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An Assessment of Landslides along Mountain Forest Roads: Bamenda Ring Road Segment through Bafut and Befang Forests on the Cameroon Volcanic Line.

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Abstract

Purpose: Landslides cause distress in communities worldwide, disrupt socio-economic activities and cause damage to roads infrastructure. The purpose of this study was to undertake a comprehensive assessment of the recurrent landslide events along the Bamenda Ring Road (BRR) segment through the Bafut and Bafang mountain forests in the North West Region of Cameroon, located along the Cameroon Volcanic Line (CVL).

Methodology: Topographic and geologic map studies, foot-borne surveys, hydro-meteorological data analysis and soil permeability tests were employed to the study. Results at the time of this study reveal 35 new slide scarps in Bafut and 16 along the Befang forests.

Findings: The topography culminates between 670-1300 m altitude, while more than 50% of the slopes in the study area are convex, the rest are convexo-linear, concave, while a few of them are linear. Natural slope gradients vary from 35-60^0, while prevalent number of slides occur on sub-vertical road-cut embankments. The slides are classified as small volume, short distance-travelled shallow translational than rotational debris flows. Base rocks of the study zone are essentially coarse-grained leucocratic granites with quartz, feldspars, biotite and muscovite minerals which appear liable to weathering. Meanwhile, residual soil samples are permeable, have increased pore water pressure and has a high liquefaction tendency due to its high clay content. The absence of recent or historic earthquakes suggests that causative factors of landslides could be linked to steep gradients, lithology, deep weathering profiles, considerable affinity for water of the weathered materials and prolonged rainy seasons. As such we highlight the contribution of the landslide hazard with the direct risk based on the extensive deterioration of the road characterized by multiple road defects and reduced socio-economic activities and the indirect risk linked to difficulties in the movement of goods and persons and management of resources.

Recommendations: This study recommend present officials to improve on their documentation and skills in monitoring rainfall and landslide hazard and manage disaster emergency; sensitize the population on landslide hazard and associated risk. There is need for government to establish a road authority for the management of landslide hazard, disaster relief and the land inside and outside the road.

Keywords: *Landslides, Bafut, Befang, Bamenda Ring Road, CVL, road defects.*

1.0 Introduction

Landslides have become known among other hazards and disasters which continue to claim lives, upset livelihoods, disrupt economic plans and destroy infrastructure such as houses, dams and roads around the world today. These landslides occur where natural conditions may become favourable for their occurrence or where such conditions have become exacerbated by human activities. This is common in parts of the world having a hilly or mountainous terrain coupled with a deep weathering profile and heavy rainfall. However, there are some few cases where the trigger has been earth tremors and volcanic eruptions. Human activities such as road building, village/urban housing development; farming etc are known to predispose hilly mountainous terrains for eventual landslide events. Petley *et al*., (2007) have postulated that one of the underlying causes of the increase in landslides in mountain areas in less developed countries is road building. Cameroon has experienced some cases of landslides reportedly due to earth tremors (Lambi, 1982; Ayonghe *et al*., 2004; Momene, 2007) and rainfall (Zogning, 1994, 1998; Ayonghe *et al*., 1999; Tangoumouken, 2004; Buh, 2009; Che, 2010; Afugang, 2010, 2015; Ghogomu, 2012; Guedjo *et al*., 2013) and with more than 75% are located along the CVL corridor. The North West Region lies almost midway on the continental sector of the CVL. Cameroon is bracing itself to become an emergent economy, with plans to develop a series of road networks linking various parts of the country. An assessment of landslides along the Bamenda Ring Road (BRR) will contribute to alleviate the impact of landslides to the envisaged infrastructural development in the region especially in the context where the knowledge base on landslides is fragile or non-existent.

2.0 Geographical and Geological Setting

The BRR is located in the North West Region of Cameroon within Longitudes 9°451 and 100 35' East and latitudes 5°45 and 6°05N. The Bafut Forest is situated 10km from Bamenda City and the Befang Forest is in the vicinity of the town of Wum. The region lies almost midway on the continental sector of the Cameroon Volcanic Line, (see Figure 1). The Cameroon Volcanic Line can be defined as an alignment of continental and oceanic volcanic peaks (about 42 m.y to recent) and plutonic basement complexes (70-30 m.y) running from Pagalu Island to the Lake Chad region. This alignment follows an N-E 30° trend. (Geze 1943; Fitton and Durnlop, 1985; Fitton, 1987; Déruelle *et al*., 1991; Lee *et al*., 1994) as shown in Figure 1. As such the terrain is rugged and the geology is simple, made up of a granito-gnessic basement complex (Dumort, 1968; Tchoua, 1974) and the weathered products of these rocks. It is part of the Pan-african tectonic activities in the Central African orogenic zone aged 500-650 Ma (Toteu *et al*., 1990; Nzenti *et al*., 1992).

The climate of the NW Region can basically be described as the mountain Cameroon/humid tropical type (Suchel, 1972; Olivry, 1986; Nkwemoh, 1999). This climate is influenced the movements of the monsoons and harmattan trade winds as they converge at the Inter Tropical Convergence Zone (ITCZ) to form the Inter-tropical front. The region is characterized by the open grassland and woodland savannah, with a variety of plant species as shown in figure 2.

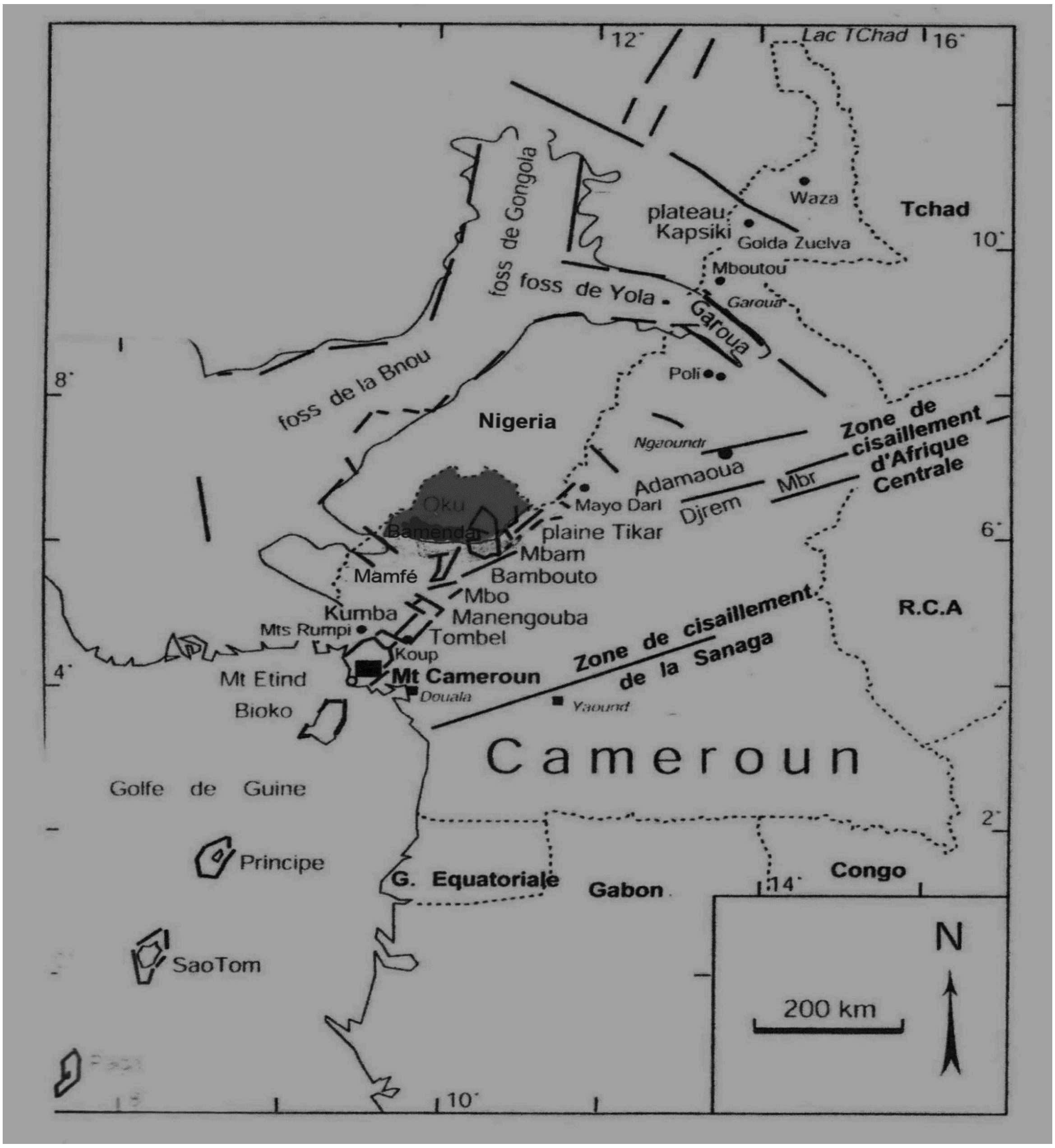

Figure 1: North West Region on the Cameroon Volcanic Line

Source: (Déruelle et al., 1991, modified).

3.0 The Road Segment

Within the labyrinth of the hilly and mountainous CVL landscape lies a dense network of roads of which the BRR constitutes the backbone (figure 3). Following the desciptions of Kellar and Sherar (2003) and Hearn (2007) on low-cost, low-volume roads, the BRR was built and constructed accordingly with some stretches having been paved. The BRR from Njinteh-Bafut to Wum goes through the Bafut and Befang Forests (figure 2) covering a distance of 62 km. The Bafut Forest stretch goes from Njinteh to Tingoh 12.5 km and the Befang Forest stretch goes from Befang to Wum covering 7 km. Eventhough the volume of traffic on this road has increased tremendously since inception it still operates as a low cost, low volume road.

4.0 Methodology

The methodology adopted included the study of relevant maps to extract useful information (mapping data), interpretation of laboratory results, analysis of rainfall data and field work.

4.1 Mapping data

A comprehensive study of road and vegetation maps published by Hof *et al*., (1983) and the Ministry of Environment and Forest (MINEF) (Fig 2), detailing the segment of the BRR through the Bafut Forest and the Befang Forest was carried out. Base topographic maps (Bafoussam 1:200.000 edited in 1978 Bafoussam 3C and Nkambe 1A and 1C) published by National Geographic Centre – Yaounde and lodged today at the National Institute of Cartography, Yaounde were consulted. A broad study of a number of satellite images; Google Earth, ASTER, Sentinnel, Landsat 7 ETM, and SPOT was also carried out. The topographic base maps and the satellite images enabled us to obtain a map (figure 3) of the BRR and a 3D of the topographic and relief structure of the area as shown in figure 4.

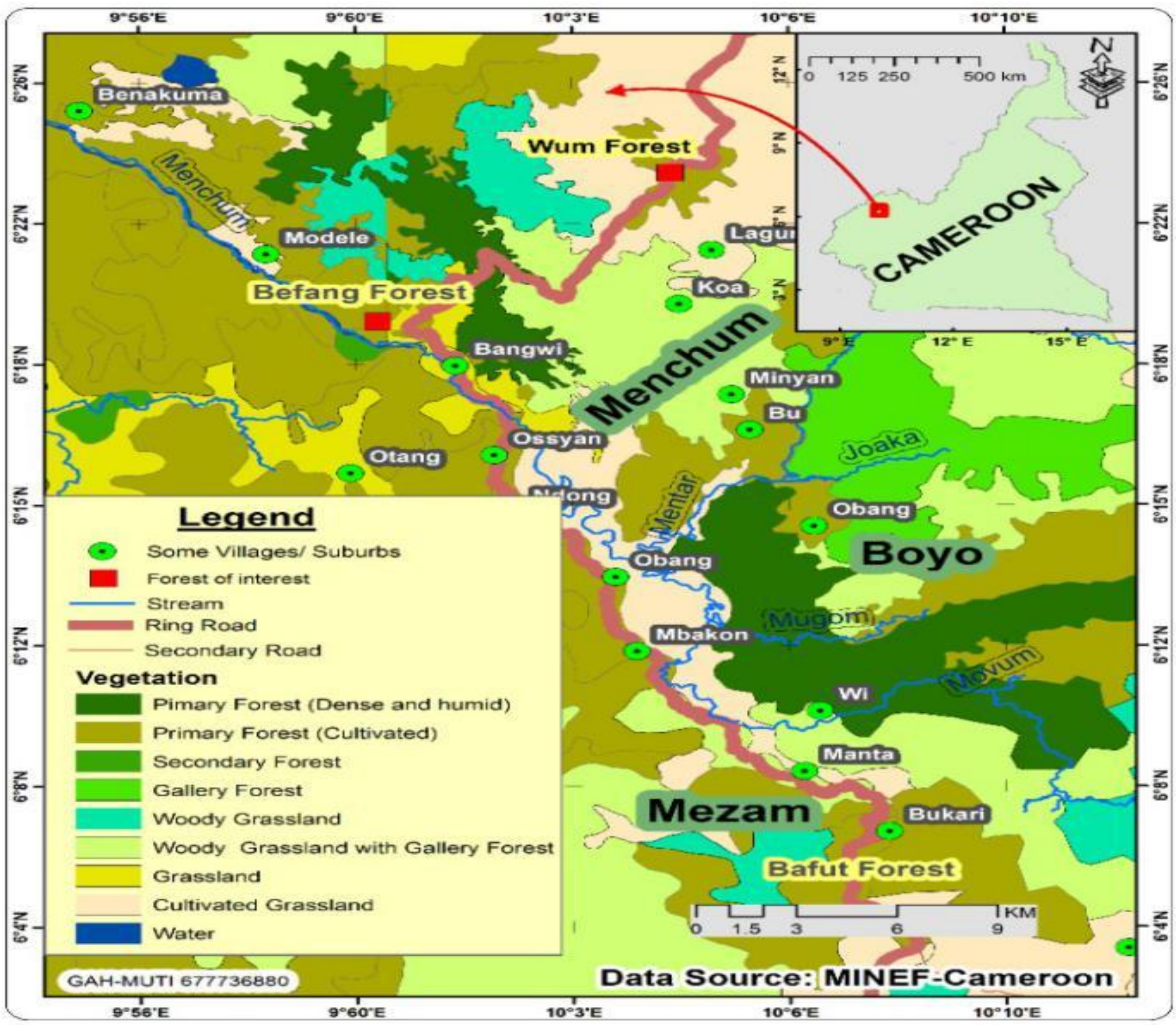

Figure 2: Road / Vegetation Map of Bafut-Wum area

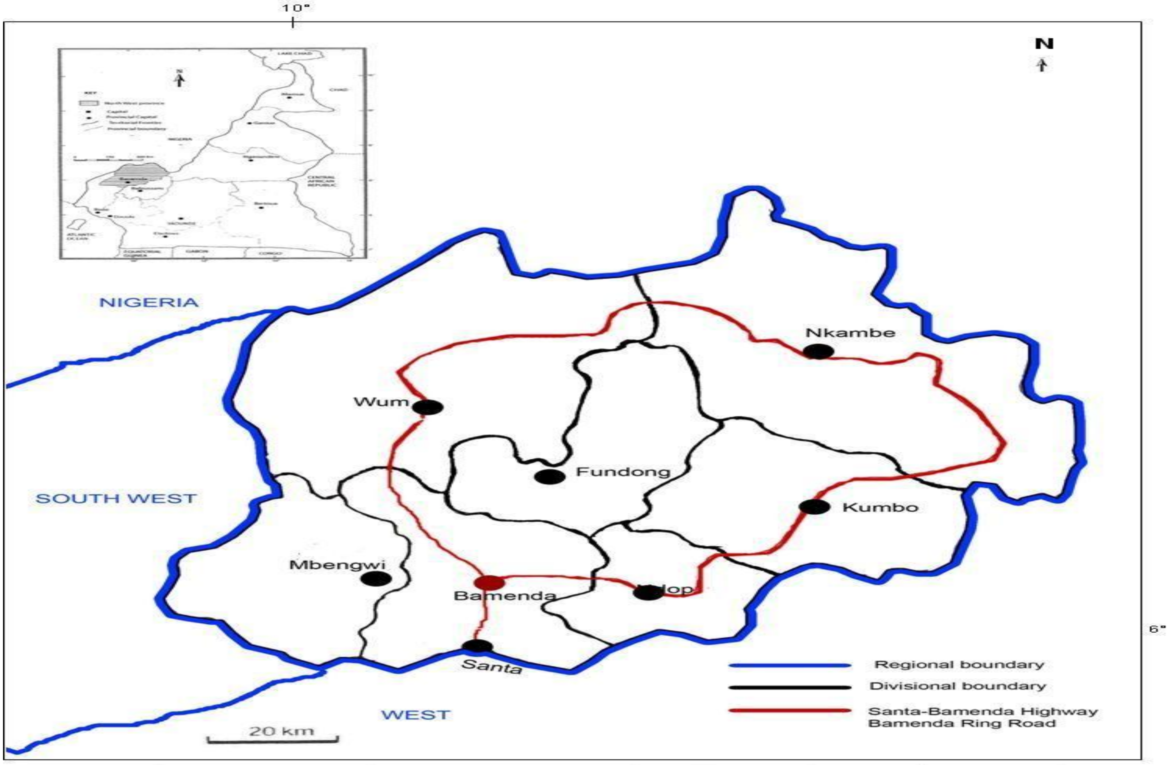

Figure 3: Bamenda Ring Road

Source: Adapted from Google Earth

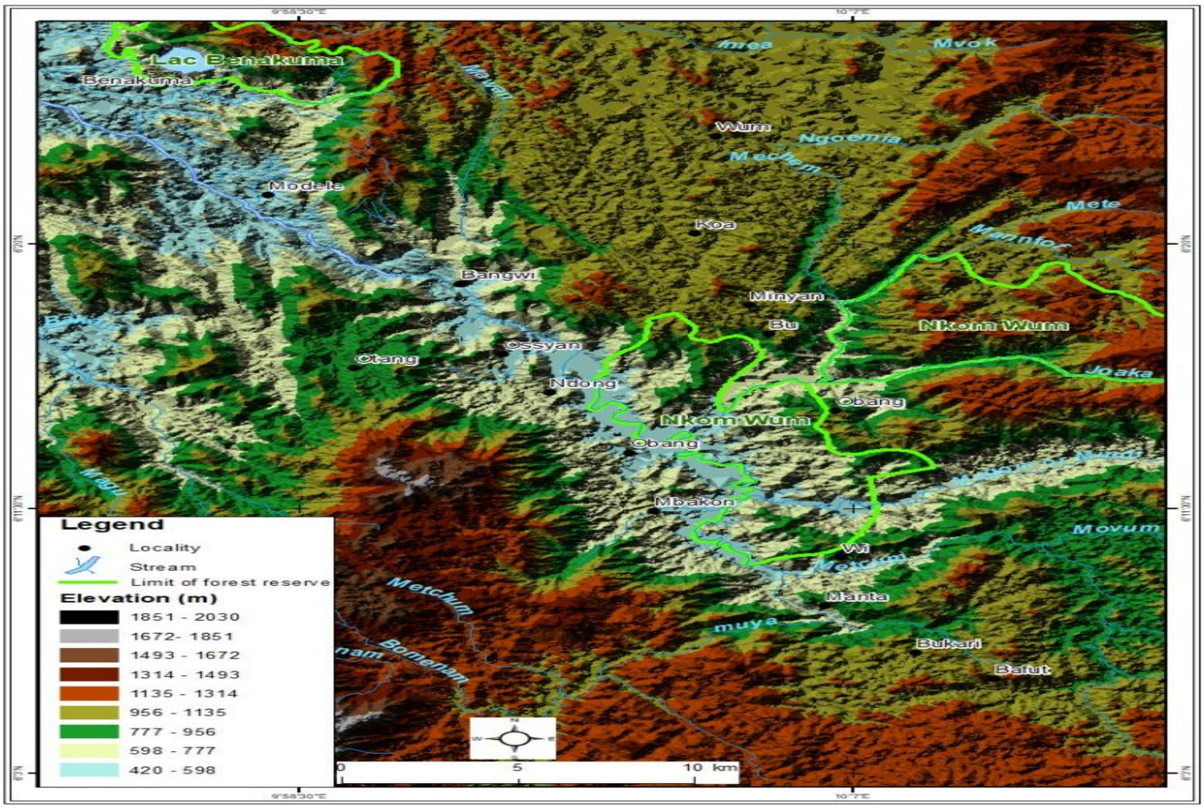

Figure 4: A 3D graphic of Bafut-Wum area

Geologic maps by Soba (1989), Peronne (1969), Deruelle et al., (1991) and Gèze (1961) were also studied. However, working with these maps gave us only a rough approximation of the geology of the study route area because of their scales (Fig 5). Therefore, only a thorough field work confirmed the lithology of the area.

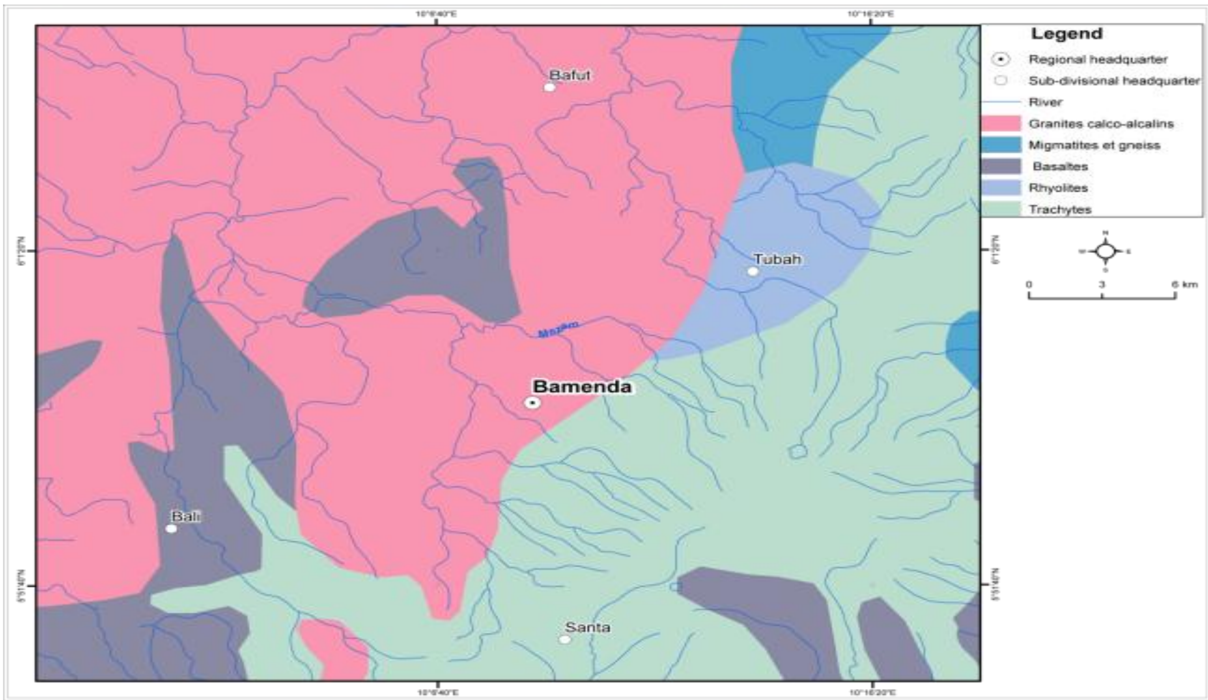

Figure 5a: Geology of the Bafut area

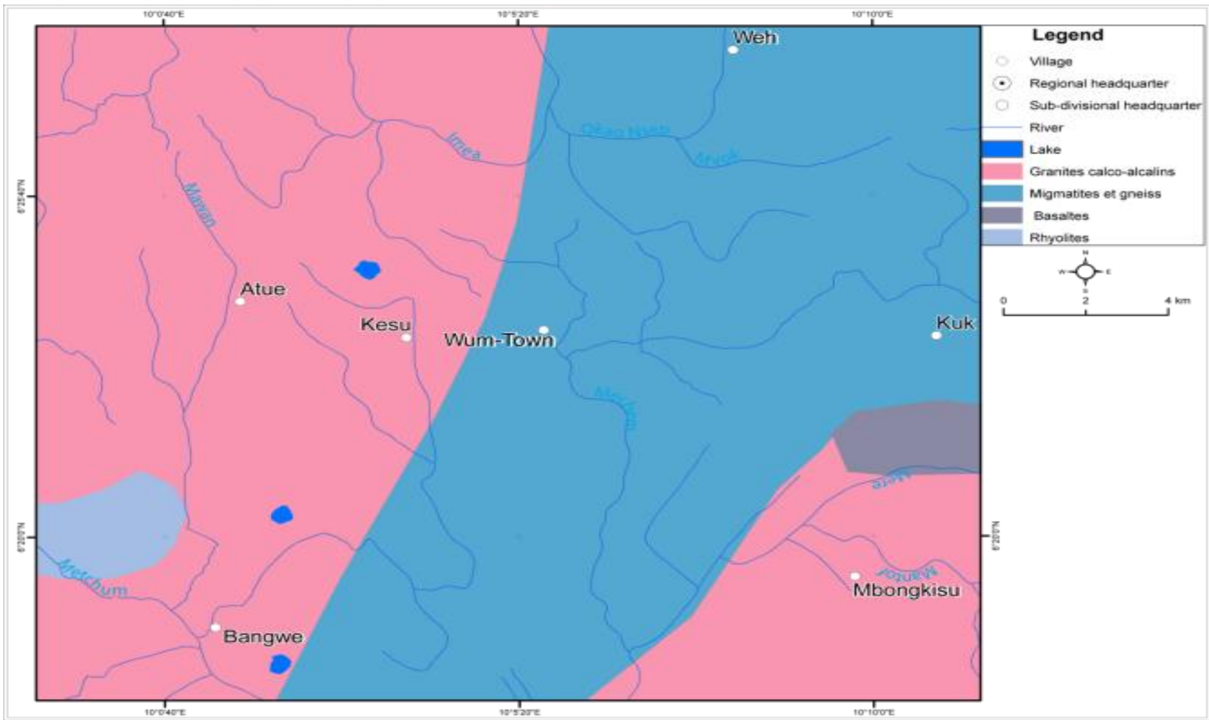

Figure 5b: Geology of Wum area.

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4.2 Collection and Treatment of Hydrometeorological Data

Rainfall, temperature and humidity data for the region were collected from the Bamenda Meteorological Station 10 km away from the Bafut Forest and 70 km away from the Befang Forest (see Tables 1 and 2). Equally, rainfall statistics for 1988, (Table 3) of the Wum area obtained from the Wum Area Develoment Authority (WADA) Station, were collected as monthly and annual totals. These totals constitute 'raw' data and the arithmetic average method gives us an estimated average depth of rainfall in the region and other characteristics of the rainfall and how these characteristics are related to the landslide events were determined by constructing bar graphs and pie-charts.

Table 1: Temperature and humidity data (Bamenda Meteorological Station)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct.	Nov.	Dec.
Avr. Max. Temp.	26.5	27.3	27	26.2	25.3	24.3	22.6	22.5	23.6	24.4	25.1	26.0
Avr. Temp.	19.4	20.6	21.2	21.5	21	20.2	19.1	19.1	19.1	20.1	19.8	19.2
Avr. Min. temp.	12.3	13.9	16.4	16.8	16.8	16.2	15.6	15.7	15.7	15.8	14.6	12.5
Max. Humidity	73.3	68.3	83	92.6	96.1	97.1	98.4	96.3	98	96.4	94.4	82.6
Min Humidity	33.9	29.6	42.3	55	59.7	69.3	75.2	77.6	70.6	557.8	50.2	38.6

Table 2: Annual rainfall and number of rainy days from 1980 to 2008

Year	Annual rainfall	Number of rainy days	Year	Annual rainfall	Number of rainy days	Year	Annual rainfall	Number of rainy days
1980	2489.7	207	1990	2284.7	176	2000	2167.8	180
1981	2485.1	203	1991	2207.7	199	2001	2103.9	176
1982	2366.9	214	1992	2566.2	189	2002	2738.0	205
1983	2186.8	172	1993	2017.0	185	2003	1779.6	138
1984	2305.0	205	1994	2607.6	190	2004	2440.9	200
1985	2275.0	203	1995	2218.1	181	2005	2572.0	203
1986	1798.4	164	1996	2107.1	163	2006	1960.9	172
1987	1969.2	168	1997	2546.3	198	2007	1708.3	197
1988	1964.9	159	1998	2613.9	209	2008	1579.1	130
1989	2310.6	178	1999	2824.1	193			

Table 3: Rainfall data for Wum, WADA station (Suchel, 1988)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Rainfall (mm)	0	0	140	275	357	305	606	575	420	321	57	31
No. of Rainy days	0	0	12	22	27	28	29	31	30	31	30	12

4.3 Fieldwork

Field work activities involved going through the entire lengths of the road segments at the end of the 2014, 2015 and 2017 rainy seasons with the aid of simple tools such as a hammer, compass/clinometer, tape, etc during these fieldwork sessions ground reference data were collected. All slopes, spurs and valleys were inspected for landslide scars, soil cracks and accumulations of landslide materials, which are typical indications of slope instability. During field work, some identified landslides were mapped using the Global Positioning System (Garmin 3x). With the compass/clinometer orientations and values of dipping angles and slope angles were obtained. A surveyor's measuring tape (100 m) was used to obtain the lengths, widths and heights of landslide scars.

A couple of classification schemes were utilized to give an insight of: the style of movements along the slide planes, the depths of slide planes, the volume of material released, composition and sorting characteristics and distance travelled by the debris material. The schemes employed include Coch (1995), Varnes (1978), Cruden and Varnes (1996), Fell (1994) (see table 4), Usuki *et al.* (2011), Sidle *et al.* (1985), and Hutchison (1995).

Table 4: Fell (1994) classification based on volume of material

Magnitude	Size description	Volume (m3)
1	Extremely small	< 500
2	Very small	500 – 5 000
3	Small	5 000 – 50 000
4	Medium	50 000 – 250 000
5	Medium-large	250 000 – 1 000 000
6	Very large	1 000 000 – 5 000 000
7	Extremely large	> 5 000 000

The landslide materials were found accumulated mostly at the base of the road embankment slopes and/or spread out on the road pavement at varying distances from the point of impact. The piled-up materials is often in demi-orange/hummocky shapes and the various descriptive parameters such as the heights and distances thrown on the road pavement were measured. Where a gutter or ditch is present at the foot of the slope embankment, such are filled up by the releaseded materials and the volumes of materials in the gutter measured. The materials are weathered to varying degrees and can be attributed any of the grades I-VI on the Chin and Sew (2001) scale. In some places the material is a soil mass but often we find a mixture of soil and clasts of varying sizes as well as dead plant tissues, live plants and even whole trees. Rock outcrops are very scarce as the weathering profile is quite deep.

Few outcrops along the road embankments were accessible and some field samples though highly weathered to various degrees were studied with the aid of a lens (3x). Soil permeability has an influence on the occurrences of landslides. The rate of flow of water through a soil is referred to as the soil's permeability. Several factors can influence the rate of water infiltrating the soil material: void ratio, grain texture, and degree of saturation. Soil samples were collected with the aid of some 125cm diameter / 30m high polyvinyl pipe cylinders. Samples were collected from 3 sites in the Bafut Forest coded Tingoh Top, Tingoh 1 and Tingoh 2 and 2 sites in the Befang Forest coded BEF Top and BEF 1. These samples were analysed for hydraulic conductivity with the aid of the Oedometer based on French Norm (Norme Française: XP P94-090-1) at the Natioanl Civil Engineering Laboratory-Yaounde. The reults obtained are presented on table 5.

5. Results and Discussion

5.1 Description of the Landslides along the road in the Bafut and Befang Forests.

5.1.1 The Bafut Forest Series of Landslides

The Bafut Forest is a typical afro-montane forest. The BRR goes through the Bafut Forest from Njinteh to Tingoh a distance of about 12.5 km. The road has been cut at approximately mid slope at an altitude ranging from 800 m to 1300 m a.s.l. More than 50% of the slopes are convex, the rest are convexo-linear, concave and a few of them are linear. However, many slopes become linear towards their bases. The slope gradients were measured and they vary from 35^0 – 60^0 meanwhile the road-cut cliffs have gradients of 90^0.

The profile of the road embankment varies in height from place to place (1.5 m – 16 m). The A and B horizons of the soil are often quite distinct. The A-horizon measures a few centimeters thick and often black in colour while the B-horizon is relatively very thick with colours in various shades of red. Where clay is in higher proportion the soil is soft and lumpy when wet and where the sand proportion is higher, the soil is friable to touch. Landslide scarps are easily recognized on the embankment of this road by their bright-coloured 'clean-faces', of fresh soil material void of any vegetation or is sparsely vegetated compared to adjacent areas (see Figure 6a). Along this stretch, at least 35 fresh landslide scarps were counted on the road embankment at the time of survey. The lengths of these slides from crown to accumulation area range from 1-16 m. The widths of these scarps ranged from 0.5 m to 20 m and depths range from about 0.5 m to 12 m. The run-out distance varies from a few centimetres where material is deposited at the foot of the embankment to 10 m and more where the material goes beyond the roadway into the adjacent ravine. The landslide material from the depletion area is dumped into the road gutter (where it is provided for) and/or carried onto the carriageway where it is abandoned as a hummocky accumulation and or beyond the road carriageway as shown in figure 6a and 6b.

According to the classification schemes of Varnes (1978) and Cruden and Varnes (1996) these failures are mainly translational debris slides as seen in Figure 6a and a few rotational slides as seen in Figure 6b. There are 32 translational slides recognized by their 'straight' slide planes. The 3 rotational slides reveal curved surface ruptured slide planes. Based on the classification of Rafek et al., 1989 and that of Hutchinson, 1995 these landslides are mainly small volume and shallow landslides respectively. Based on travel distance (Moriwake (1987), Kusomoto *et al*. (2003), Usuki *et al*. (2011), Igwe and Fukoka (2014) and Igwe (2015), these landslides are short-distanced travelled landslides.

5.1.2 The Befang Forest Series of Landslides

The Befang forest is a typical afro-montane forest and this stretch of the BRR of 6.5 km has been cut on the east flank of the Befang Forest hill. From Befang the road rises from about 670 m to about 970 m.a.s.l. The hill slope is essentially convex and the gradient is quite steep-60-80^0. Along the embankments of this road at least 16 landslides were counted at the time of survey. The slides expose "fresh" soil profiles (see figure 6c and 6d). The typical soil profile here is characterized by a very thick B-horizon. The A-horizon is relatively thin and mainly black in colour. The soil is soft when wet and friable. Within this soil material are caught core stone clasts of varying sizes.

According to the classification schemes of Varnes (1978) and Cruden and Varnes (1996), 14 of these landslides are translational debris slides revealing flat planar slide planes (figure 6c and 6d) and the rest are rotational slides. Most of the translational debris slides have incomplete depletion zones. Based on the classification of Rafek *et al*., 1989 and that of Hutchinson, 1995 these landslides are mainly small volume and shallow landslides respectively. Based on travel distance (Moriwake (1987), Kusomoto *et al*., (2003), Usuki *et al*., (2011), these landslides are short-distanced travelled landslides.

The relatively new slides show sharp and barren scarp features with steep gradients. Landslide materials are abandoned as heaps or hummocky deposits on the road carriageway or fills up the gutter where one is present as in figure 6a. The residual soil material caps a granite bedrock from which it developed and also constitute the main bulk of the landslide material.

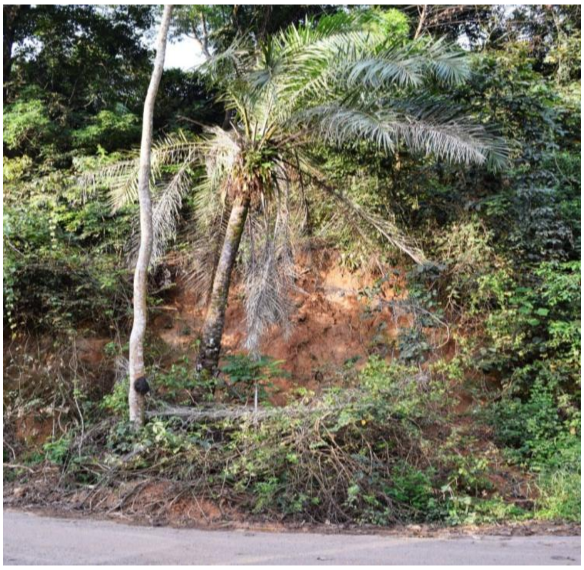

Figure 6a: Landslides of Bafut Forest

Figure 6b: Landslides of Bafut Forest

Figure 6c: Landslides of Befang Forest

Figure 6d: Landslides of Befang Forest

5.2 Laboratory Results

Table 5: Permeability test results

σ (kg/cm^2)	BEF TOP (cm/s)	BEF1	TINGOH TOP	TINGOH 1 Mile 23	TINGOH 2
0.05	1.11 E-04	7.43E-05	3.31 E-05	4.57E-04	7.96E-05
0.25	1.08E-04	5.57E-05	2.48E-05	4.14E-04	6.80E: 05
0.5	1.03 E-04	4.46E-05	2.I4E-05	3.45E-04	6.59 E-05
1	8.42E-05	3.4SE-05	1.91 E-05	3.20E-04	6.31E05
0.25	1.22E-04	5.07E-05	2.02E-05	4.39E-04	7.21 E-05
0.05	1.48E-04	6.97E-05	2.06E-05	3.60E-04	7.66E-05
0.25	1.15E-04	4.85E-05	1.68E-05	2.97E-04	6.75E-05
1	8.34E-05	3.38E-05	1.64E-05	2.I6E-04	6.36E-05
2	8.01 E-05	2.48E-05	1.62 E-05	1.95E-04	5.69E-05
4	7.68E-05	1.86E-05	1.60E-05	1.54E-04	3.15E-05
8	7.56E-05		1.56E-05		

These results indicate that these soils are permeable at low pressures. In the field the soil materials suffer such pressure variations during rainfall which may either be as relatively short storm outbursts or prolonged steady downpours. Low increased pressures seem not to have any significant effect on the permeability of the material.

5.3 Causal Factors

Processes and events leading up to an eventual slope failure or landslide are spatio-temporal in nature. Some of such processes and events may be quite imperceptible taking very long periods of time while others are actively dynamic. The contributory factors which come into play are divided for convenience into preparatory or intrinsic factors and triggering factors.

5.3.1 Preparatory Factors

Preparatory factors can bring long term changes in an area or slope which will gradually alter the stability state of the slope and contribute actively if a landslide were to occur in the area. However, these factors cannot be used to determine any approximation of the chances of any landslide event occurring on the slope. Nature of base rock, slope angle, weathering and the residual soil produced by the weathering are the main preparatory factors in favour of landsliding along the road going through the Bafut and Befang Forests. Equally road maintenance activities leading to changes in soil strength and permeability somehow prepare the hillslope for any triggering factor.

5.3.1.1 Influence of slope angles

Slope angle as a property in initiating landslide has been studied by a number of researchers such as Bryant, 1991; Alexander, 1993. The 3D (see Fig 4) was projected and used in this study to analyze the topographic features of areas of these mountain forests road segment. All the landslides in the forests occurred on slopes 30^0-90^0.

5.3.1.2 Nature of Base Rocks

There are numerous associations of mass movements with particular rocks which demonstrate the importance of lithology and mass movements (Sidle et al., 1985). In the Bafut and Befang Forest the base rock is a granite and filed hand specimens indicate that it is light coloured and coarse grained. Crystals of quartz and feldspars measuring several mm across can be seen (especially when a magnifying lens is used) in addition to flakes of muscovite and biotite (Fig 7a and 7b). Close observations indicate that these minerals are at varying stages of decomposition due weathering.

Figure 7a: Bafut forest rock (Granite)

Figure 7b: Befang Forest Rock (Granite)

5.3.1.3 Weathering and the Residual Soil Material Produced.

Many authors such as Terlien, 1998; Zhou *et al.*, 2002; Sajinkumar *et al*., 2011 have treated weathering as conditioning mechanism in favour of landslide occurrence. However, according to Miscevic and Vlastelica, (2014), the relationship between the influence of weathering and instability (i.e. landslides, rock falls, and surface erosion) is still not well understood. All-natural landscape which has been shaped initially by tectonic activities evolves under normal geomorphic processes and with time these changes will continue. Weathering is one of the processes in the evolution of the slopes of the landscape and produces thick mantle of unconsolidated materials on the slopes. Landslides rely on and are per cussed by weathering on natural or artificial slopes. Meanwhile, weathering is the in-situ break down of intact rock and rock masses due to physical and chemical processes under the influence of atmospheric and hydrospheric factors (Hack, 2006) and this implies decay and changes in state from an original condition to a new one (Price, 2009) provided no large-scale transport of the loosened products is involved (Holmes, 1978).

Weathering of the base rock in these moist forests, has led to the development of the residual soil profiles through which the road segment under survey have been cut. The residual soils form a mantle capping of substantially thick layers. Such capping layers are of weaker unconsolidated clayey and/or lateritic materials lying above the (generally unseen) mechanically high strength granite rock. Blight, (1997) defines residual soil as a soil-like material derived from in-situ weathering (both physical and/or chemical weathering) and de-composition of rock which has not been transported from its original location.

Despite the vegetative cover of the forests, the high relief exposes many facets of the undulating landscape to solar radiations during the day. At night temperatures drop to as low as 12.3 ^{o}C. Where the basement rock mass is riddled with incipient cracks, joints and fractures (naturally occurring or created by machinery during earthworks) these serve as passages for air, water, and rootlets. Coupled with the effective wetting and drying cycles imposed by the diurnal temperature variations and the seasonal changes, water in these planes of weakness can exert sufficiently high pore pressures. Equally, roots of plants wedged in these openings, exert appreciable pressures. Under such pressures the rock mass breaks into angular particles of varying sizes that form a scree or talus at the foot of the slopes.

The mineralogical compositions of the granite rocks have aided in the development of the residual soils profiles as seen along the road embankments. These minerals, mainly the feldspars are influenced by various processes of chemical alteration or chemical decomposition. Bobrowsky and Marker (2017), define chemical weathering as the weathering of rocks caused by the chemical action of water containing atmospheric oxygen, carbon dioxide, and some organic acids in solution on the rock –forming minerals leading to an adjustment of the mineralogical composition with the formation of new minerals like hydrous phyllosilicates, iron oxides/hydroxides, soluble salts, and other alterations products. These granites are composed of aluminosilicate feldspars, biotite, muscovite and quartz. According to Durgin (1977), granitoids undergo progressive, physical, chemical and biological weathering that weakens the rock and prepares it for mass movement.

5.3.1.4 Influence of Undercutting of Slopes

Landslides are likely to occur whenever slopes of roads are undercut during maintenance and repair works. Along the road stretch studied, repair work is imperative every year as each year brings a new set of landslide materials on the road pavement. Our observations showed that the desired repairs and maintenance works could not be done as required due to budget constraints. These maintenance activities resulting in slope toe undercutting, reduction in lateral support and vegetation removal may not trigger any landslides but would mechanically destabilize the hillslopes and enhance rock shear failure, conditions which predispose the slopes to failure. Maintenance and repair work with movement of weathered materials on slopes alter the permeability potentials of the various horizons of the slope. Along certain high portions (>30 m in places) of the road embankment in the Befang Forest, road engineers have recently cut terraces in order to check failures within the embankment regolith materials. This strategy has not paid off as expected due to two main reasons. Firstly, terracing reduces the speed of water rushing down slopes thereby enhancing infiltration. Secondly, pearmeability tests results (Table 5) show that the weathered soil materials along the road embankment have a high affinity for water especially at shallow depths. The combined effect of these conditions is the reason for so many sahallow landslides observed along this road embankment.

5.3.2 Triggering Factors

In general, a number of elements will contribute to a landslide event, but often there is one which triggers the movement of material. Commonly known triggers for landslides are volcanism, earthquakes and rainfall. Cannon and Ellen, 1988; Corominas and Moya, 2008; Forbes *et al*., 2011 consider the last two as the most common and Terlien, 1996 states that rainfall acts as one of the main triggering factors in tropical zones. The triggering mechanism is exogenous to the system and comes into action such that sufficient energy is imparted into a stable or quasi-stable slope zone material generating dynamic movements that may last for a few seconds or take very long time over varied depths and distances. The movement of the slope material and the changes in the immediate environs can be recorded for study and posterity on GIS tools- GPS, altimeter, clinometer, satellite imagery and/or geophysical instruments such as- geophone, seismograph and/or ordinary gadgets such as- still photographs and video cameras. The La Conchica 1995 landslide is on video camera and is today known to have lasted 60 seconds. Studies show that, two main triggers are responsible for landslides in Cameroon, viz: earth tremors and rainfall.

More than 75% of landslide events in Cameroon are concentrated along the corridor of the CVL. By the nature of the substratum of the CVL, earthquakes can easily be generated along this corridor and due to the position of Cameroon relative to the Atlantic Ocean and the Sahara Desert rainfall is abundant. Lambi (1989), holds that the September 1982 landslide at neighbouring Santa was induced by earth tremors. However, Tabod et al. 1992 assessed the entire region to be aseismic for the period 1988 to 1992.

5.3.2.1 Rainfall as Triggering Agent

All hydro-meteorological variables including sunshine, movement of winds, cloud movements, temperature changes, humidity and rainfall interplay to bring about the landslides in these forests and its environs. Data for humidity, temperature changes and rainfall collected at the Bamenda Meteorological Station are shown on tables 2 and 3. From table 2 the temperature in this area ranges from about 12.3°C to 26.5°C. The relative humidity is constantly high with the weather being relatively humid throughout the year. Relative humidity is about 97 % during the raining season and remains quite high throughout the rest of the year though it may drop to low as 30 % in the dry season. Very low temperatures are especially experienced during the months of June, July, August and September and high temperatures in December, January and February.

Worldwide, rainfall stands as the landslide inducing factor with the highest number of events and claims the highest casualties annually (South Asia Report, 2007). Rainfall as a trigger is reported to be responsible for many landslides in Cameroon. According to Buh, (2006), all recorded landslides in Cameroon within the last 18 years have occurred between the months of June and September, which are the rainiest months of the year. In neighboring Dschang and Magha, 159.3 mm of rain on the 25th and 26th August 1978 (Tchoua et al., 1983) and 84.2mm of rainfall on the 18th, 19th and 20th July 2003 (Zogning et al., 2007) respectively triggered massive swarms of landslides in these localities.

The North West Region typically has two seasons. The dry season is known to run from October to February and the rainy season which takes the rest of the year. The rainfall oscillates between short very intense cloud outbursts and low prolonged continuous down pours. Unlike dew and fog huge amount of water reach the ground provoking flash floods such that hillside slopes may suffer landslide as a major erosion process. The temporal and spatial probability of occurrence of landslide anywhere along the Bamenda Ring Road in general and/or the segment through the Bafut and Befang forests is closely related to the two seasons regime obtained in the region.

Table 6: Annual percentage of rainy days

Year	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**
Number of rainy days	207	203	214	172	205	203	164	168	159	178	176	199	189	185	190
Annual percentage	56.56	55.62	58.63	47.12	56.01	55.62	44.93	46.03	43.44	48.77	48.22	54.52	51.64	50.68	52.05
Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
Number of rainy days	181	163	198	209	193	180	176	205	138	200	203	172	197	130	
Annual percentage	49.59	44.54	54.25	57.26	52.88	49.18	48.22	56.16	37.81	54.64	55.62	47.10	53.97	35.61	

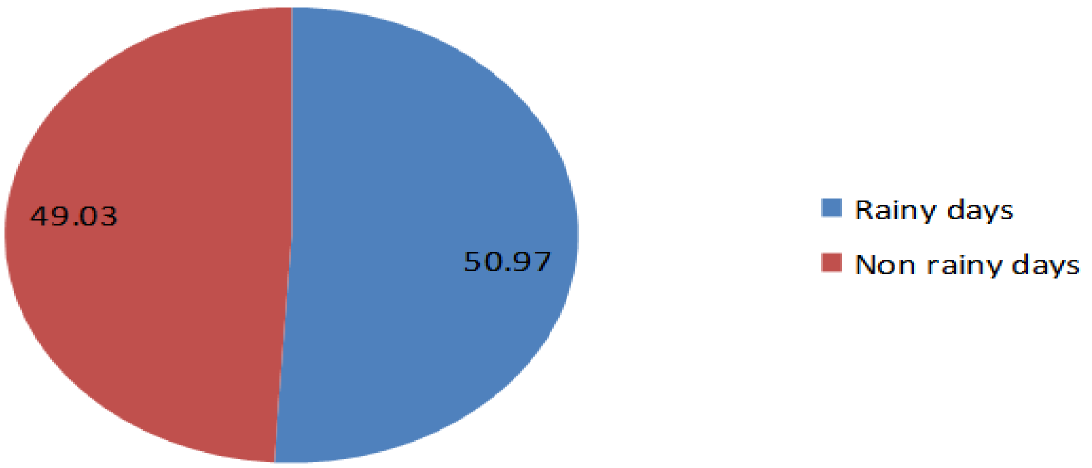

Figure 8: Pie chart representation of percentage of rainy days of the year.

Table 7: Monthly percentage contributions to the annual rainfall budget estimated over 25 years adapted from table 3. (1980 – 2008)

Month	Jan	Feb	Marc	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
%	0.52	0.36	0.86	7.91	7.81	9.26	18.67	19.36	6.28	4.49	1.27	0.50

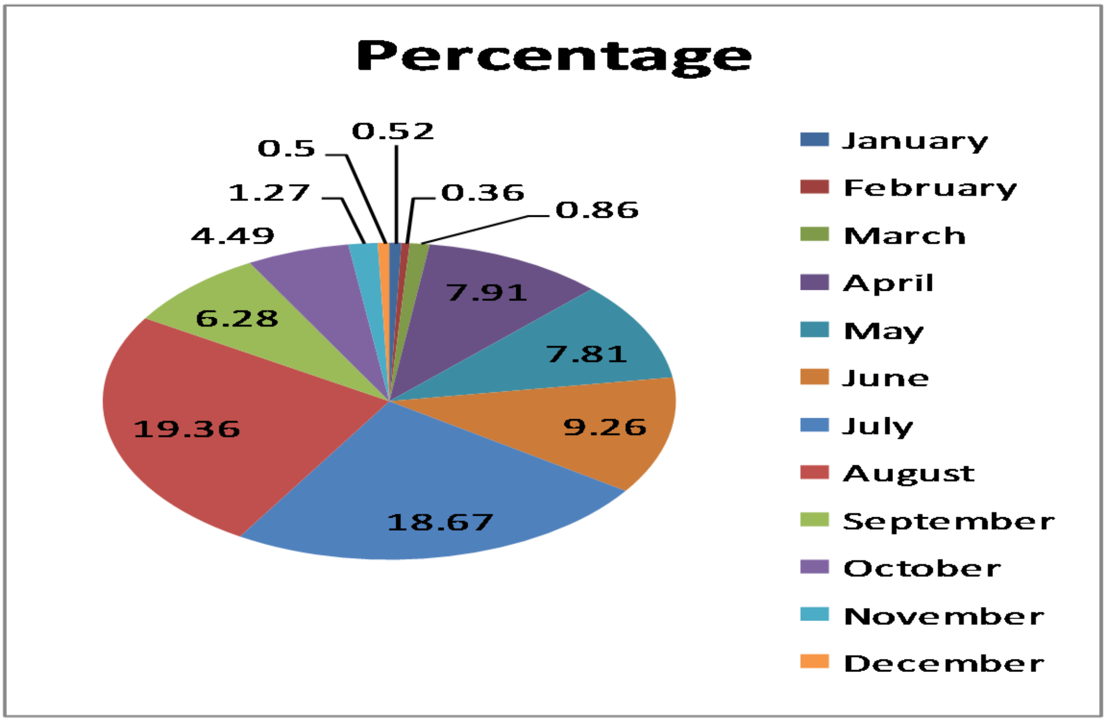

Figure 9: Pie chart representation of monthly contributions to the annual rainfall budget

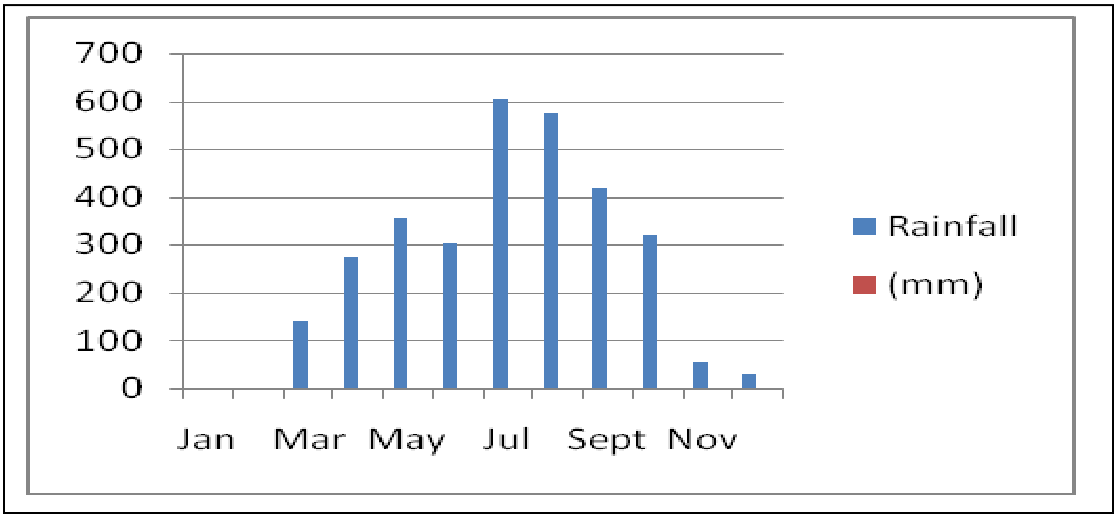

Figure 10: Monthly rainfall contributions 1988. Wum

According to tables 6 and 7 and figures 8 and 9, it can be realized that rainfall is likely to occur every month of the year. This ensures a minimum volume of water held by the soils before the main rainy season. The months of June, July, August and September contribute more than 60% to the annual rainfall budget. The annual average rainfall for this region as calculated is 2400 mm (Bamenda Meteorological Station). This annual average far exceeds the averages in other parts of the world where rainfall is known for triggering or inducing landslides.

In the south slopes of the Himalayas we have 1530 mm https://www.britannica.com/Himalayas/climate. California, 21.44 inches. https://nationalmap.gov/small.scale. New Zealand, 1600mm. https://www.niwa.co.nz/education-and-training/schools/resources/climate/overview. Kenya and Uganda on the Mount Elgon region, 1600mm (Muggaga, 2011)

Typically, the action of water during heavy rains often acts as the main triggering cause of landslide as the sudden downpours in huge quantities helps in reducing the cohesion of soil on the slopes of mountains (Deoja *et sal.*, 1991; Naithani *et al*., 2000; Meunier *et al*., 2008; Ashok, 2012). Drivers and villagers along this road segment attest to rain incidents as being either intense rainstorm outbursts or prolonged low intensity falls. The latter condition favours inflow which then exceeds discharge and resulting in increased pore water pressures and liquefaction on the slope road embankments soil and regolith materials provoking landslides.

With more than 2000 mm of fresh water from rainfall these forests are adequately supplied and the vegetation cover maintains a moist environment. The water budget within the soil and regolith of the road embankments and hillslopes is sustained by the antecedent supply. The water present continuously fuels the weathering process and enhances changes in the physical and geotechnical engineering properties of soil and regolith materials, rendering them prone to landsliding.

5.3.2.2 Water Pore Pressure

Water pore pressure influence in the mechanisms leading to slope instability and potential failure has been studied by some authors. These forest areas receive a high annual rainfall estimated at 2400 mm/year. The water budget of the soils and regolith materials of the slope of the road of these forests remains high throughout the year because of (1) a dense forest vegetation cover (2) a relatively permeable soil (3) a high density of roots penetrating the soil (4) continuous precipitation as dew and fog (5) a relatively short dry season and (6) an extremely long rainy season. This water is held mainly by the clayey mineral composition of the soil developed by weathering of the granite base rock. The weathering has also contributed to a high sand content and enhanced inherent relict structures such as cracks and joints developed at the time of formation of the granite rocks. Under conditions of high rainfall all of these contribute to increased pore water pressures leading to liquefaction.

6.0 Landslide Mechanism

Increase in shear stresses leading to yielding can be provoked by loads or surcharges at the top of the slope (buildings, plants etc), increase of the unit weight of the soil by water (from rainfall or groundwater) and seismic shaking of the ground and vibrations. A geophysical survey of the entire North West Region by Tabod *et al*., (1992) shows that the region is aseismic. Vibrations can be generated by the movement of heavy-duty machinery and other traffic. Of particular note are vibrations produced by mass movement chain-effect, a phenomenon reported by Zogning et al. (2007) in the Magha landslides.

Within the relatively dense moist Afro-montane forests field observations show a lateral root spread for some trees but most trees carry the tap root system. These roots aid in the rapid percolation of water into the subsoil and the less permeable soil materials. According to Cohen and Schwarz (2017), redistribution of forces in roots across the hill slope plays a key role in the stability of the slope during rainfall events. The roots also afford adhesive and binding strength forces for the soil particles through which they pass. The lateral root network reaches far from the trunk and can become intertwined with roots from neighbouring trees and under storey vegetation to create a nearly continuous mat of roots literally tying various parts of the slope together, (Terzaghi, 1996). In addition to the lateral reinforcement, reinforcement of roots under compression have been demonstrated to contribute to soil stiffness and passive earth pressure forces (Schwarz et al., 2015), thus increasing slope stability, (Giadrossich *et al*., 2016). However, Van Beek *et al*., (2010) state that in-situ direct shear test indicates that a contribution of root systems to the soil shear strength within the top soil is present but limited. The strength conferred to soil particles or a lump of soil depends on the plant type, root system and soil type. Trees with roots which hardly go beyond the A-horizon and those whose roots barely reach the B-horizon add their weight as load on to the slope regolith or soil material. Such plants are swept along as part of the debris of the landslide material as shown in figure 6b. Some roots are pulled out while others are severed and the severity of the breakage is indicative of the pressures and stresses involved in the movement of the landslide material.

Given the high annual rainfall, high porosity and moderate permeability of the soil and regolith materials along the road under survey we expect high water pore pressures to develop with subsequent liquefaction in case of any rainfall event. The intake of water, whether rapid or gradual at each stage, modifies the consistency and behaviour of a soil and consequently equilibrium on any slope is disturbed with deformation and movement likely to happen. Any rainfall event is likely to cause lumps or columns of soil regolith materials along the embankments to become saturated such that yielding leading to deformational sliding as low magnitude shallow landslides become prevalent. Xu *et al*. (2017) performed tests on saturated loess after considering that landslides on the loess commonly occur in saturated layers. In addition, as liquefaction sets in and the shallow landslides may move as translational slide or a flowslide structural framework of the particular soil. The landslides studied along the road segment in these forests have occurred having their sliding planes in the residual material, of the various weathered soil profiles. These profiles developed on the granites as basement rock. The works of Komoo (1997), Jamaluddin and Deraman (2000), Chin and Sew (2001), Tan and Chow (2004), Nurly and Azman (2014), indicate that the presence of relict structures inherited from parent rocks in highly granitic material representing former joints, fractures, bedding, render the material not only more porous and friable, they also serve as weak zones that are prone to landslides. According to Larsen and Simon (1989), the failure planes of many landslides, have exposed these relict fractures and joints as slickensides and landslides appear to occur on these pre-existing planes of weakness in the saprolite. This explains the numerous shallow landslides events recorded along the embankments of the road under survey.

When the regolith soil materials of the slopes bounding the road under survey, come under compressiv pressures especially induced by rain water saturation, the nature and aggregate structure of the soil regolith material become altered. These alterations cause new dynamics within the embankment slope soil regolith mass and instability prevails. The capability of soil to bear loading are different depending on the soil types (Widodo and Ibrahim, 2012). Sufficient water also provokes changes such as dissolution of compounds within soil masses and the breaking of physical as well as chemical bonds and upon the absorption of water into the soil regolith mass swelling changes occur. According to Leroueil and Vaughan (1990) and Hight *et al*. (2002) even simple swelling can provoke destructuration of bonded clays while Kumar *et a*l. (2002) observed that swelling affects compressibility parameters to a large extent.

In clays physical- chemical forces between the particles control their behaviour (Shipton and Coop, 2012). Soil behaviour depends strongly on its initial degree of saturation and the initial water content (Wc). Being incompressible, some of the water is taken under pressure into the skeleton of the soil particles. The presence of excess water volumes in the skeleton of the soil particles ruptures some bonding, affects the cohesion and adhesion properties, and causes greater mobility of individual grains. The mobility within the slices and lumps of soil regolith materials on the slopes of the road embankments is influenced by the proportion of the fine content. According to Lade et al., (2009) the fine content of (soils, sands, and geo-materials) affects maximum and minimum void ratios, compressibility, shear strength, and static liquefaction under undrained conditions. These movements affect the kinematics within the lumps and columns of the embankment slope regolith soil materials reducing the shear resistance of such and instability prevails. Equally, excess water in the saturated soil and regolith columns or lumps is sent out as it flows within the body of the soil lump or column in a general horizontal manner. Dissipation of excess pore pressure and accompanying water flows in any direction of lower pressure. This direction is offered by the modified slope aspect of the road embankment.

7.0 Effects of the Landslides on the Road

The empirical observations of the road segment under survey shows that at the time of its creation, effective engineering practices were considered during the design and construction because drainage was given due consideration as necessary. Highway drainage is the process of removing and controlling the surface and subsurface water within the rightway (Tiza *et al*., 2016) and the primary purpose of a road drainage system is to remove water from the road and its surroundings (Roadex Project, 2017). In addition, any road properly engineered will have good bearing capacity, to be nice and safe to drive, and adapt well to the environment.

Proper interconnection or integration between the road network and the drainage infrastructures is required (Getachew and Tamene, 2015; Magdi, 2016) and according to Magdi, (2016) poor drainage conditions especially during rainy seasons, force the water to enter the pavement from the sides as well as from the top surfaces.

Generally, any road will fail due to poor drainage, traffic load, utilization of poor grade and substandard materials, wrong engineering practices, environmental factors (RoadexProject, 2017) and nefarious anthropogenic activities such as burning of vehicle tires on the pavement and spilling of petrolieum produtcs on bituminous asphalt paved road. Twerefon *et al*., (2015) state that irregular climatic conditions such as erratic rainfall and increase in rainfall intensity are responsible for degradation of road infrastructure in Ghana.

The road system in the NW Region of Cameroon is at the mercy of a number of environmental parameters. The prevalent environmental variables as observed here are seasonal winds, temperature variations, humidity variations, sunshine and rainfall. The seasonal winds are characterized by either the heat or moisture they bring. Temperature variations are very important to the existence of the roads. In this region a mean monthly temperature variation between 12.3 ^{0}C and 26.5 ^{0}C are recorded (see table 2). Temperature differences between night and day (especially during the dry season) affect the materials of the road. Sunshine brings UV radiation and the UV radiation causes asphalt to undergo oxidation during which lighter oils combine to form heavier oils. Additional heavy oils make the asphalt more brittle and more likely to crack and/or ravel (Brown, 2017).

Rainfall is the most important climatic variable along this road segment which affects the conditions of the road. With a mean annual rainfall of more than 2000 mm, so much water is available for more than half of the year. Moreover, water comes in high intensity rainfall or long precipitations over several days. The rainfall poses a great challenge to the stability of the carriageway and the drainage structure of the road directly or indirectly. The direct presence of rainwater with a pH of 4-7 (Holmes, 1978) on the bituminous asphalt causes components such as carboxylic acids and sulphuroxide to dissolve, which weakens the fabric of the bituminous asphalt. An increase in the moisture content decreases the strength of the pavement (Abhijit and Jalinder, 2011) and according to Diefenderfer *et al*., (2011) excess water has an adverse effect in the reduction of shear strength of unbound materials in the road structure as well as stripping of asphalt in flexible pavements. Water on the road carriageway as we observed renders the road slippery and accumulate as ponds of various sizes in many places as well as in potholes, ditches and gutters. Infiltraton of this water below the pavement creates excess pore water pressures in the basement which can lead to rapid degradation with possible development of cracks and potholes. Unpaved sections are exposed to direct pounding by rain drops and rushing of run-off during rainfall which create rills and small gullies.

Acting indirectly, water as rainfall is the triggering factor for the occurrence of the numerous landslides along the road. According to Mckean and Roering (2003) landsliding is a geologic process that occurs over a wide variety of spatial and temporal scales. Each landslide big or small contributes to the present extensive deterioration of this road segment characterized by the presence of defects such as rutts, stripping, potholes, swells and depressions, raveling and cracks of all kinds. Materials of these landslides occupy the gutters or ditches of the road and in some cases stretch on to the carriageway and as such the design and construction precautions put in place by the engineers are defeated. The presence of the landslide debris in the carriageway and/or gutter directly affects the drainage system causing the observed effects

- Reduce the size of the roadway
- Encourages flooding, ponding and seepage
- Water stays on the carriageway much longer than necessary
- Slows down and or prevents surface water falling on the highway to follow the proper way as fast as possible.
- Alters the physiographic structure of the road.
- Change the drainage system originally set for the road
- Forms a hummocky structure at the edge of the carriageway which in places is as high as 80-100 cm as in Figure 5
- Exacerbates erosion as rain water rushes
- During the rainy season this material holds water which penetrates the pavement long after the rains have stopped. During the dry season the material produces dust which reduces visibility for drivers and inconveniences breathing for commuters.
- The landslide materials provide the rushing water sufficient sand and gravel particles which act as scouring tools and further degrade the road carriageway paved with tar or not.
- The Bafut and Wum Councils which are directly concerned must spend about 7.5 million Francs CFA per km for repairs and maintenance every year even though their coffers may not have the required money for certain years.

8.0 Conclusion

Expanding road systems into mountainous landscape in developing countiries significantly increase the risk of land slides with increased vulnerabilities for residents (Sidle *et al*., 2014) as well as passing vehicles and commuters. According to Sandy Brown (2017), the three most important details to look at when designing a pavement to last: drainage, drainage, drainage and proper drainage ensures lasting asphalt pavement structures. Natural factors and processes and human activities have made it inevitable for landslides to occur along this segment of the BRR on a temporal yearly basis. The landslide event may be of a huge type, such that landslide materials block the road pavement which calls for immediate attention as communication will be cut off and the movement of people and goods halted until the rubble is cleared out. With or without huge landslides, numerous small volume slides do occur which are not spectacular but have the capacity to alter the drainage system of the road. These slides therefore contribute immensely to the slow and imperceptible destruction of the road system with consequences as:

- Inconveniences to commuters
- Excessively prolonged travel times
- Low investments by transporters as only old rickety vehicles and motocycles ply the road
- Goods tonnage and number of persons ferried are greatly reduced
- The budgets of the Councils are greatly affected whenever repairs along the road become a must.

9.0 Recommendation

Under the present circumstances we are making recommendations to the present officials of the Bafut and Befang Councils who are currently on the ground and to the government for long term solutions which can be applied for the entire region and other parts of the country.

The Council officials;

- Must improve on their documentation and skills to monitor rainfall
- Must put in place an emergency plan to go operational in the event of a major landslide and an agreed procedure for moving goods and persons while the crisis lasts.

- Must always sensitize the local population on landslide hazard and associated risks.

- Can put in place and implement a policy of periodic closures of the road especially during intense rainfall

The government should;

- Establish a distinct and recognizable road authority made up of scientists, engineers, decision makers, technicians and support staff.
- Provide for its work an adequate and easily accessible facility equipped with documentation; technological instruments, laboratories and necessary heavy duty machinery
- Ensure that the staff of the road authority must always have an expert responsible for disaster response management and a materials geo-technical engineering properties engineer / expert.

Once in place the road authority would be called to;

- Ensure continuous training and research, collection, interpretation , dissemination and archiving of information
- Liaise with other competent bodies to ensure constant investigation of sites of high instability and real time monitoring of rainfall.
- Establish an emergency plan to go operational in the event of a major landslide and an agreed procedure for moving goods and persons while the crisis lasts.
- Always carry out sensitization campaigns and capacity building workshops and seminars to create a society that in fully aware of landslide hazard in particular and environmental issues in general. This will go a long way prepare the population to contribute positively in case of emergency.
- Train the local people on how to use bioengineering technics in slope stabilization

The government should encourage further studies in landslide hazard, susceptibility, vulnerability, risk and rainfall modelling and management for the area and the entire region as well as in the use and applications of satellite imagery.

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