THE CATASTROPHIC GEOMORPHOLOGICAL PROCESSES IN HUMID TROPICAL AFRICA: A CASE STUDY OF THE RECENT LANDSLIDE DISASTERS IN CAMEROON.

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INTRODUCTION

Located at the interior of the Gulf of Guinea, Cameroon extends from Latitudes 2° to 13° North and Longitudes 9° to 16° East. Better known as Africa in miniature, this country is characterised by the large diversity of its natural setting: relief, climate, vegetation, soils and geology etc.

Within the last three decades, Cameroon has experienced a number of catastrophic mass movements. These include rock fall, landslides and mudflows, both in the rural and urban areas. Examples of these scenes in urban areas occurred in 1989, 1992, 1996, and 2001 at Limbe, 1978, 1985, 1986, 1990 and 1998 at Yaoundé in 1998 at Nkongsamba, and in 2003 at Poli amongst others. In rural areas they were registered at Fossong Wetcheng in the Dschang area in 1987, Pinyin in 1991, Bafaka in 1993, Melong area in 1986, Kribi in 1987, Awae in 1998, Nwa in 2000 and Wabane (Magha and its neighbourhood) in 2003.

In many cases, these events have caused enormous damages, notably on human lives, houses, agriculture, equipment and different infrastructures.

A retrospective survey of this phenomenon indicates a net increase in their occurrence and magnitude. These are not only more and more frequent, but also increasingly severe in terms of their extent and the damage caused. One can therefore raise the following questions: Why is there an upsurge in the occurrence and magnitude of land mass movements in Cameroon?

AN OVERVIEW OF CATASTROPHIC MASS MOVEMENTS IN CAMEROON WITHIN THE LAST THREE DECADES.

In the course of the last three decades, precisely from 1978, about thirty known catastrophic landslides have been recorded in Cameroon, leading to the loss of some 128 human lives. This figure may appear less significant when compared to that from other calamities like AIDS, malaria, or traffic accidents that plague the African continent as a whole. When one however includes the immense damages caused in material form, often associated with these movements and above all, the net increase in the phenomenon, this therefore becomes a real matter of concern.

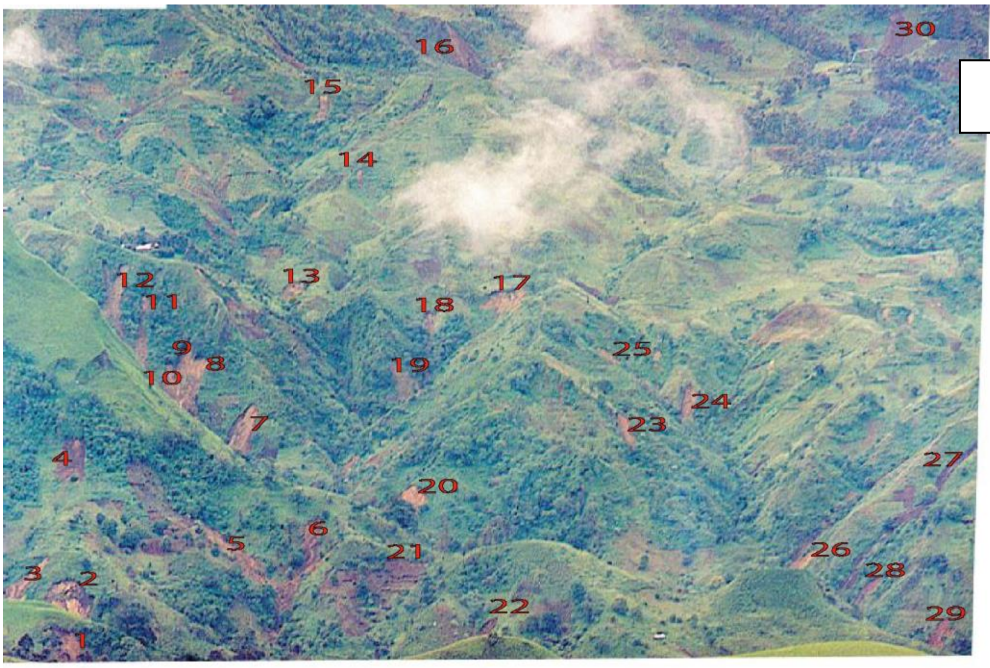
A) <u>Frequency and Trend of the Phenomenon</u>

An analysis of the frequency and magnitude of landslides and mudflows in Cameroon make it obvious that the phenomenon is on a net increase.

A total of seven known landslides were recorded during the 1978-1987 decade. From 1988 to 1997, the number recorded almost doubled, with twelve more cases reported. From 1998 to 2003, in only six years, seven cases were observed, with five of them taking place in a single year-2003.

This rate of occurrence may be higher if one considers the number of landslides registered per scene. In fact, landslides are becoming more frequent and affect progressively larger areas. This general trend manifested itself in the landslides that hit Limbe in 2001. In this specific case, more than thirty scares could be counted, while in the case of Magha and its neighbourhood in 2003 several hundreds of scares could be counted, stretching over a few square kilometres.

Photo_1



Panoramic view of a section of Magha in the Bamboutos caldera. *Cl. A. ZOGNING*

About more than 30 scares of landslides can be observed.

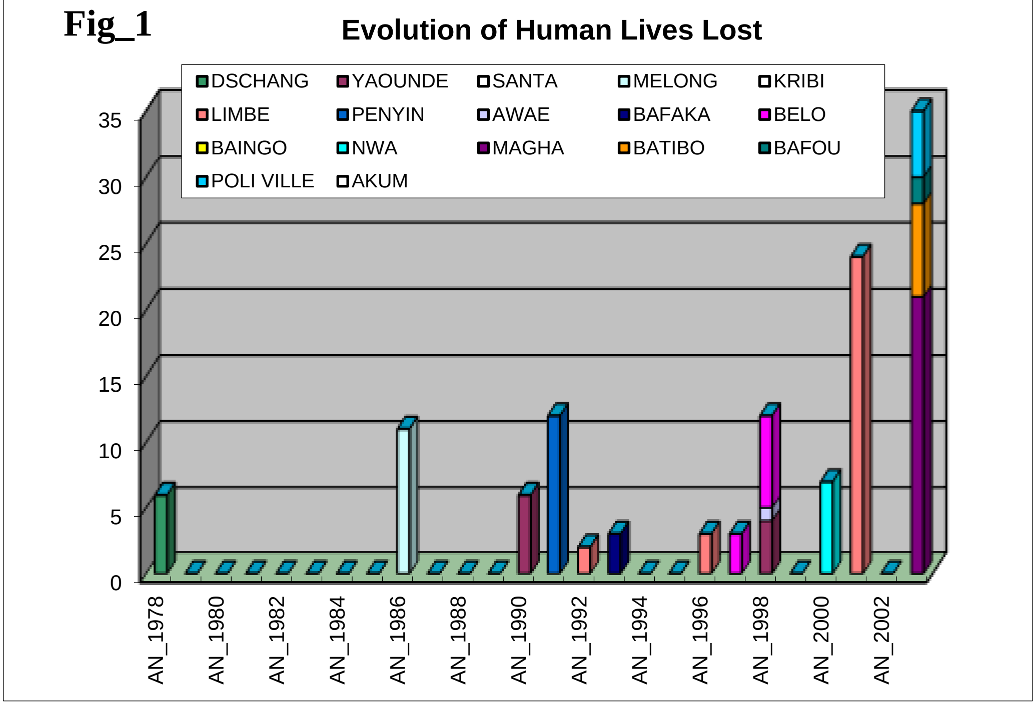
These landslides lead to more and more significant consequences. Two main indicators enable a better appreciation of this importance. These are losses in human lives and material damage.

Losses in Human Lives

A total of seventeen out of twenty-six landslides recorded during the period led to losses in human lives. Their distribution over time is an eloquent proof of the tendency for the number of people affected to grow exponentially (Fig 1)

During the first decade (1978-1987), two deadly landslides were recorded: the Dschang landslides that resulted to six deaths and those of Melong which claimed eleven lives. Within the second decade (1988-1997), six deadly landslides were recorded out of which twenty-eight people lost their lives. In the middle of the third decade, (1998-2003, i.e. six years) there were already eighty-two deaths recorded, out of which thirty-five deaths (42.7 per cent) occurred in 2003 alone !

Fig_1



B) <u>Material Losses</u>

With regards to material damages incurred, the losses can be evaluated at several tens of US dollars. These include:

- The total or partial destruction of more than 700 buildings including residential houses, churches, school and administrative establishments, etc. rendering more than 2500 people homeless and thousands displaced to new localities.
- The total or partial destruction of tens of bridges
- The sweeping away of thousands of hectares of plantations or parcels of food crop farms.
- The deaths of several hundreds livestock, made up of cows, pigs, goats and sheep…

Apart from human lives lost, most of the damages reported here were recorded during the first six years of the third decade, especially during the catastrophes of June 2001 in Limbe and July 2003 in Magha and its environs.

An important question to be asked thus, is: why this phenomenon has increased in intensity?

The landslides and mudflows observed in Cameroon are of different types and vary from one place to another depending on the causes and factors in operation. Two major groups of causes and factors can be distinguished:

- Remote causes responsible for the vulnerability of the physical milieu
- Immediate causes or opportunistic factors

II- REMOTE CAUSES

These are mainly the topography, geology/pedology and hydrology, which determine the degree of susceptibility of the milieu to rock falls, landslides and mudflows.

A) <u>Topography</u>

Topography is characterised by the degree of ruggedness of relief and the slope gradients which determine:

- The level of material instability due to gravity;
- The speed and type of flow of dislodged material and,
- The types of deposits or sediments.

In Cameroon, the relief of many regions is susceptible to mass movement. This is particularly the case of:

a- The highlands of the Cameroon volcanic line, a chain of mountains which is more or less deeply dissected, often with more or less steep slopes. These include the mount Cameroon massif, the Rumpi Mountains, Manenguba, Bamboutos, Oku, Tchabal Mbabo and Ngandaba etc.

b- The isolated massifs rising above plains and plateaux such as the Mbam Minkom massif in Yaoundé, those of Yoko, Mbam and Poli amongst others.

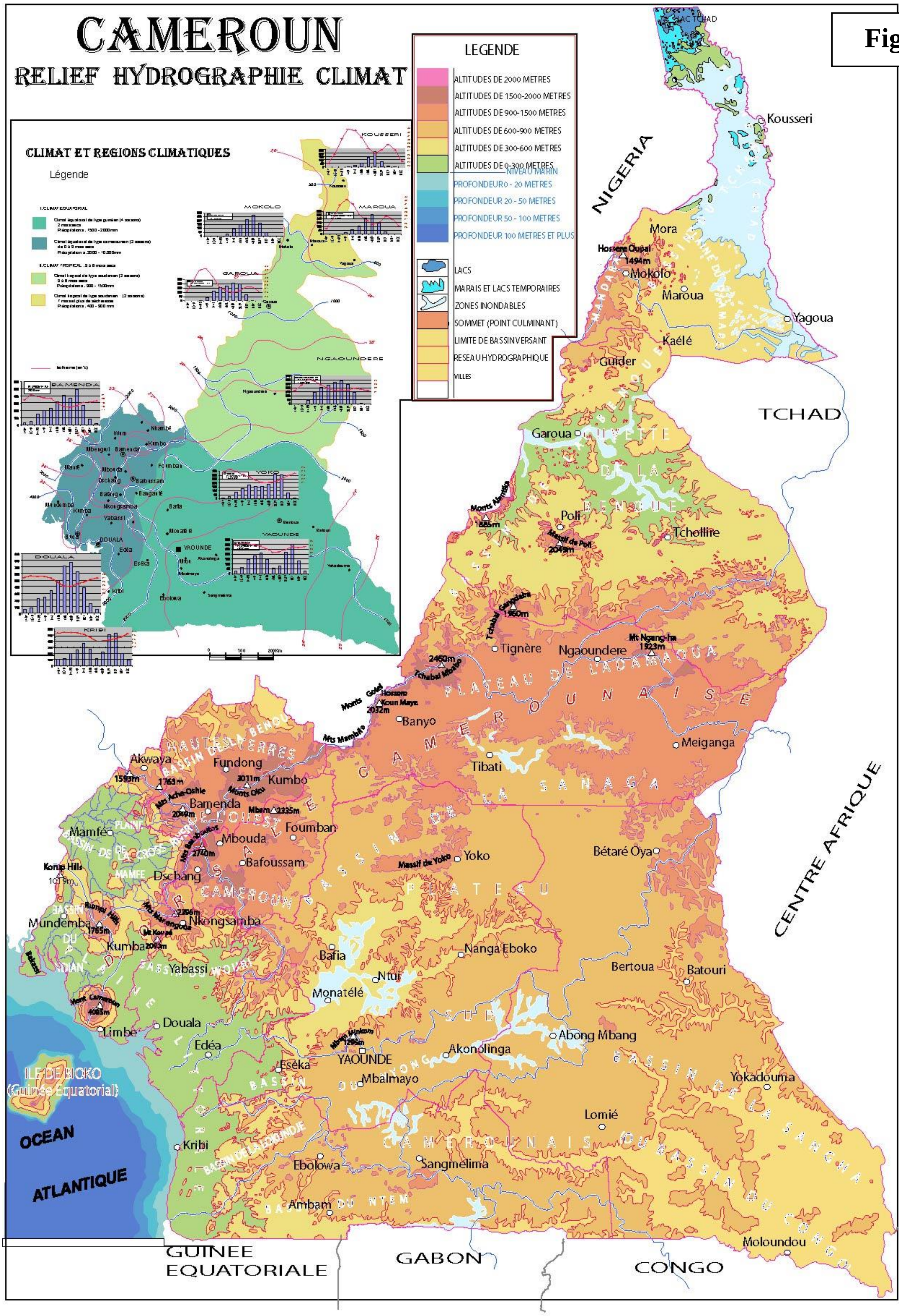
c- The South Cameroon plateau region with the half-orange topographic model characterised by convex-concave slope profiles amenable to landslides especially in urban areas.

B) Geology

The wide variation in relief is the result of a complex geological basement, characterised, according to the location by:

- The intense tectonic activity, which has broken the country into a multitude of compartments. Some of these compartments, such as the Western Highlands and the Adamawa, have been greatly uplifted;
- The pre and post tectonic intrusions which have built up numerous plutonic massifs rising far above the surrounding plains and plateaux.
- The volcanic eruptions which have formed vast basaltic plateaux above which rise volcano-tectonic complex like the mounts Cameroon, Rumpi, Manenguba, Bamboutos and Oku, etc.

Fig_3



Besides its influence on the relief, the geological basement combined with the diversity of climates and paleo-climates, have resulted in the formation of soil types which are more or less susceptible to mass movements. This susceptibility depends on the soil structure, soil moisture and soil depth. Thus depending on the relief conditions (slopes gradient), the vulnerable soils are characterised by:

- A porous upper layer with loose particles and thickness varying from few decimetres to several metres, which allows high level of infiltration and a high capacity to hold back water.
- An impermeable interior layer, resulting either from clays (for mature soils) or from the parent rock (for young and predominantly mineral soils) which reduces the water holding back capacity, causing rapid over saturation, depending on the thickness of the soil, the duration and intensity of the triggering factors (rainfall, and earth tremors).

III- THE IMMEDIATE CAUSES OR TRIGGERING FACTORS

The immediate causes or triggering factors are those responsible for the process of slope instability and mass movement. These involve rainfall, seismic activity and human action.

1) The role of excess rainfall in landslides and mudflows generation in Cameroon

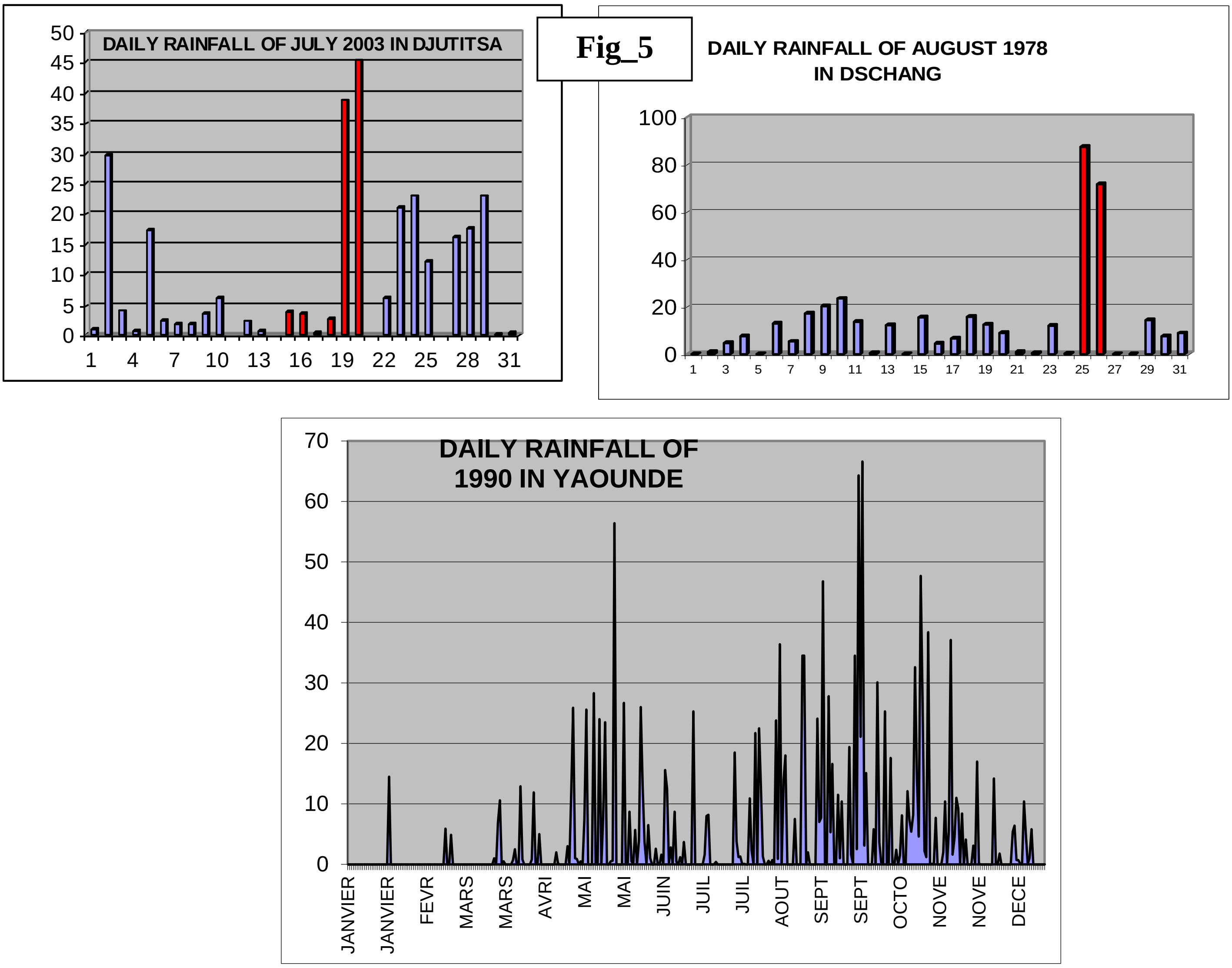
Because of the important role played by water in the processes leading to landslides and debris flows, the abundance, intensity, duration and frequency of rainfall determine the critical thresholds for the saturation of soils and the volume of runoff responsible for the rapid and intense erosion that affects slopes.

This was the case with the series of landslides and mudflows of the nights of the 25th and 26th of August 1978 in Dschang and its neighbourhood, which were caused by a sequence of rainfall events with a total of 159.3mm recorded, representing over 41.3 per cent of the total monthly rainfall in only two days. In the neighbouring Mbo plain, this rain caused severe floods… (Tchoua F. M. et al. 1983).

In the same vein, concerning the July 2003 disaster in Magha and its neighbourhood, the population of the area observed that there was an exceptional and an unprecedented amount of rainfall between Friday the 18th and Sunday the 20th of July around the Bamboutos mountains. Many people who have lived in the Bamboutos caldera for well over 40years and one sexagenarian (resident in Mbouda) confessed that they had never witnessed such a heavy and prolonged rainstorm event. This, therefore suggest that such rain were coming up after half a century (50 years).

The observations drawn from the Djutitsa agro-meteorological station, located not far from the site of the catastrophe of 20th July 2003, attempts to confirm these declarations of the local population. Though located at the leeward side of the caldera, the most hit area by the landslides, these data (fig 5) just paint a picture of the sequence of two days of continuous rainfall amounting to 84.2mm, i.e. 30 per cent of the total monthly rainfall of the station.

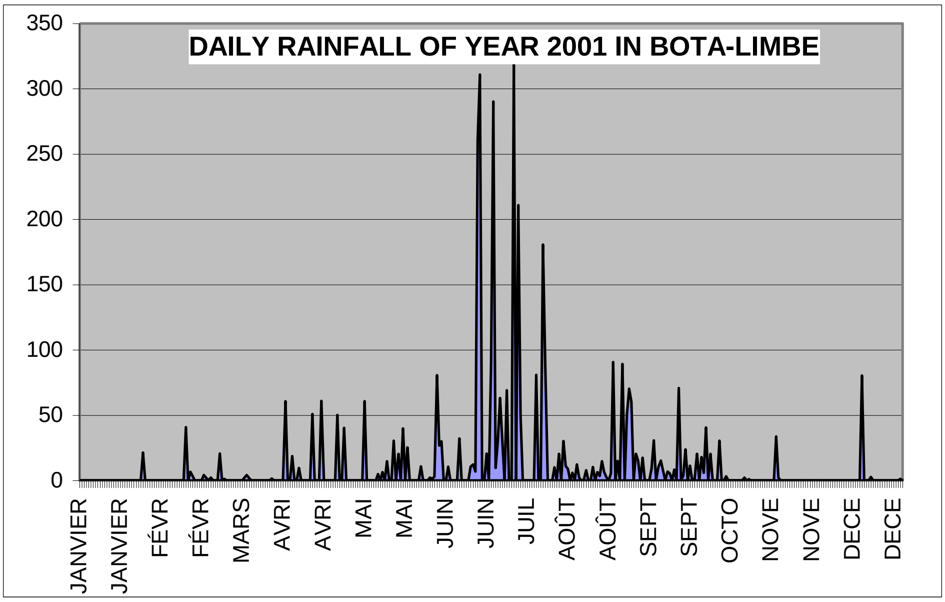
Fig_5

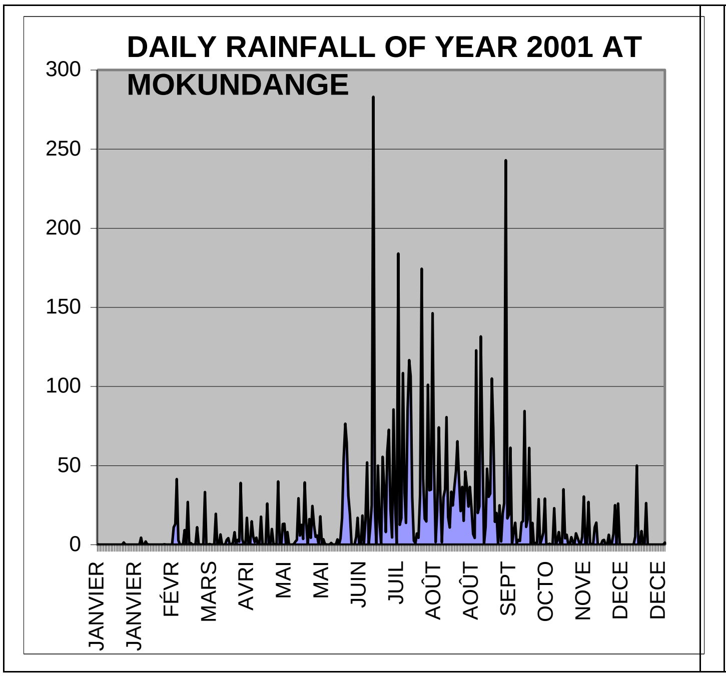


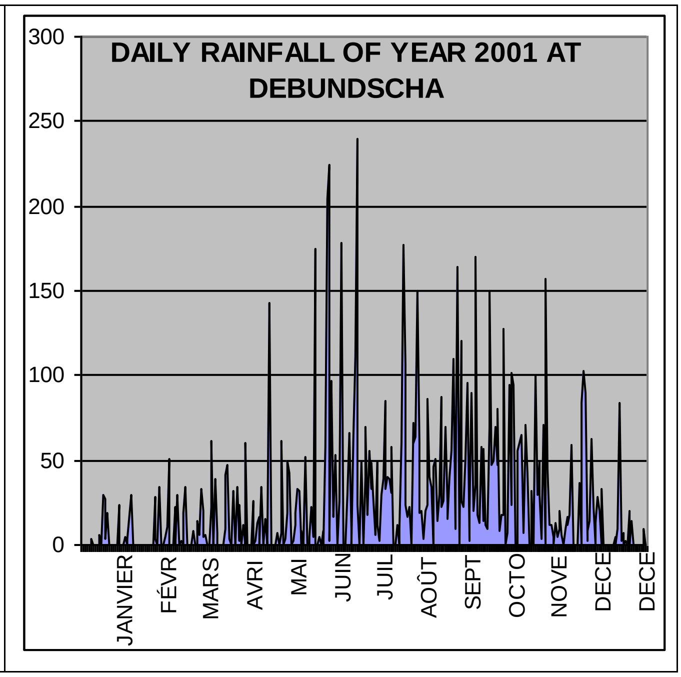
The most glaring examples are:

- The case of Oyomabang mudflow of 25th September 1990 in the outskirts of Yaounde, with a rainfall amount of 101.3mm in three days, of which 64.3mm fell on the day of the catastrophe, and especially,
- That of the landslide and mudflows of Limbe on the 27th of June 2001. The records of the network of the agro-meteorological stations of the Cameroon Development Corporation (CDC) show abundant rainfall with a mild displacement over time at different stations between the 26th and 27th of June 2001 around the affected area:
  - 571.3mm at Bota (a station based in the town)
  - 308mm with 283mm for the 27th of June, the day of the catastrophe at Mokundange, a station situated some 3 km to the north of the town;
  - 350.6mm with 240mm for the 27th at Debundscha, a station situated about 15 km to the west of the town.

Fig_6







2) Rainfall deficit and increasing vulnerability of the physical environment to landslide

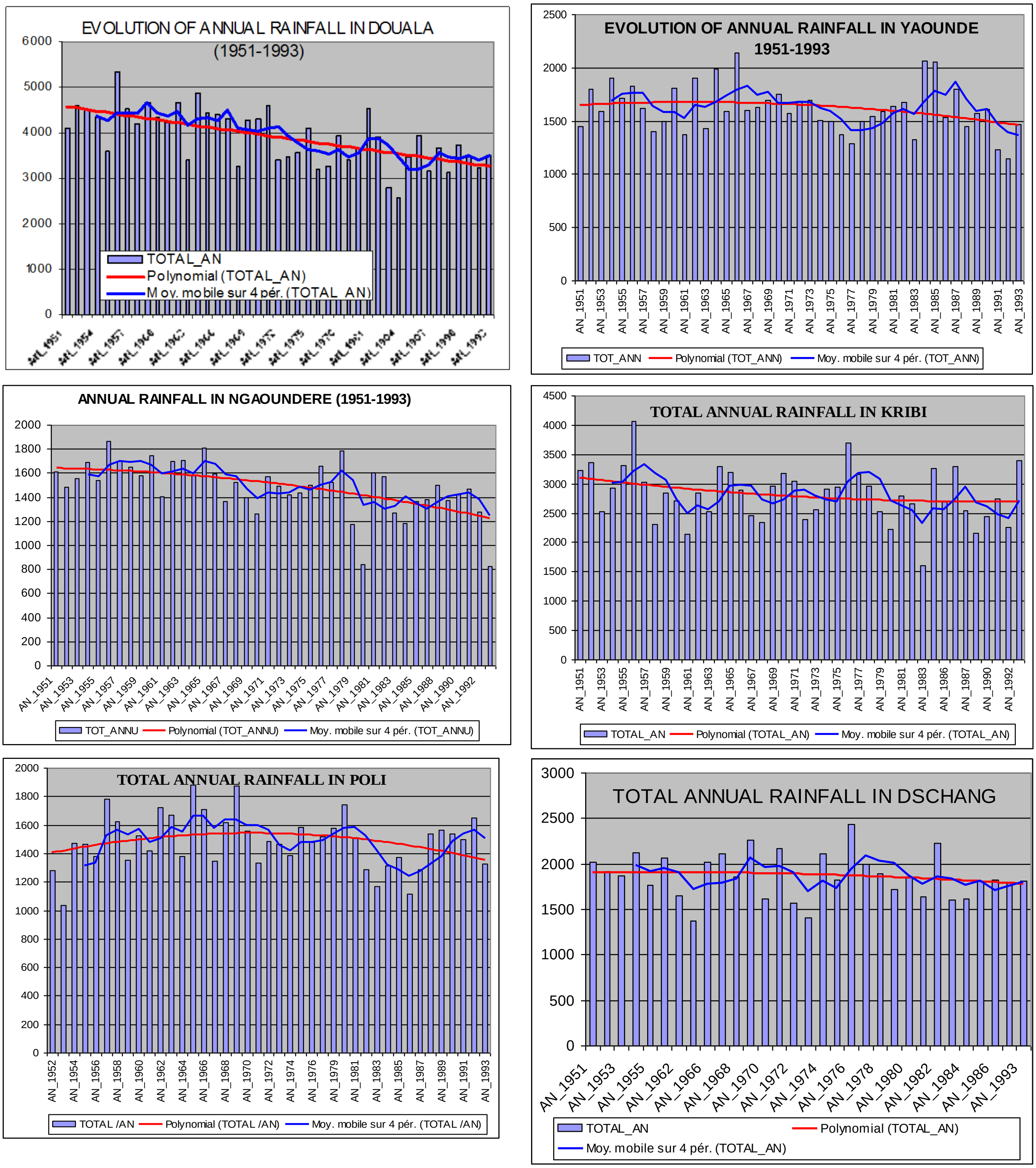
As seen above, rainfall is the prime triggering factor of mass movement in Cameroon. The upward trend of this phenomenon may suggests a significant contribution of this factor. In order to understand the true picture of the situation, six weather stations, fairly well distributed in the affected zones, were selected (the Western and the Adamawa Highlands, the South Cameroon plateau and the coastal area). Analyses covering the period from 1951 to 1993 (43years) are centred on:

- The total annual rainfall (for the eight stations)
- The maximum daily rainfall (in two key stations).
- Frequency in terms of the number of days of rainfall.

a) Total Annual Rainfall

Contrary to the hypothesis that the multiplication and increase in magnitude of catastrophic mass movements in Cameroon are justified by increase in rainfall, an analysis of the evolution of the climate, rather portrays a generalised tendency for rainfall to reduce in the six stations studied.

Fig_7



This is glaringly obvious in the cases of Douala and Kribi (Littoral) and that of Ngaoundere (Adamawa), with an average rainfall deficit ranging from 1000 to 1200mm for the first and second, and 300 to 400mm for the third station respectively. The other stations have witnessed significant deficits. This is the case of Yaoundé with about 250mm and Dschang with 100mm among others.

The question then arises over the relationship existing between rainfall deficit and the increase in the number and/or magnitude of mass movements. In other words what are the characteristics of this deficit and eventual incidents on mass movements? The time scale was therefore changed to enable daily data analysis.

b) The Maximum daily rainfall

For the maximum daily rainfall, two key stations, Yaoundé and Douala are taken as case studies. The rainy days are classified, according to the maximum rainfall received, into five categories:

- more than 100mm,
- between 50 and 100mm,
- between 25 and 50mm,
- between 10 and 25mm and,
- less than 10mm).

A remarkable deficit is then observed at Douala, especially at the level of the highest category (above 100mm); therefore the polynomial curve indicated an average rainfall deficit of about 25mm during the period. It is the same for Yaoundé where, all things being equal, the category with rainfall over 50mm had an average deficit of 5 to 7mm.

The lowest categories (less than 100mm for Douala and 50mm for Yaoundé), are fairly constant. The deficit, therefore, affects mostly heavy rainfalls, those capable of triggering mass movements. Without doubts, the factors responsible for the increase in the frequency and/or magnitude of mass movements are different and obviously related more to the frequency of rainfall.

c) Frequency: Number of Rainy days

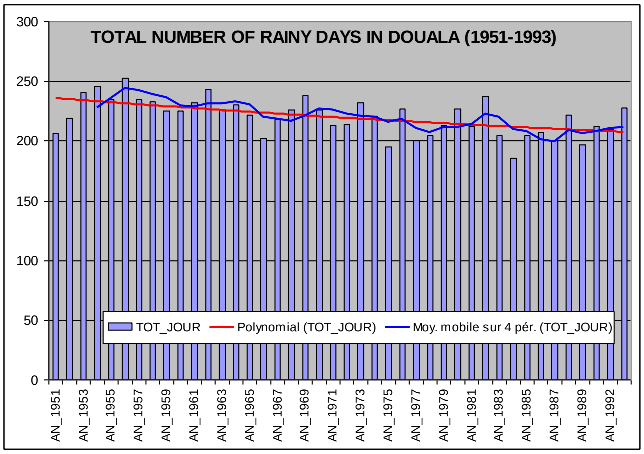
Statistical analysis of the number of days of rainfall portrays the general tendency towards a decrease, with an average deficit of close to 25 days a year in Douala and 16 days in Yaoundé. The monthly distribution of this deficit shows that:

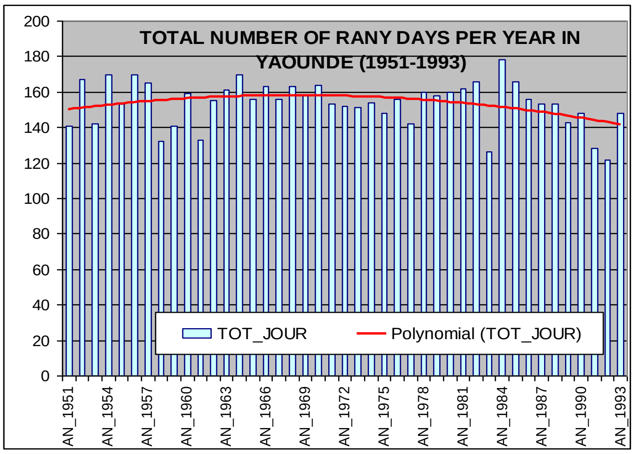
- In Douala, the decline is general, except in April and August. The most affected months are: January and February (with -4 to -5 days), July and November (with -3 to -4 days.)
- In Yaoundé, the evolution is a bit complex, with a tendency that portrays a more or less decrease for nine out of the twelve months of the year, and a remarkable increase for the remaining three months i.e. May, and especially July and August with +2.5 and +4 rainy days respectively. Like in Douala, the months at the start of the rainy season (February and March), and those at the end (October and November) more or less experience high deficits.

At a seasonal scale, this evolution portrays a tendency towards the "tropicalisation" of the climate, characterised by:

- Rainfall deficits during the months of January and February, October and November, which testify a very long or harsh dry season and,
- Rainfall excesses during the months of July and August which, in the Yaoundé area, re-enforce the rainy season and tend to eclipse the short equatorial dry season.

Fig_8





If mass movements in Yaoundé can more or less be justified by the surplus rainfall recorded in the months of July and August, the impact of the deficit on this phenomenon is not evident and may be indirect !

d) The Impact of Rainfall Deficits on the Evolution of Mass Movements

Evidences of rainfall deficit confirm the hydrological consequences of drought, which are more or less catastrophic for the population and the economy of Cameroon.

Hydrologically, these consequences are manifested by a fall of water input into the soil, resulting to the depletion of ground water reserves, leading to a pronounced drop in stream or river discharge.

These low discharges, which are very acute in the Bamboutos Mountains today, are vivid evidences of the profound decline in ground water, whose consequences are, the development of a network of crevasses that destabilise the cohesion of the soils, exposing them to mass movements, in case of heavy rainfall.

A) <u>Seismic Activities</u>

Seismic manifestations destabilise the soil and often trigger mass movements. These can act as their initial or secondary causes. In actual fact, because of their vibrations at more or less high frequencies, earthquakes may result to mass movements. Many unstable zones, that are prone to this phenomenon as those described above, are mechanically destabilised and pulled out by the violent shocks to which they are subjected. That is the case of the rotational slips, in form of Panamanian faults as described by Kueté M. et al. which were caused by the earthquakes of the 4^{th}, 10^{th} and 17^{th} of September 1987 at Kribi, in the southern coastal part of Cameroon.

After the landslides of Limbe in 2001, Magha and its neighbourhoods in 2003, no earthquake capable of triggering a landslide in these zones was recorded. Meanwhile, shallow micro-seismic activities can be envisaged as secondary causes. If one considers the huge amounts of debris involved in the movements and the revelations of the population, (the hearing of a loud noise from the mudflows), it can be accept that superficial and local micro-seismic activity was generated. Within the context that is characterised by generalised instability and the morphological conditions mentioned above, micro-earth tremors provoke vibrations and liquefaction of masses of soil, and consequently lead to their pulling out and flow.

Well known in seismology, this phenomenon, which consists of softening the soil which is more or less saturated, by the mechanical destruction of their particles structure, which mixes with interstitial water to form a more or less liquid mud, ready to pull off and flow, if the configuration of the slope is favourable. In addition to heavy and continuous rainfall, the numerous combined landslides that occurred in Limbe in 2001 and in Magha in 2003 can therefore be explained by the fact that the first movements generated vibrations which provoked secondary landslides in the immediate vicinities.

B) <u>Mechanical erosion by mudflows</u>

The analysis of the spatial distribution of these combines landslides indicates that a good number of slides result from the sudden erosive action of the mudflow. This is notably the case of the scars located along the flow corridors to which they directly converge. In fact, because of the huge volume of material transported, the rocky composition of debris and the power involved, considerable abrasion is exerted on the flanks of the valley. This results in instantaneous mechanical erosion that cuts away and destabilises the flanks of the valley, leading to subsidence and a series of rock falls and landslides, which increase the amount of material flowing.

Photo_2

Mechanical action of mudflows Downstream of the 14 Deaths Site

C) <u>Human Action</u>

1) Anthropogenic factors of environmental vulnerability in rural areas.

Because of the increase in population and rate of economic, social and cultural development, human pressure on the environment has considerably increase in recent years in highly populated areas. This is typically the case in the Bamboutos mountains, which have witnessed a large volume of return migration since 1985 (birth of the economic crisis).

From close observation, a good number of landslides recorded, start from farming areas. This clearly indicates the impact of agriculture as an anthropogenic factor. In fact in most cases, these landslides often affect the thin uppermost layers under cultivation. These are recognised by the dark colour of the scars and flow corridors. This colour is caused by the type of material being carried-dark humus soils. The question therefore arises as to what is the relationship between agricultural activities and landslides?

The relationship resides on the modification of the capacity of the soil to sustain its water balance. This modification is explained by three main factors, namely:

- <u>**The destruction of the vegetation cover**</u> which increases the runoff and consequently the erosive capacity of water (torrents) which removes and destabilises entire soil sheets, exposing them to slides and flows, if the least favourable conditions are met.
- <u>**The destruction of the cohesion of the soil**</u> by weeding, which weakens the surface layers, making them more permeable than the deeper ones. In case of heavy rainfall

like that of the 18th to the 20th July 2003 in Magha, the upper layers are more rapidly saturated to beyond their threshold, than the deeper and unwedded layers. A discontinuity plane rapidly develops between the two layers, and easily becomes a sliding plane, if the least favourable slope conditions are fulfilled.

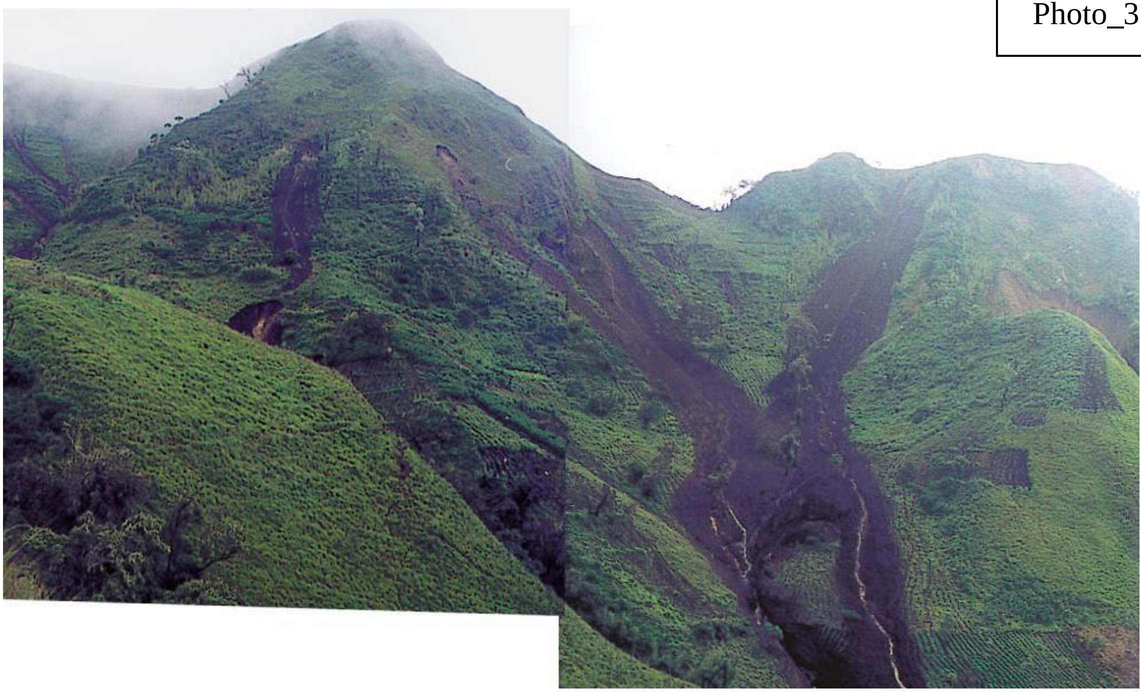
Being the case observed in many farming areas, the role of the human factor in these slides is obvious.

- **The practice of ridging across the slope.** This system is recommended for erosion reduction on mountainous areas, marked by steep slopes. Nevertheless, this is efficient only to a certain extent and thereafter, becomes more or less dangerous.

The anti-erosive role of this system consists of constructing ridges perpendicular to the slope, in such a way that they retain the most of the rain water behind them. This then limits runoff, which is the main agent of transport of soil particles, notably those loosened and weakened by weeding. The water trapped then has time to infiltrate to increase the amount of ground water store.

Unfortunately, in times of prolonged and/or heavy rainfall, the retentive capacity of the ridges may become insufficient, in which case water overspills, flowing downstream, destroying and carrying along, a more or less significant part of the ridge. This may be the starting point of a flow, which can become widespread from up to downstream, degenerating into a real mudflow that clears away everything on its path.

Photo_3



Cl. A. ZOGNING

2) Anthropogenic factors of environmental vulnerability in urban settings.

Urbanisation in Cameroon, like in most other African countries, is very high, with an average annual rate of 6 to 8 per cent. The populations of Yaoundé and Limbe, the most affected towns in Cameroon by mass movements, increased from 60 000 in 1957 to more than 1 500 000 in 2002 and from 16 000 in 1964 to about 100 000 in 2004 respectively. This rate, which varies from one town to another, indicates a more or less high pressure on the environment. This is manifested by the spatial expansion of the town towards risky zones such as hillsides, marshy areas or flood prone areas. The consequences of this pressure are twofold, involving the destabilisation of the slopes and risky settlements.

The destabilization process on slopes, due to human action, is double and includes a mechanical process of man direct intervention and a process of indirect intervention by gulling.

a) Mechanical slope destabilisation

This results from civil engineering activities, which involve important excavations on the flanks of steep hill sides with gradient above 20° or even more than 45°. This is the case of slope cutting for road construction and laying of rails, more or less deep excavations for building and other installations.

This construction constitutes a serious threat to slope stability, especially when the cuttings reach the weathering front or the zone of intermittent saturation, which is well known as a “soap – layer”, a slippery zone which facilitates the sliding. The upper layers having lost their stability, can henceforth, begin moving down slope once the least hydrological or geophysical conditions are met.

Most of the mass movements observed in Yaoundé and in Limbe, are a result of this process.

b) Indirect Destabilisation, by Gulling

Indirectly, human activities induce another process of destabilisation that is gulling, which combines with mechanical action to increase slope instability. The spatial expansion and intensification of built up areas often associated with paved and metal surfaces, limits infiltration and significantly increases the rate of run off, and consequently the erosive power of water. The poor management of water from runoff leads to the formation of more or less deep gullies, which perpendicularly intersect the hill side cuttings, forming isolated sheets of earth material, which needs only a triggering factor to slip down slope.

Numerous hill slopes of towns in Cameroon in general, of Yaoundé, Limbe and Nkongsamba in particular, are thus destabilised, which justifies at least partially, the increase in frequency and/or magnitude of the catastrophic mass movements observed nowadays.

CONCLUSION

Finally, in the course of this study, it was observed that many causes and factors do lead to mass movements, but two major ones, however, stand out for the increase in and /or magnitude of these catastrophes. They are;

- Man, judging from:
    - His actions that destabilise the slopes and open the way for mass movements,
    - His poor perception /evaluation or misjudgement of risk,
    - His ill adaptation to risk and unpreparedness to contain it, which as a consequence, makes human and material losses inevitable.
- Climate, characterised by:
    - The steady downward trends of the rainfall amounts that do accompany
    - the temperature rise that entail water deficits, which more or less account for the profound readjustments, exposing the soils, and making them vulnerable to mass movements.

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