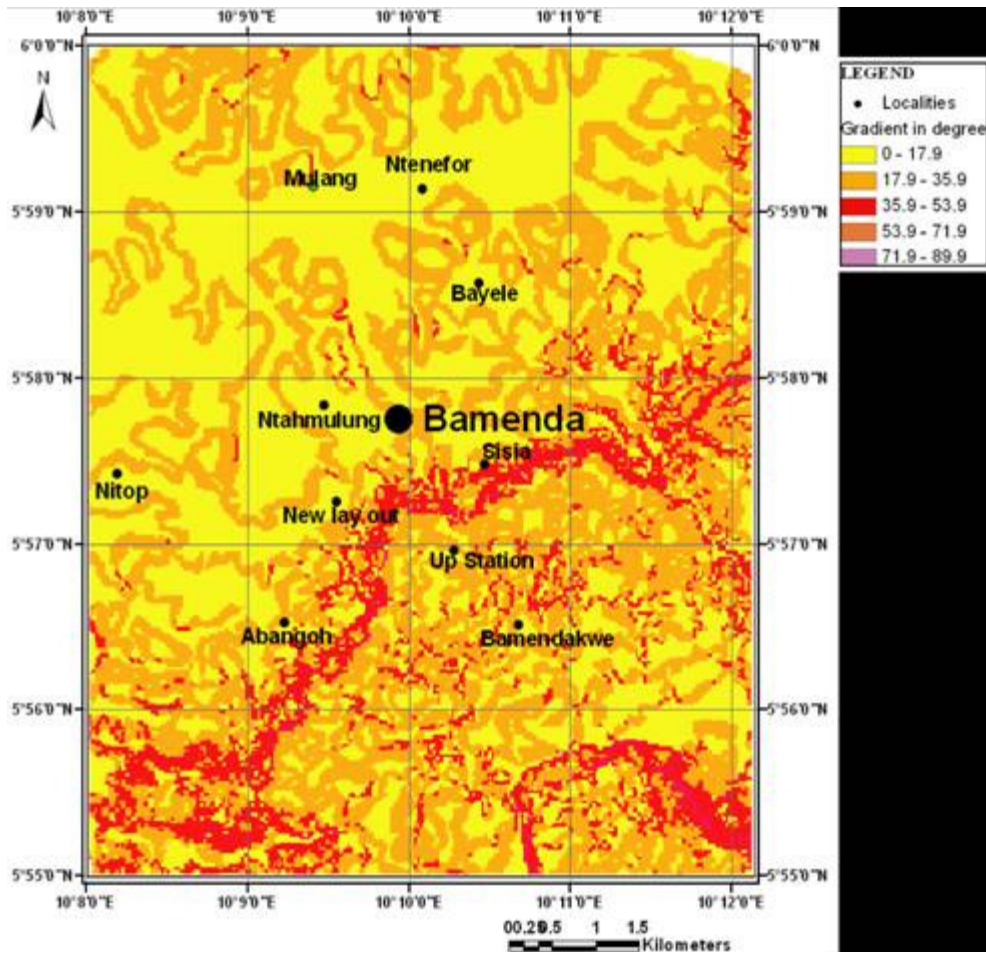


Figure 3. Slope map of Bamenda

stunted tress that is the savannah type. The soils are ferralitic, vertisols and andosols, which are easily eroded and cannot support dense vegetation and intense agricultural activities. River Mezam is the main river which drains Bamenda. The hydrography presents a characteristic dendritic drainage pattern. Farming is the main activity carried out here which is mostly crop based farming, pure pastoralism and mixed crop-livestock.

Numerous natural hazards have occurred in Cameroon especially along the Cameroon Volcanic Line CVL (Figure 4). Some examples are: at Fossong-Wentcheng (South-West Dschang) which took place on the 28th August 1978 killing six people (Tchoua 1984; 1989); at Limbe, the 27 June 2001, killing 24 people; that of Maga 20 July 2003, which led to 20 deaths (Kagou Dongmo, 2006; Zogning et al., 2007), at Santa, 12th September 1992 that killed 12 people and at Kekem 20 October 2007 with one death (Aboubakar et al, soumis 2011).

In the town of Bamenda, landslides and floods are recurrent, particularly in the months of August and September causing loss of human lives and property.

For example on the 24th August 2004, four kids belonging to the same home were killed in a landslide at Abangoh quarter (Lambi, 2004), and on the 4th August 2009, another kid was killed in an event in the Sisia neighbourhood (Ndi, 2010). Still on the 4th of August 2009, a landslide occurred in the proximity of the governor's residence at "C-Bend" station hill hindering communication between Up Station and Down town. On the 6th of August 2009, the national road (N11) linking the Western region and the North-west regional capital (Bamenda) was cut off after heavy rains at Mile one Bamendakw

The assessment of landslides, rock fall and floods are indispensable in managing hazards and in understanding landscape evolution. This study thus presents a comprehensive landslide, rock fall and flood assessment for the Bamenda area. The geology and geotechnical characterisation of the soils carried out provides adequate parameters which are vital for the realisation of landslide, rock fall and flood risk maps. This study will provide adequate information for the Ministry of Land Tenure and Town Planning as well as the Bamenda City Council to consult for the civil

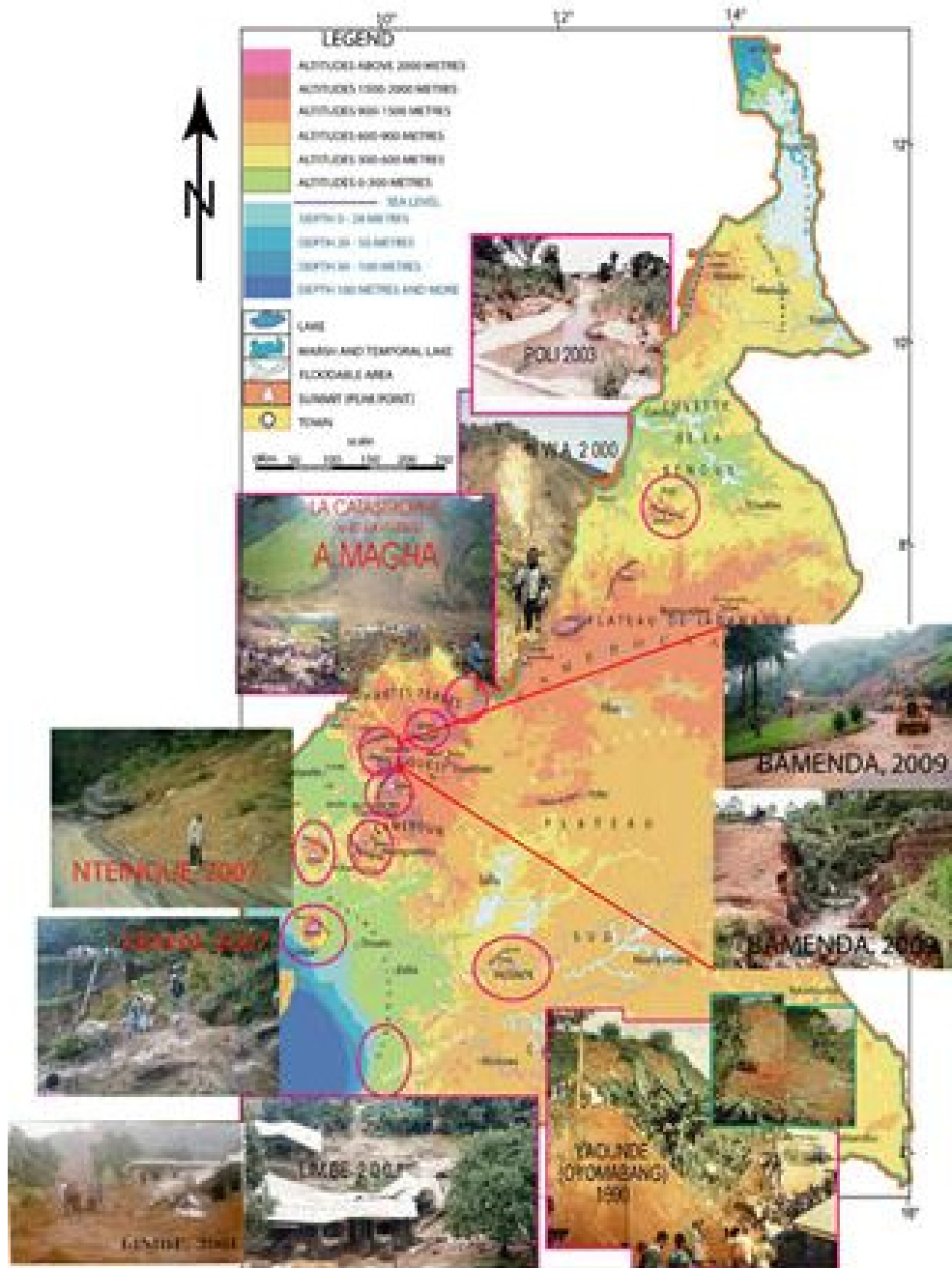


Figure 4. Localization of some mass movements that occurred in Cameroon (in Zogning et al., 2007); completed); the majority of the phenomena are along the Cameroon Volcanic Line.

protection.

METHODS

Many geoscientist have worked on landslides assessments according to Vijith et al. (2009) mitigation can only be successful when detailed information about the frequency, magnitude and character of the hazard within a particular area is known. Hazard mapping

involves indicating areas where a potentially damaging hazard may occur (Varnes, 1984; Van Westen et al., 2006). Risk assessment with a minimum set of data, using a reproducible methodology is a major challenge to geoscientists (Glade and Crozier, 2005; Zezere, 2002). This is the case of Bamenda due to the lack of historical data. The statistical approaches in risk mapping can either be bivariate or multivariate depending on the analytical method (Soeters and Van Westen, 1996).

Hazard mapping

In this study, a data-driven bivariate hazard mapping model is implemented to build a landslide, rock fall and flood risk map for the Bamenda area. The model employed here assumes the parameter independence. The influence of each parameter on the hazard is treated independently and then summed up. It exploits the Geographic Information System (GIS) and uses the following parameters; slope, type of material, nature of river, the presence of escarpment and/or jointed rocks and the influence of geotechnical parameters. This model is based on the following steps:

- Realization of a raster slope map in degree based on the ANUDEM in Arc GIS program developed by Hutchinson (1988) which is categorized into classes and attributing risk factors to each class;
- Determination of geotechnical properties on the soils along the slopes;
- Mapping of the petrographic units and setting up risk factors based on the different formations and transforming them into raster maps;
- Categorization of rivers based on diameter and nature and giving them risk factors then transforming them into raster maps;
- Determination of height of the escarpment and presence of fractured and/or jointed rocks;
- For a particular hazard, the appropriate parameters are treated independently then superimposed and their risk factors summed up;
- The superimposed raster maps are then categorized and vectorised into three classes based on risk intensity.

This model was adopted because it is flexible, easy to realize and can minimize field approximations. Other studies on landslides along the CVL such as that of Thierry et al. (2008) uses slope as the principal parameter in landslide susceptibility zonation. Che et al. (2011) uses a combination of parameters such as; rock type, slope gradient, land cover, mean annual precipitation, slope orientation, distance to the road and stream density in realizing the landslide susceptibility map for the Limbe area. Geology and slope are the main parameters used by Zangmo et al. (2009) in the zoning of the landslide risk in the Mount Bambouto caldera.

Determination of geotechnical parameters

Geotechnical physical parameters (densities, water content, porosity, void ratio, saturation ratio and compacity) of soils are carried out on perturbed samples. The grain size distribution analysis of the samples is realized by the dry mechanical sieving method. Atterberg limits (plastic and liquid limits, the indexes of plasticity and consistency) are carried out on perturbed soil samples. The study of the shear strength

parameters (cohesion and angle of internal friction) is carried out on unperturbed samples. The analytical methods used in this work are the same as those used by Ekodeck, (1984) and Aboubakar (2010). This model is implemented and tested in Bamenda North-West Region Cameroon with the goal of identifying areas most likely to have landslides, rock fall and floods and can be applied in other areas along the CVL.

RESULTS

Petrography

Volcanic formations outcrop in the form of flows above and along the escarpment and represented by trachytes, dolerites and ignimbrites rocks. The ignimbrites are characterized by the presence of fiammes, trachytic enclaves, quartz, carbonized wood, fractured crystals of alkalis feldspars and spherulites and grouped into four facies (Figure 5). Trachytes are rich in sanidine, biotite, herdenbergite, oxides and some calcite (Figure 6a-d).

Dolerites have an ophitic texture and composed of phenocrysts of olivine, pyroxenes and oxides embedded in a phaneritic ground mass composed mainly of plagioclase (Figure 6e). The geologic map (Figure 7) shows that basement rocks (granites and gneisses) occupying over three quarter of the Bamenda area.

The various rock formations in Bamenda (Figure 7) play a role in the occurrence of landslides, rock fall and floods in the area. Ignimbrites which are unstable outcrop as flows along steep slopes. They weather into clays which easily retain water and increase the bulk weight of the soil thus reducing its shear strength. Some basement rocks and ignimbritic blocks occur at high altitudes and can easily be dislodged and fall under the influence of gravity. The weathered materials along and above the escarpments are carried to the Down town area by streams and rivers which is more or less flat. These particles composed mostly of clays reduce the rate of infiltration of water when they settle, consequently increasing the volume of water in streams and rivers channels provoking floods.

Geotechnical analysis

Geotechnical characterisation of the soils carried out in the laboratory on unperturbed and perturbed soils samples enabled the determination the physical parameters (Table 1), granulometry (Figure 8), Atterberg limits (Table 2), and mechanical parameters (Table 3) of the soils of the Bamenda area.

The physical parameters (Table 1) play a vital role in slope stability. The bulk densities (d_a) are low due to the premature cementation of the soil particles by Al and Fe oxides before the complete consolidation of the

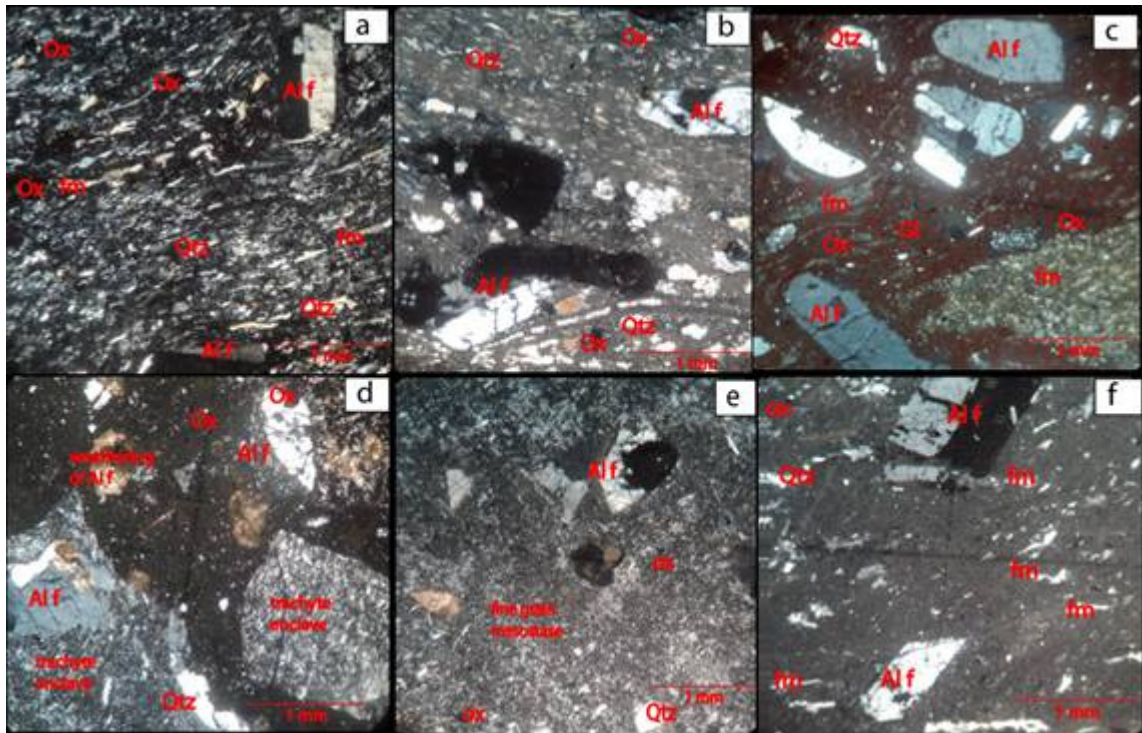


Figure 5. Microphotography under Polarized light of the various ignimbrites facies found along the Bamenda escarpment: (a and b) Columnar-jointed welded rhyolitic ignimbrite facies; (c) Devitrified Ignimbrites facies; (d) Rhyolitic ignimbrites facies; (e and f) Rubefaction facies

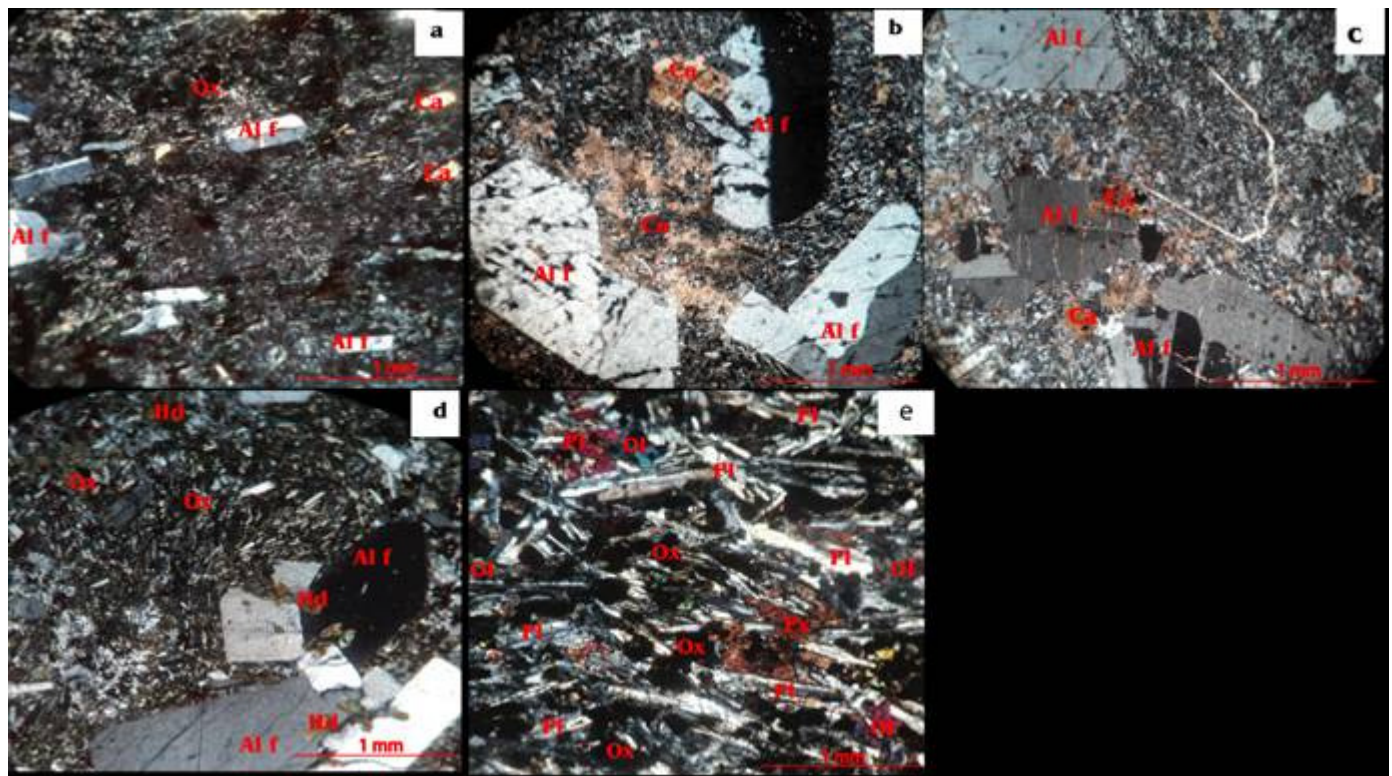


Figure 6. Microphotography of some representative thin sections of rocks from Bamenda; (a, b and c) Strict sense trachyte (d) Herdenbergite trachyte and (e) Dolerite.

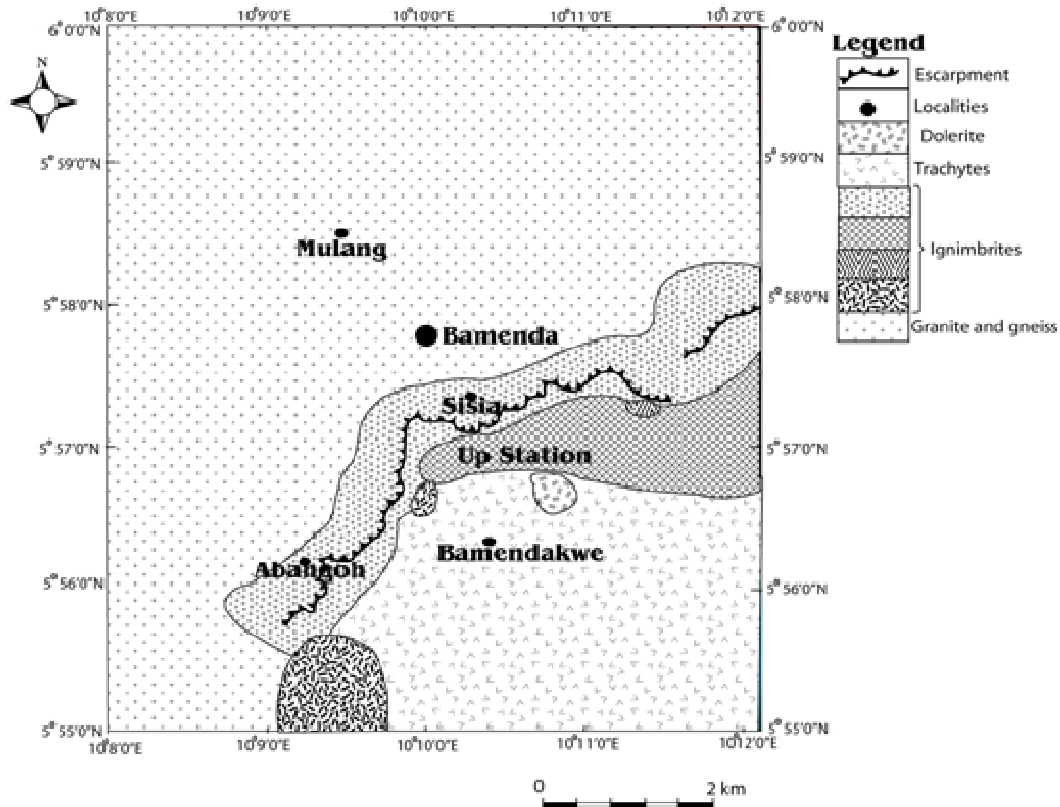


Figure 7. Geologic map of Bamenda

Table 1. Physical parameters soils of the Bamenda area

Sample	Depth (cm)	Bulk densit, da	Specific density, ds	Water conten, w (%)	Dry density, d _d	Porosit y, n (%)	Void ratio, e	Degree of saturatio, Sr (%)	Compaci ty, C (%)
SIS4	50-75	1.45	2.23	33.57	1.06	52.38	1.10	68.05	0.49
SIS2	10-35	1.52	2.20	39.52	1.02	53.70	1.16	74.95	0.49
SBE3	30-55	1.59	2.52	28.79	1.05	58.33	1.14	51.82	0.48
ABA4	10-35	1.32	2.58	43.17	0.92	64.28	1.8	61.88	0.38
ABA5	12-37	1.56	2.27	31.57	1.18	47.92	0.92	76.91	0.52

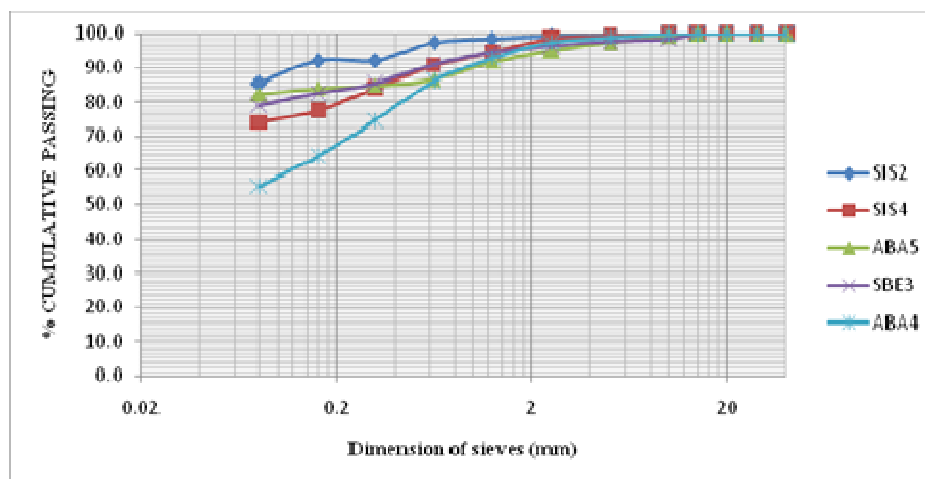


Figure 8

Table 2. Atterberg's limits of Bamenda escarpment soils

Sample	Liquid Limit LL (%)	Plastic Limit PL (%)	Liquid Index I _L (%)	Plastic Index I _P (%)	Consistency Index, (I _c)
SIS4	74.20	41.72	-25.09	32.48	1.25
SIS2	55.71	36.70	14.83	19.01	0.85
SBE3	68.94	41.21	-44.79	27.73	1.45
ABA4	72.92	46.22	-11.42	26.70	1.11
ABA5	56.30	38.00	-35.14	18.30	1.35

Table 3. Mechanical properties of Bamenda escarpment soils

Samples	Angle of internal friction, ϕ_u (°)	Cohesion, c_u (kPa)	Angle of the natural slopes (°)
SIS2	27	2.60	68.2
SIS4	25,5	3.10	51.34
SBE3	28	3.20	60.26
ABA5	26	3.60	41.01

soil under its own weight. The specific densities (d_s) of the samples are lower due to the nature of the clayey soils formed from the weathering of the volcanic rocks. These low densities affect the cohesion and degree of compaction, thus the soils can easily slide. The water content (w) are high due to the presence of fine particles, this increases the weight of the soil as water is easily retained and can easily slide. Dry densities (d_d) of the soils are low thus low cohesion of soils. The porosity (n) values are averagely high due to the high specific surface of the clay minerals formed from the weathering of feldspars. This high porosity enables the soil to easily retain water. The void ratios (e) are high as a consequence, the soils tend to be porous and retain water thereby increasing the bulk weight of the soil. The degrees of saturation (S_r) of the various soil samples are reasonably high thus it reduces the shear strength of the soil. Compacity (C) of the soils are low, thus the soil particles can easily be dislodged from the main soil mass.

The granulometry or grain size analysis of the studied Bamenda escarpment soils is shown in figure 8 which presents a similarity in their nature.

From the granulometric curve (Figure 8), it is observed that more than 70% of the soil particles pass through the sieves indicating the predominance of fine grain and poorly graded soils. This indicates that the soils are clays which are porous but less permeable and can easily absorb and retain water after heavy rains. This greatly reduces its shear strength making the soil unstable and predisposed to slide.

Atterberg's limits are a basic measure of the nature of a fine-grained soil. Depending on the water content of the soil, it may appear in solid, plastic or liquid state. The results obtained from laboratory analysis of the Bamenda escarpment soils are presented in Table 2.

The Atterberg limits values (Table 2) affect the general behaviour of the soils in terms of stability. The values of the liquid limit (LL) and the plastic limit (PL)

indicate that the soils are fine grained i.e. clays. These clays are unstable especially when they absorb water. Liquid index (I_L) of the samples is < 0 indicating that the soil is of a semi solid state. The plastic index (I_P) indicates that the soil is in a plastic state. When the plasticity limit has been attained, the soil is susceptible to pass to a liquid state or flow state with the least increase in water content. Consistency index (I_c) values show that the soils are soft and plastic in nature. Plastic soils can easily swell and have a high tendency to slide or flow.

The shear strength properties of soils are vital as it determines whether a slope will slide or not. It is defined in terms of cohesion and angle of internal friction. The values obtained from laboratory analysis of the Bamenda escarpment soils are presented in Table 3.

The cohesion of the soils is very low due to the nature of the clay minerals which have a high specific surface and high water retention capacity. This water tends to reduce the cohesive and adhesive forces between the soil particles. As a consequence, the shear strength of the slope is reduced below that of stress which may provoke a landslide. The angles of internal friction or angle of shearing resistance of the soils are high indicating that the slope is unstable and can likely collapse. The angle of the natural slope is greater than the internal angles of friction. Generally, a slope is unstable when the angle of the natural slope is greater than the internal angle of friction (the angle below which the slope is stable).

Mapping of the hazard

In this study, risk is perceived as the likelihood that a population or a specific structure would be affected by a hazard. It can be estimated by overlaying elements at risk.

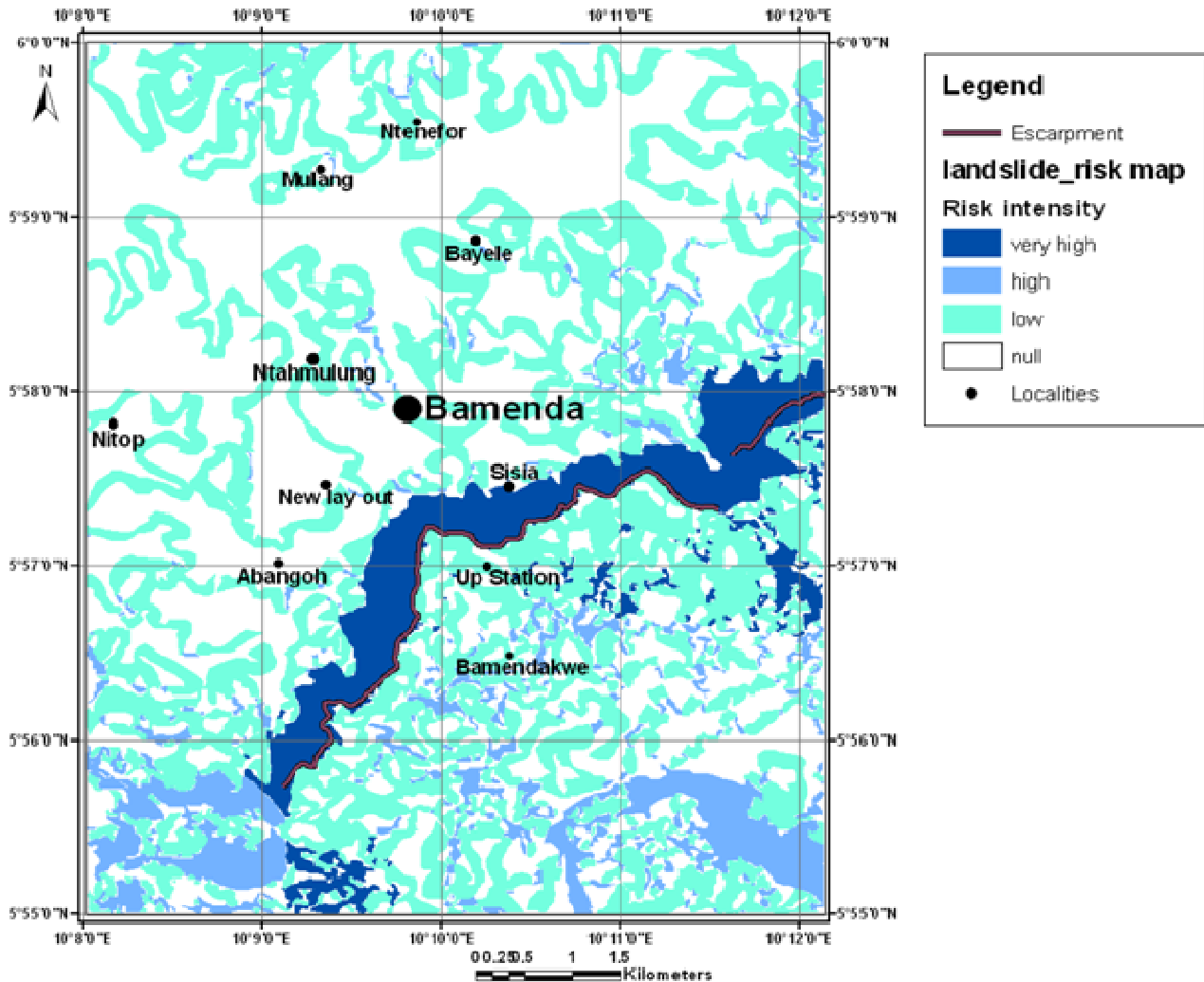


Figure 9. Landslide risk map of the Bamenda area

Landslide risk

Landslide risk is the most widespread in the area and may affect a greater population than the other hazards. The landslide risk map is realised by superimposing the slope, geologic raster maps and taking the geotechnical properties of the soils into consideration. The factors which actually trigger landslides in the area are; nature of the bedrock, rainfall, steep slope, ground water percolation, deforestation and high thickness of the soil. The presence of poorly welded, highly jointed and very thick ignimbric flow allows easy weathering from the top to the bottom of the profile. This hazard spreads through out the area (Figure 9).

The landslide risk is very high along the escarpment, high in the SW and SE part of the area (Figure 9) this is due to the steep gradient along the escarpment, thick soil profile and presence of weathered ignimbrites. In the Uptown and Down town areas are some portions of low to high risk (Figure 9).

Flood risk

Floods are triggered by rainfall and are caused by factors such as: geomorphology, sedimentation at river channels, narrowing of stream channels and gutters. It is observed that it is not necessary major rivers that cause floods but some temporal streams may flood an area when run offs flow into them after heavy rains. This hazard may easily be monitored since it is not abrupt as the case of rock fall and landslide thus giving time for the inhabitants to flee. This risk is localised in the Down town area (Figure 10).

Floods are common in localities such as below Foncha, Ntenefor, Mulang, Lower Bayele, Old town, Nitop and Ntahmulung.

Rock fall risk

Rock fall risk is common only where rocks are hanging

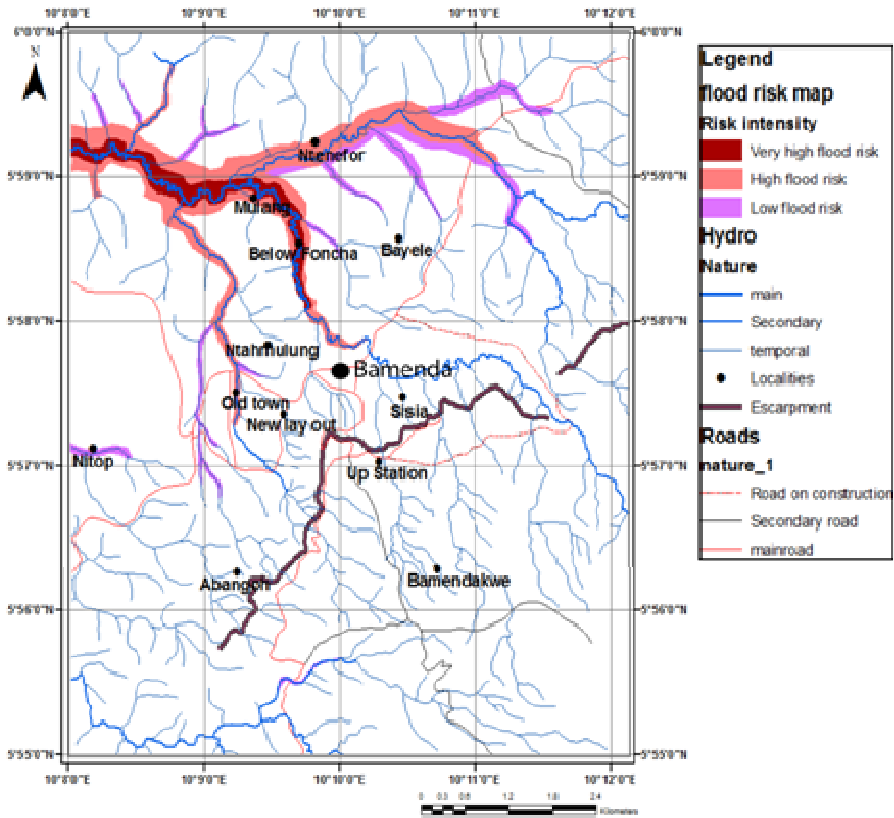


Figure 10. Flood risk map of the Bamenda area

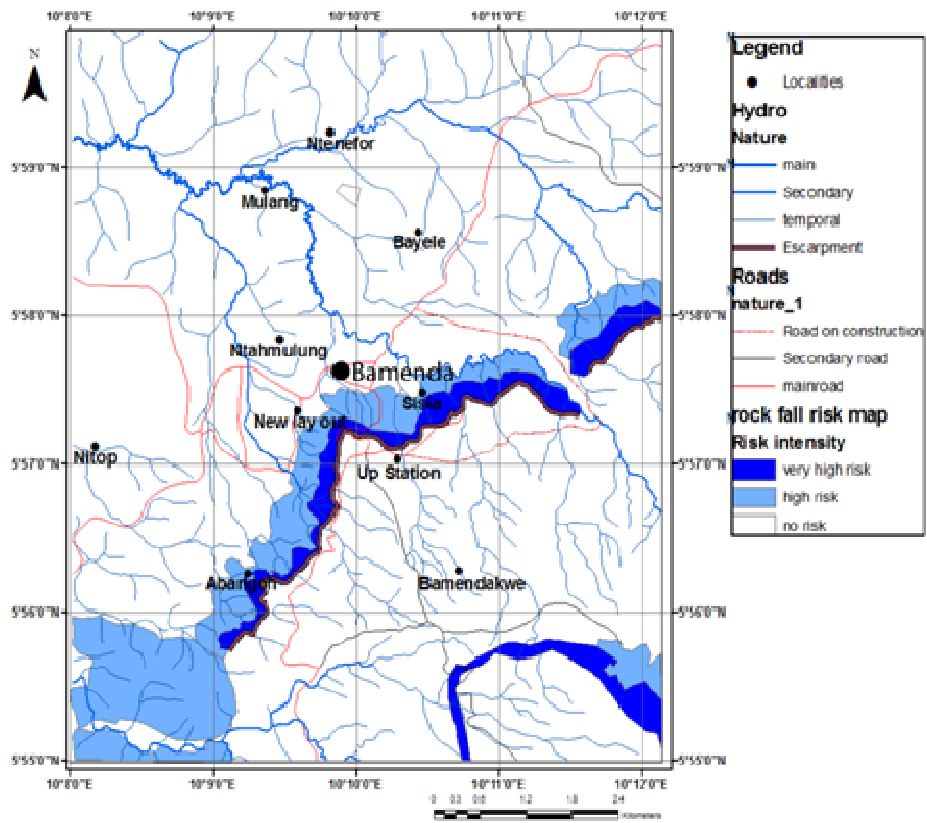


Figure 11. Rock fall risk map of the study area

along steep slopes. This is the case along the escarpment, SW and SE part of the area (Figure 11). This risk is less common but can have a more devastating effect if it occurs. Unlike the landslide risk map it covers a smaller area.

Despite the gradient of a slope in the absence of jointed or fractured rocks, the rock fall risk would be absent. This hazard has not been recorded in recent times. However, rock fragments along and at the foot of the escarpment are indicative of an ancient rock fall hazard.

This paper has a lot of findings that can be exploited in the Bamenda area and other parts along the CVL as regards hazards assessment. Based on this study risk maps can be realised in any given area, critical areas may be pinpointed where risk management, prevention and environmental protection measures can be implemented.

DISCUSSION

Landslides are the most deadly of these hazards in Bamenda even though floods do affect a greater population when they do occur. Ndi (2010) reveals that apart from natural causes, anthropogenic activities influenced by urbanisation increase the frequency of certain hazards like floods and landslides. Petrographic studies carried out in Bamenda shows that the volcano is made up mainly of trachytes, dolerite and ignimbrites covering the crystalline basement complex consisting of granite and gneiss. According to Kamgang et al. (2007) the petrography of the trachytes of Mount Bamenda allow us to understand that they are either aphyric or porphyritic and their ground mass consists of alkali feldspars, clinopyroxenes, amphiboles and aenigmatite. Gountié Dedzo et al. (2011) characterizes the ignimbrites in Bamenda as massive lapilli tuff, and lithic massive breccias facies, mostly trachytic in nature with minor portions of granite, rhyolite, obsidian, pumice and carbonized wood. Anwi (2011) argues that the high feldspars content are responsible for landslide since feldspars weather into clays. In this study it is observed that trachytes and ignimbrites are common in Bamenda overlying granites and gneisses, with ignimbrites occurring in many facies all rich in alkalis feldspars.

The resulting risk maps classify the risk based on intensity specifying areas of very high to low risks. The model employed in this paper is based on the GIS and involves the following parameters; slope, type of material, nature of river, the presence of escarpment and influence of geotechnical parameters on soils compared to that used by Ayonghe et al. (2004), Zangmo et al. (2009), Anwi (2011) and Che et al., (2011).

The host rocks on which the soils lie play a vital role in the cause of landslides. Rocks such as pyroclastics (case of Limbe landslides) and ignimbrites (Mt Bambouto Caldera and Bamenda escarpment)

generate less dense and less cohesive soils which easily slide. Studies carried out along some parts of the CVL by Ayonghe et al. (2004) in Limbe, Zangmo et al. (2009) in Bambouto caldera and Aboubakar (2010) in Kekem, Kagou Dongmo (2006) in Maga (in the Bambouto caldera) respectively reveals that anthropogenic activities greatly enhance the occurrence of landslides. Anwi (2011) argues that the high feldspars content are responsible for landslide since feldspars weather to form clays.

According to Apah (2011) physical and mechanical geotechnical parameters, have scientifically justified the fact that geotechnical factors do influence landslide occurrence in the Bamenda area. Studies carried out by Aboubakar (2010) in the Western high lands of Cameroon on ignimbritic products precisely in Lepoh (North of Dschang) shows that the soils have low specific and bulk densities. The granulometry shows the predominance of fine grain particles, with high water content and the soils are plastic in nature. These parameters make the soils predisposed to landslides (Rastogi et al., 2011; Singh et al., 2011). All these properties are similar to the soils analysed along the Bamenda escarpment.

The occurrences of these hazards in the Bamenda area have severe environmental and socioeconomic impacts on the population. This include destruction of the landscape leaving behind ugly landslide scars Njilah (1999), destruction of building and farmland, disruption of communication by road as was the case the road cut at Bamendakwe and landslide at C-bend Up station hill in August 2009. These events affected sociop-economic activities as the road between Bamenda and the Western region was totally obstructed. There are many local and government structures found in these risk zones. Prominent are the Government Bilingual High School Down town and the new Governor's residence. The buildings along the face of the escarpment are not usually accompanied by any stabilization measures thereby increasing vulnerability.

Previous studies carried out along the Bamenda highlands by Lambi (1989), Ndenecho and Eze (2004), Acho-chi (1998), and Abia (2003) working on natural hazards did not realize risk maps for the Bamenda area with the use of appropriate parameters and GIS. In this paper, a thematic risk map of landslide, rock fall and floods are realised stating the extension of the various risk zones in the Bamenda municipality.

CONCLUSION AND RECOMMENDATIONS

The Bamenda area is prone to landslides, rock fall and floods owing to its morphological setting. High population density along slopes and close to river channels increases the vulnerability in the area. Landslide, rock fall and floods risk maps of the area realised specify areas at risk where risk mitigation and management measures can be implemented.

Evacuating the risk zones will be very costly because of the high population density in these zones. To mitigate the hazards in the Bamenda area, some slope stabilisation measures are proposed. For landslides, the building of supporting walls, terracing, grading, surface and underground water drainage, and impermeabilizing the soils at sensitive areas. For rock fall, rocks which are dangerously hanging should be safely removed; cementing cracks in joints; and removing trees growing on rocks. And finally, for floods the deepening, cleaning and straightening the river channels, building artificial levees, raising foundations of building in flood zones and constructing bridges. The population should be sensitized on these natural hazards and emergency mechanism to be implemented in case of a crisis.

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