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The Debris Flow of 1st August 2012 in Kakpenyi-Tinta (Akwaya Sub Division) Southwest Cameroon—I: Event Description, Causes and Impacts

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Abstract

Compared to large-scale infrequent disasters like volcanic eruptions, earthquakes, and gas explosions from volcanic (maar) lakes, most small-scale everyday disasters (e.g., landslides and floods) are not well reported and documented in Cameroon, despite the fact that cumulatively, they cause the most casualties and distress to the people affected. This paper documents a debris flow that occurred on the 1st of August 2012 in Kakpenyi, a quarter found in Tinta, one of the villages of Akwaya Sub Division in Manyu Division of the Southwest Region of Cameroon. The event started from the western slope (06˚14.350'N & 09˚31.475'E) of a hogback in the settlement, and mobilized *ca* 3.47×10^6 m^3 of material over a *ca* 1 km distance. The material was made up of a chaotic mix of mud, rock fragments, boulders, twigs, tree logs, trunks, and roots. Its distal part dammed river Kakpenyi forming a 10 m deep lake which eventually safely emptied itself. No casualties were recorded but 20 people got injured and 21 people lost farmland. The debris flow was not caused by earthquake shaking. Instead, inappropriate land use acted as a remote cause to predispose the steep slope, while heavy rainfall triggered the flow. Verbal reports talk of a similar event 40 years ago in the area. This shows that Kakpenyi is vulnerable to this kind of hazard, requiring that major infrastructural development projects like roads and bridges in the area be preceded by detailed hazard and vulnerability assessments.

Keywords

Debris Flow, Kakpenyi-Tinta, Land Use, Rainfall, Debris-Flow-Hazard Evaluation

1. Introduction

Cameroon is located in Central Africa, extending from the Gulf of Guinea to Lake Chad (**Figure 1(a)**). It is divided into five geographic zones that mimic the main climatic and vegetation regimes of the African continent, thus the appellation "Africa in miniature". The disaster risk profile of Cameroon reflects its geography, geology and socio-economy. It is affected by and/or vulnerable to hydro-meteorological hazards (floods, landslides, droughts, sea level rise), geological hazards (volcanic eruptions, earthquakes, gas explosions from lakes), ecological hazards (locust swarms), technological or man-made hazards (urban fires, conflicts, industrial and transport accidents), and biological hazards (epidemics) (e.g., [1]). Most of the geological hazards in the country are linked to the existence of a geological feature called the Cameroon Volcanic Line (CVL, [2] and refs therein). Volcanic eruptions occur on Mt Cameroon in the southwest part of the country. It is the only currently active volcano on the CVL, and has erupted 7 times within the last hundred years, with the last 2 eruptions in 1999 and 2000 [3] [4]. Lava flows, ash fall, pyroclastic fall, mud flows, lahaars, rock fall and volcanic gas emissions are common threats posed by the volcano. Volcanic eruptions have destroyed private property and public infrastructure like bridges, communication lines, roads, rail lines and agricultural farmland. Landslides have killed at least 64 people every year for the past 30 years in Cameroon [5]. Devastating landslides have occurred in Melon, Yaoundé, Santa, Bafaka, Dschang, Belo, Limbe, Buea, Kemkem, Wabane and Bamanda [1] [6] [7]. Maar Lakes Monoun in the Western Region and Nyos in the Northwest Region of Cameroon were sites of catastrophic gas explosions in 1984 and 1986, which killed 37 (Monoun) and 1800 people and over 3000 cattle (Nyos). Lake monitoring studies showed that the killer gas in both lakes was magmatic carbon dioxide. The lakes are currently being degassed artificially [8] [9]. Floods are common in urban and rural areas and are on the rise in major cities. In 2012, three massive rain-triggered floods stroke the northern parts of Cameroon [10]. Floods have resulted in several casualties and a huge loss of property and misery especially by urban slum dwellers. Climate change-triggered fluctuations in rainfall patterns, poor urbanization and misguided waste disposal (dumping in water channels or undredged canals), are some of the common causes of inundation in Cameroon [1] [11] [12].

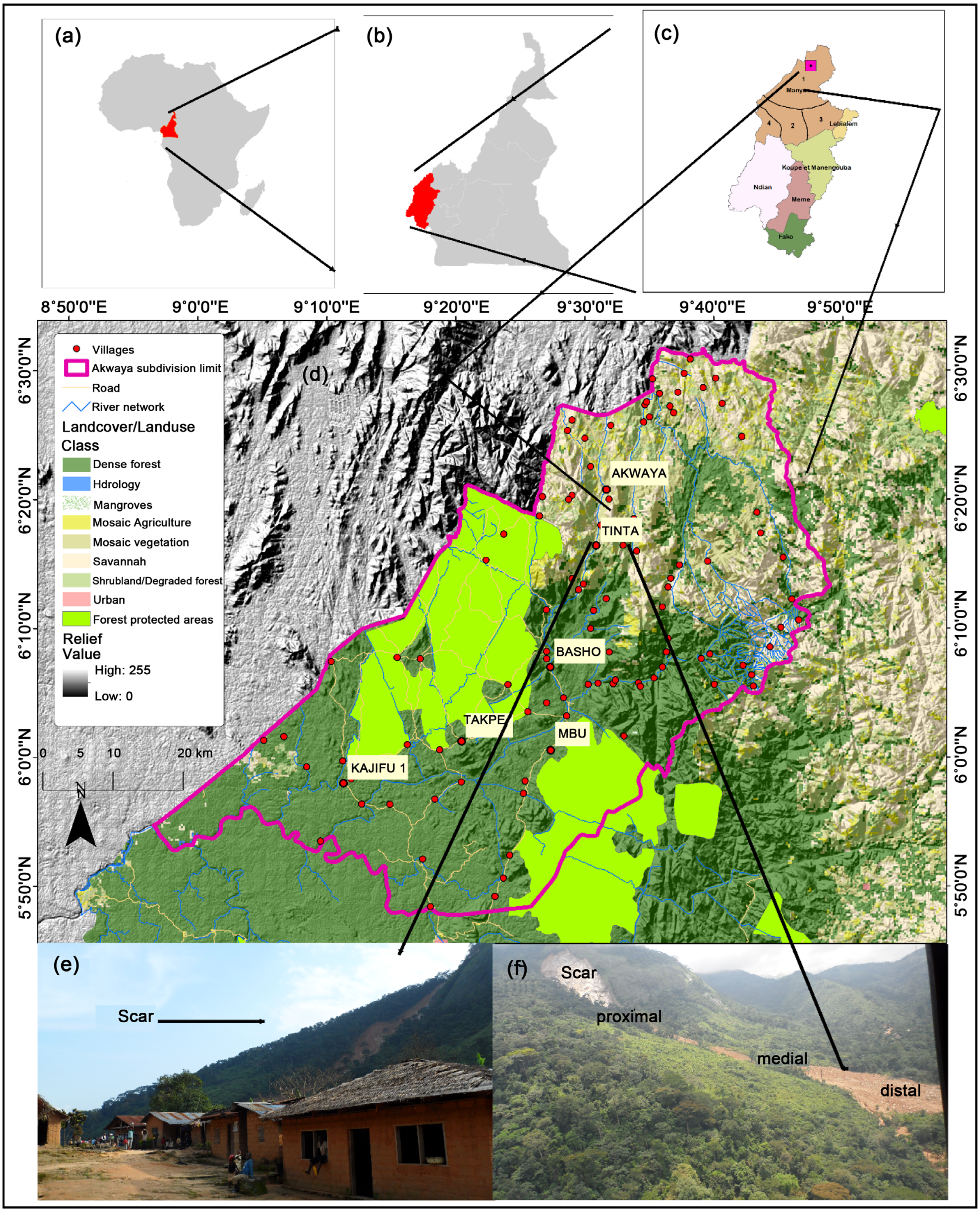

Figure 1. (a) Location map of Cameroon in Africa; (b) Location of Southwest Region in Cameroon; (c) Location of Akwaya Sub Division (1) as one of the 4 Sub Divisions (2 = Mamfe Central, 3 = Eyumojock, and 4 = Upper Bayang) of Manyu Division in the Southwest Region; (d) Akwaya Sub Division with location of Tinta village (red square in (c)); ((e) & (f)) Air photos showing Kakpenyi quarter (long arrows from d) and the debris flow with its proximal (scar), medial, and distal parts. The distal part terminates in the Kakpenyi River to the far right (see Figure 2(c)). Source: (a), (b), (d), (e) & (f) are this work, (c) is modified from [15].

Compared to large-scale infrequent disasters like volcanic eruptions, earthquakes, and gas explosions from volcanic crater (maar) lakes ([9], most small-scale everyday disasters are not well reported in Cameroon, despite the fact that cumulatively, they cause the most casualties and distress to the often very poor people affected [13] [14]. This can flaw the inventory and evaluation of economic impacts of disasters in the country particularly for landslides found in remote areas. This problem is compounded by the fact that the scars of these events are easily obliterated by erosional and depositional processes in the humid equatorial climate. This paper describes the debris flow that occurred in Kakpenyi, a very remote area in the Southwest Region of Cameroon (**Figure 1**).

2. Location, Hydrography and Geology of Kakpenyi, Akwaya

Cameroon is divided administratively into 10 Regions. Kakpenyi is a quarter of Tinta village in northwestern corner of Akwaya, one of the 4 Sub Divisions that make up Manyu Division of the Southwest Region. Akwaya is the Sub Divisional headquarters located 137 km from Mamfe, the Divisional headquarters. It is bordered by Nigeria to the west, Eyomojock, Memfe and Upper Bayang Sub Divisions (Southwest Region) to the south, and Widekum, Njikwa and Menchum Valley Sub Divisions (Northwest Region) to the east (**Figure 1(d)**, [15]).

Akwaya area has two major geographical features—dense forest and steep hills in the South, and savannah in the North. The Takamanda National Park and the Mone Forest Reserve are high value conservation forests in the south [16]. The northern part is grassland (**Figure 1(d)**), famous for cattle grazing. Kakpenyi is located at an altitude of 1300 m *asl* at the foot of one of the hills that peak at 2300 m *asl* (**Figure 1(d)**). There are many rivers, streams, and springs in the Akwaya area. Most of the rivers empty into the Cross River down to Nigeria and then into the sea. Although Tinta village is found at the head of Nkomon River which is an affluence of Katsina Ala in the Niger basin, Kakpenyi quarter (in Tinta) is located at the head of the Ebe River which is an affluence of Munaya in the Cross River basin.

The geology of Akwaya consists of old Precambrian rocks [17] [18]. Kakpenyi is built on highly folded and fractured migmatitic gneisses cut by numerous late E-W quartz veins and gneissic foliation planes (**Figure 2**). The fractures act as infiltration routes of rain water into the rocks that have been highly altered to give thick soils on which are planted cocoa, palm trees, cassava, groundnuts and rice.

3. Narrative of the Event

3.1. Report of the Akwaya Divisional Officer

The smallest administrative unit in Cameroon is the sub division, headed by the Divisional Officer (DO) who is the most senior government representative in the unit. Having been informed of the event on the 2nd of August 2012 by an envoy

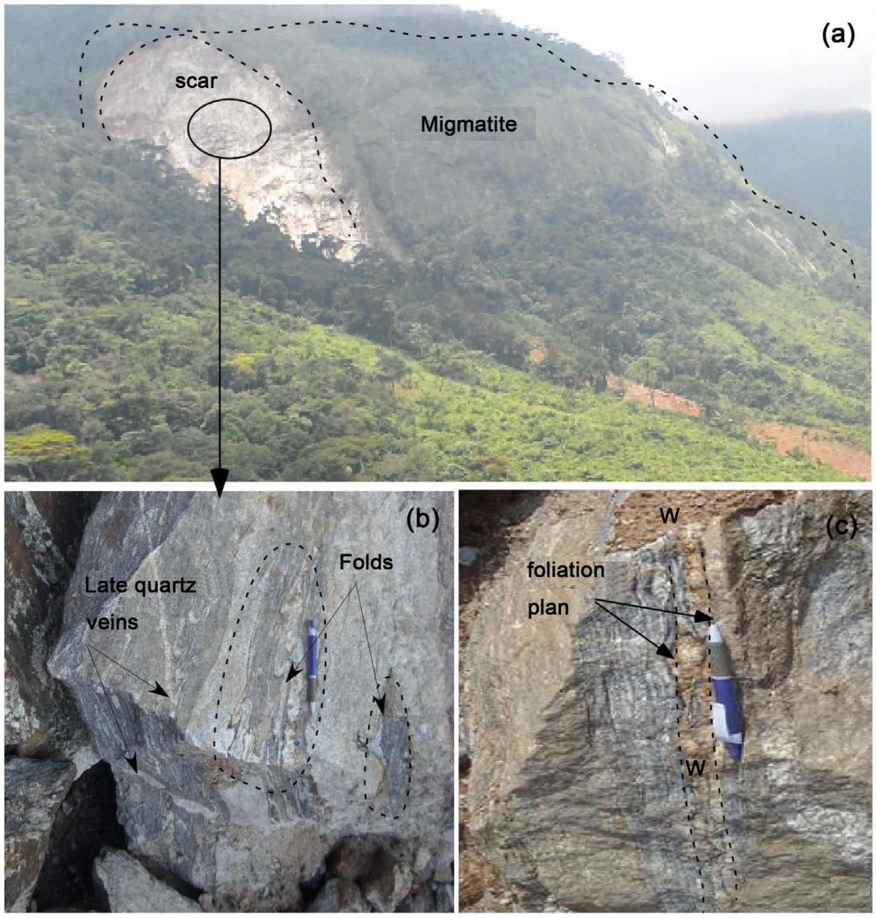

Figure 2. (a) Migmatite that forms the Precambrian bed rock of Kakpenyi. The migmatite is folded and contains late quartz veins (b) together with foliation planes (c) which facilitate infiltration of water as an agent of chemical weathering (w). The pen used as scale is 18 cm. Source: this work.

of the Chief of Kakpenyi quarter, the DO of Akwaya together with 2 gendarmes and a medical doctor trekked to Kakpenyi on the 3rd. From their observations and interviews with the local people, it all started on the 29th of July 2012 by ground rumbling similar to gun shots, followed by shaking from the nearby mountain (Figure 1(e)). This situation remained intermittent till around 4 PM on August 1st when villagers heard loud explosions from the mountain, followed by the collapse/detachment of rocks and soil from the western flank of the mountain. People who were working in their farms nearby heard the sounds and saw the mountain break loss. They fled back to the village. Some were injured by falling material and by walking across what they described as hot sharp debris of broken rocks. Luckily, no human or animal casualties were reported. Twenty people had injuries that ranged from bruises on knees, head and eyes, and 21 people lost farmland (palm trees, cocoa, cassava, plantains, groundnuts, pineapples, etc). As of the 3rd of August when the DO visited, activity had reduced to occasional detachment of blocks from the mountain, with the emanation of an odour that had the smell of rotten eggs.

3.2. Our Field Observations

3.2.1. How We Got Information about the Event

The Department of Civil Protection (DPC) in the Cameroon Ministry of Territorial Administration and Decentralization (MINATD) is in charge of disaster management in Cameroon. Having got news about the event, the DO of Akwaya reported to the Senior Divisional Officer (SDO) of Manyu, who reported to the Governor of the Southwest Region, who in turn reported to MINATD. MINATD informed the Presidency of the Republic. On the 9th of August 2012, the Secretary General in the Presidency sent a note asking the Minister of Scientific Research and Innovation (MINRESI) to render technical and other appropriate support to DPC in the investigation of the events in Kakpenyi. MINRESI contacted the Director of the Institute for Geological and Mining Research (IRGM) who immediately sent a team of 3 researchers and a driver to the field [19].

3.2.2. Materials and Methods

We took along materials to locate the site of the event (hydrographic/road maps, compass, GPS); make measurements (pH, temperature, conductivity, dissolved oxygen) and collect samples (water, soil and rocks). We got rainfall data for 8 years (1st January 2005 to 12 August 2012) from the Mamfe (Bissongabang) meteorology station. We took many pictures and interviewed the affected people.

The site (Kakpenyi) was visited on Sunday 12 August 2012 by a military helicopter from Mamfe, in a team of 15 people led by the Director of DPC, and comprising the DO of Akwaya, the SDO of Mamfe, the Inspector General in MINRESI, and experts from the Southwest Regional Departments of Health and Defense. The helicopter landed at Tinta after overflying the landslide area (**Figure 1(e)** and **Figure 1(f)**), and we trekked for 7 km (2 h 30 min) to Kakpenyi for site investigations. Our initial plan was to stay on site long enough for detailed studies and measurements. However, due to time constraints imposed primarily by the inaccessibility of the area, we had to return in the helicopter with the administrative and civil defense authorities, so we had only one hour to study the event. This work is therefore mostly qualitative.

3.2.3. The Event

Our field observations confirm the report of the DO. It was a flood surge that started on the western flank of the migmatitic mountain (06˚14.350'N and 09˚31.475'E) in the Kakpenyi settlement. The area of initial failure consisted of broken bedrock and a thick (*ca* 10 m) forested soil layer. The flow slipped down along a steep (*ca* 70˚) V-shaped valley carrying part of the forest with it. It then swept through farmland, growing in size by increasing its load that was made up of a chaotic mixture of mud, rock fragments ranging in size from clay, silt and sand, to huge boulders several meters in diameter, twigs, tree logs, trunks and roots (**Figure 3**). The flow moved down slope in a single wave and too fast for any sediment sorting to occur [19]. After moving for about a kilometer, it

Figure 3. (a) Proximal and upper medial parts of the Kakpenyi debris flow. The flow cut through farmland (F). Note the lateral levee; (b) Tree trunks and reworked logs in the medial part; (c) Lower distal part with dammed river that created a temporary lake. Source: this work.

stopped in a valley where its distal part dammed the river Kakpenyi forming a 10 m deep lake. Villagers picked life fish from the bed of the dammed river. We estimate that about 3.47×10^6 m^3 of material was mobilized. The surface (5 cm deep) temperature of the lake was 22.3˚C, and that of the clay material of the debris flow (5 cm deep) was 22.8˚C, not very different from ambient temperature (23.2˚C). Villagers reported that a similar event occurred in 1972 on the opposite side (eastern slope) of the same mountain facing Atolo village, but no casualties were recorded. No written records of this event are available. Since material forming the dam was not consolidated, water eventually eroded it away, gradually emptying the water behind the dam and thus eliminating any danger to downstream dwellers of a debris flow surge that could result from its eventual collapse [20].

4. Discussion

4.1. Was It a Landslide Or Debris Flow?

Scattered literature on mass movements in Cameroon is dominated by landslides [6] [7] and rock falls [21]. Even though debris flows are a form of landslide, they are distinguished from landslides by the fact that debris flows contain grains with greatly differing sizes and irregular shapes. They include mudflows which are debris containing mostly sand, silt and clay-sized particles; debris floods that are very rapid surging flows of water, heavily charged with debris in a steep channel; debris avalanches that are a very rapid to extremely rapid shallow flow of partially or fully saturated debris on a steep slope. They also differ from lahars that are volcanic mudflows [20] [22]. The consistency of debris flows ranges from watery mud to thick, rocky mud that can carry large items such as boulders, trees (**Figure 3**), houses and cars. A feature distinguishing debris flows from many other shallow flows is the presence of roughly equal volumes of diverse solid grains and incompressible, viscous interstitial fluid that interacts with the solids. Solid-fluid interactions and sediment movement by formation of lateral levees and lobes are important characteristics of debris flow behavior [23] [24]. Debris flow also differ from slides in that they are made up of loose particles that move independently within the flow, compared to a slide that is a coherent block of material that slides over a failure surface [22]. The sequence of events involved in the development of debris flows and its characteristic deposits is given by [23]. From our field observations, we consider the Kakpenyi event to be a debris flow because it contained a wide variety of particle sizes (incoherent), had levees and lobes on its medial part (**Figure 1(e)**), and had dewatered and consolidated enough to allow secure passage on foot only after a few days (**Figure 3**).

4.2. What Caused the Debris Flow?

Potential causes of the debris flow would be any of the factors that allow the force of gravity to overcome the resistance of earth material, *i.e.*, those that predispose the slope to failure. These could be 1) a volcanic eruption, 2) alternate freezing or thawing (snow melt), 3) earthquake shaking, 4) anthropogenic factors like inappropriate land use (fire, timbering and farming that destabilize hill slopes), and 5) moisture from heavy rain. Kakpenyi is located in the equatorial zone on crystalline basement to the far west and away from the CVL, so the first 2 factors can be eliminated. The other contextually relevant potential causes are discussed below.

4.2.1. Earthquake Shaking

Some parts of Cameroon are seismically active. Close to 40 felt tectonic earthquakes have occurred in and around the country within the last 165 years. The magnitudes (Richter scale) range from 2.6 to 5.7, and their intensities (Modified Mercalli) range from III to VIII [25]. Since 1984, IRGM has operated a network of seismic stations around Mt. Cameroon in the southwest Region to monitor the volcano. Eruptive activity is associated with the occurrence of volcanic earthquakes, some of which are strong enough to rock houses [3] [25]. Some landslides along the CVL were speculated to have been triggered by earthquakes [21]. Even though the Mt. Cameroon seismic network is eccentric to the Kakpenyi area and so cannot be used to accurately locate earthquakes there from, it does register earthquakes from other regions of Cameroon [21] [26]. However, seismic records covering the pre- and syn-unrest period of the debris flow (29 July to 3rd August 2012 in **Figure 4**), do not show earthquakes that could have emanated from the Kakpenyi area. The waves generated by noise and ground shaking during the unrest period, as testified by the villagers, would therefore have gotten attenuated before reaching the seismometers around Mt. Cameroon. We conclude that the debris flow was not triggered by earthquake shaking.

4.2.2. Anthropogenic Causes

Fire and tree felling that denude slopes of vegetation render them vulnerable to debris flows and landslides. The removal of vegetation by burning or timbering has 2 effects: 1) it removes the anchor that the tree roots have on soil particles, thus rendering them loose and easily erodible; 2) it deprives the area of rainfall-absorbing trees, thus increasing runoff and sediment removal. This reduces the threshold rain that can trigger a debris flow or landslide [27] [28]. Because of the remoteness of the area, not much of timbering activities are going on in Kakpenyi now. However, the people, all of whom are farmers, do use fire to clean their farms (**Figure 3**), so inappropriate land use like burning and farming on hill slopes could have, if only remotely, contributed in causing the debris flow.

4.2.3. Rainfall

The closest rainfall station in the same hydrological basin like Kakpenyi is the Bissongabang meteorological station in Mamfe run by the Cameroon Ministry of transport. We got rainfall data on this station from January 2005 to August 2012. Total rainfall for 7 years (2005-2011) was 19649 mm. Note that Debundscha which is found in the windward slope of Mt. Cameroon records 52% of this rainfall only in one year. The driest year (2005) recorded 2337 mm of rain; meanwhile the wettest year (2009) recorded 3232 mm of rainfall (**Figure 4(a)**). **Figure 4(b)** shows that May to October are the rainiest months of the year in the area, with a peak in July. Even though the total July rainfall for the 8 years shows that July 2012 was not the rainiest (**Figure 4(c)** inset), data for July 27 only, of each year from 2005 to 2012 clearly show that July 27 of 2012 recorded the highest (87 mm) amount of rain over the 8 years (**Figure 4(c)**). The first 26 days of

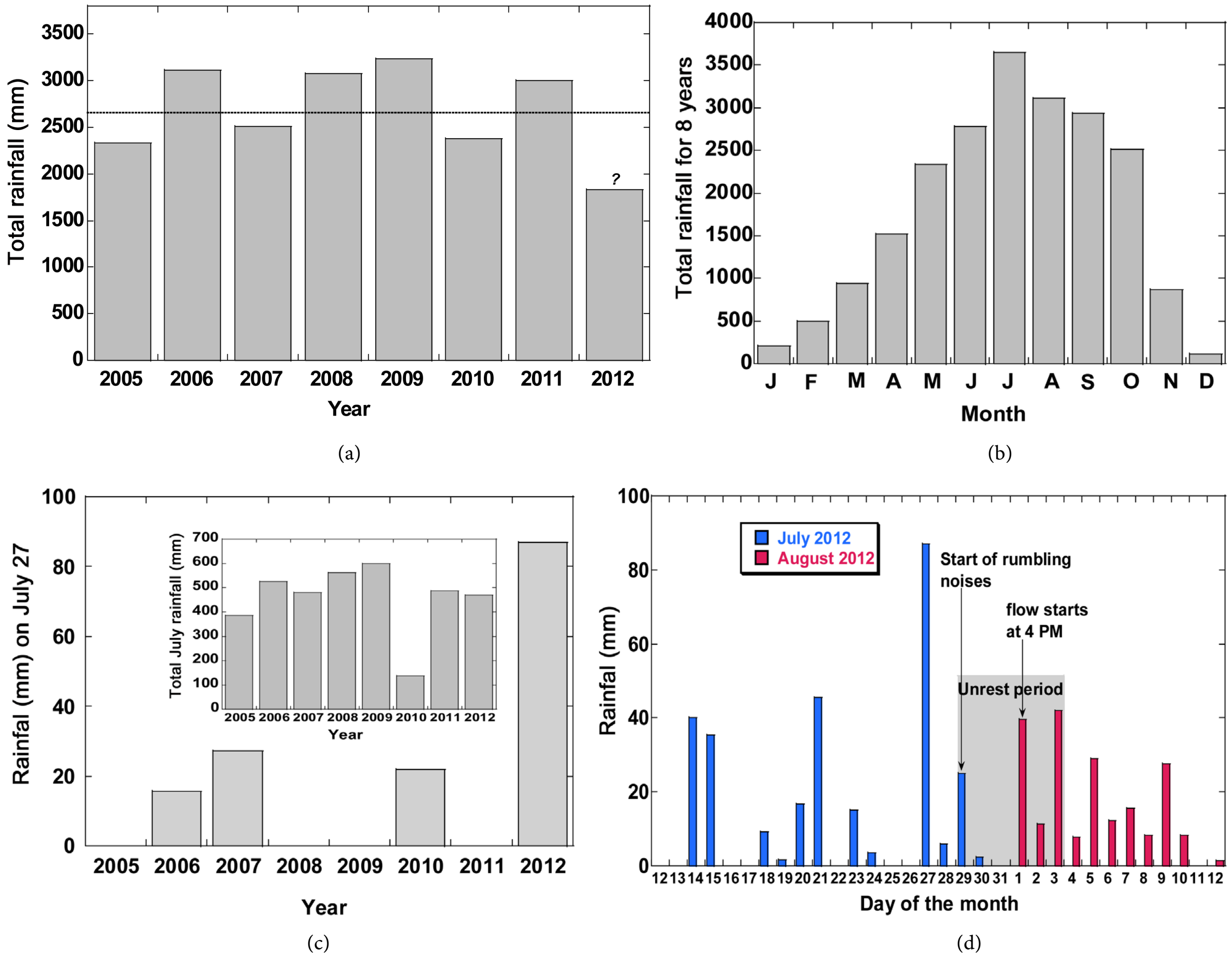

Figure 4. Distribution of yearly (a) and monthly (b) total rainfall for 8 years (January 2005 to 12 August 2012) at the Bisongabang meteorological station. Horizontal dashed line in (a) shows the average yearly rainfall; (c) shows the 27 July rainfall for each year from 2005 to 2012 (inset shows the total July rainfall for the 8 years); while (d) shows the daily rainfall from 12 July to 12 August 2012. Note that the debris flow occurred on August 1st, but the unrest period lasted from July 29 to August 3rd. Rainfall data for 8 years (2005 to 2012) was taken from the Bisongabang Meteorological Station run by the Directorate of National Meteorology, Cameroon Ministry of Transport.

July 2012 recorded 349.3 mm of rain (average of 13 mm/day), meanwhile 46% of this fell in only 5 days from 27th July to 1st August (average of 32 mm/day). The unrest that preceded the debris flow on 1st August started on July 29 (Figure 4(d)). Lack of information on rainfall duration and the rainfall mean intensity that resulted in the slope failure prevents us from pushing this analysis further to derive rainfall thresholds for the area [29] [30] [31]. However, on more general terms, it can be speculated that heavy rainfall will provide the water that is channeled and soaked down through rock cracks and crevasses (Figure 2). Such water not only hastens chemical break down of the rock, thus rendering its blocks loose, it also lubricates the material and adds weight to it. We suggest that inappropriate land use activities in the area (see above) predisposed the steep slope. The 8 year-high 27 July 2012 rainfall then acted as antecedent rain that increased the initial moisture content of slope materials [31]. The August 1st rainfall (39.6 mm) triggered the event by increasing the rate and depth of wetting, as well as the soil pore-water pressure that led to failure [24] [32] [33].

4.3. Impact of the Debris Flow

The Kakpenyi debris flow had environmental and socio-economic impacts. No human casualties were recorded but 20 people got injuries from being hit directly by falling debris. The debris flow material denuded vegetation and covered cultivated land (palm trees, cocoa, cassava, plantains, groundnuts, pineapples) that will not more be available for use before it is re-colonized by soil. Some people said the material was hot. This is confirmed by what the medical officers described as first degree burns on the feet of some individuals when they walked bare-footed on the flow material. A consideration of the energetics of debris flows suggests that it involves a cascade of energy conversions and transmissions (up to 10^{15} joules of potential energy) that can lead to the release of heat [24] [34]. The flow clogged river Kakpenyi to form a temporary dam (**Figure 3**). In addition to rendering the river muddy and thus unusable downstream, it cut off water circulation that resulted in life fish that villagers picked on the river channel. Explosions and ground rumbling similar to gun shots reported by villagers would have resulted from trees cracking and/or the detachment and knocking together of boulders in the proximal part of the flow (**Figure 3**). The reported smell of rotten eggs probably came from hydrogen sulphide as a decay product of organic matter (tree leaves and trucks).

4.4. Possible Mitigation Measures

There are broadly two categories of debris flow mitigation measures—passive and active. Examples of passive measures include avoidance of the area, land-use regulation, notification and education of the public, and warning systems. Active measures involve some form of engineering to reduce the possibility of the debris flow occurring in the source zone (hill side treatment), reducing or modifying the size, velocity, and flow path, or effects of the debris flow in the transportation and/or deposition zone [35] [36]. Given the current highly underdeveloped and remote nature of the Kakpenyi area, short term active mitigation measures like education of the people on debris flow risk awareness and appropriate responses when the hazard is imminent, are recommended. The debris flow (luckily) had premonitory signs like roaring noises, knocking of boulders, cracking of trees, and heavy rainfall, which residents should learn to recognize and take precursory measures like moving uphill to possible relative safety. Building settlements on hill slopes should be avoided. Before undertaking major development projects like roads and bridges in the area, detailed hazard identification and vulnerability assessments (HIVA, e.g., [37] [38]) should be carried out and active debris flow mitigation measures applied where appropriate.

5. Conclusion

This paper describes the debris flow that occurred in Kakpenyi quarter of Tinta village in Akwaya Sub Division of the Southwest Region of Cameroon on the 1st of August 2012. Even though it did not result in any deaths, people got injured and farmland was destroyed. The debris flow started from the western slope of a hogback in the settlement, and mobilized about 3.47×10^6 m^3 of material over a 1 km distance. It was not caused by an earthquake. Instead, inappropriate land use practices like farming on hill slopes predisposed the slopes to failure. Heavy antecedent rain 5 days before, and the heavy rainfall of 1st August, then triggered the event. The proximal part of the debris flow formed a shallow lake on river Kakpenyi that subsequently drained without causing a debris surge. As a short term mitigation measure, the local people should learn how to recognize premonitory signs of debris flows like roaring noises, knocking of boulders, cracking of trees and heavy rainfall. Verbal reports of a similar event in the area 40 years ago require that infrastructural development projects like roads and bridges be preceded by detailed debris-flow-hazard evaluation including location and recurrence of flows. Information given in this paper will be helpful in such situations, particularly given that the debris flow surface will shortly be buried by soil.

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