STATE OF HYDROGEOLOGICAL DISASTERS IN NORTHWESTERN RWANDA

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Abstract
About fifty people lost their lives in the recent disasters that occurred on May 8, 2016 and which affected mainly districts of Northern Province, particularly Gakenke District. Similar disasters take place yearly and they are likely to continue, even to a higher extent, unless serious studies and measures are taken for their prevention. This study was conducted to that end. It focused on landslides and floods in Northwestern part of Rwanda. The study reveals that these disasters result from the combination of the factors related to rainfall, topography, vegetation cover, bedrock, soil development and human activities. Deep analysis shows a big effect of unsuitable land use. The study proposes appropriate preventing measures.

Key words: Disaster, Hydrogeological disaster, Northwestern Rwanda, landslide, flood.

1. Introduction
In Rwanda high population density in rural areas (415 in hab/km²) is mainly associated with subsistence agriculture (80 %) which constitutes the backbone of the livelihood and economy. This form of land use is practiced on steep slopes, marginal land (60 %), and insufficient land (with less than 0.7 ha) (MINECOFIN, 2012; 2013). This causes soil erosion and triggers hydrogeological disasters in high rainfall areas: slope wash, landslides, debris flow, mudflow and floods. The absence of fallow and other mitigation strategies as well contributes to the continuous deterioration of vegetation cover and increases soil erosion (Moeyersons, 1991; Rossi, 1991).

Disasters constitute a huge threat to population lives, settlements, various infrastructures as well as economic activities and national economy especially in mountainous regions of Rwanda (Nsengiyumva, 2012). This issue urged to conduct this study with the objective to analyse the state of hydrogeological hazards in Northwestern Rwanda. A special emphasis was put on landslides and floods which recurrently cause serious damages during rainy seasons. For instance, in May 2016 at least 49 people...
have been killed by floods and landslides and 1,600 ha of arable land were destroyed.

The research tries to analyse the causes of landslides and flooding from different physical and human factors namely rainfall, topography, vegetation cover, rocks, soil development and human settlement and activities. These patterns were investigated on nine sites located in five districts of Rulindo, Gakenke, Musanze, Nyabihu and Rubavu.

In addition to the introduction and to the conclusion which briefly discuss the findings and its relevance to this research, this paper is made up of three sections: methods, hydrogeological disasters factors analysis and the results.

2. Materials and methods

This research was designed in three steps. The first one concerned the inventory of recent disasters in the whole country from 2007. At this step, the information was gathered from the population, districts and sectors leaders as well as written documents and online sources. The second step was to identify the northwestern Rwanda as a prone zone to disasters. This was done by analyzing the impact of each of the following geographical parameters: rainfall, topography, geology, soil development and human activities. The last step concerned the empirical research in the selected zone and sites.

Three techniques were used to collect data on the field namely observation, interviews and measurement and analysis of the disaster.

- **Observation**
  The observation allowed knowing the state of damages and forms of floods and landslides in different sites visited, the land use techniques, the nature of relief and settlement in the surroundings. At this level, disaster-prone areas were identified basing on the historical records and testimonies from local communities and population. Photos were taken for illustration and support in analysing different field phenomena.

- **Interviews**
  Interviews contributed to collecting information on land use techniques and describing the period, the damages and the extent to which the hydrogeological disaster occurred. Interviews have been so useful since they involved face-to-face discussions with local residents and allowed to probe further and keep the responses on the issue of interest.

- **Empirical study of the disaster: measurement and analysis**
  At every selected site, the empirical study concerned the analysis of the following:
  - **Soils:** analysis of soil textures, structures, thickness and parent rocks. The section is based on information found in the soil map of Rwanda;
- Vegetation cover: biomes and their degree of degradation with reference to De Martonne (1970) formula to calculate the aridity index;
- Rainfall: date, month, year and rain quantity from Busogo weather forecast station;
- Land use: excessive land use, overgrazing, deforestation and settlement;
- Topography: values and lengths of slopes with the help of clinometer;
- Mapping: identification of the site and use of arc GIS to produce maps.

The study of landslides consisted of determining the location, environmental setting, description of characteristics (size, soil profile, nature of the rocks, identification of all other phenomena contributing to landslide such as water springs). The study of floods consisted of identification of the drained and flooded surface, the origin of water and the environmental setting. For both landslides and floods we observed damages around the site.

3. Hydrogeological disasters factors analysis

The factors of hydrogeological disaster in northwestern Rwanda are associated with nature of rocks and soil, vegetation cover, topography and rainfall (Bizimana and Sönnez, 2015) as well as human features.

3.1. Nature of rocks

The geologic map, Gisenyi and Ruhengeri sheets (Antun, De Mulder, Tahon and Nsengiyumva, 1991) shows a variety of geologic zones: the cenozoic volcanic rocks belonging to a continuous geochemical series rich in potassium, the pelites and arenites composed of phyllades or quartzophyllades, schist, micaschist and quartzite; magmatic rocks particularly granites and pegmatites; gneissic granite rich in micas (both biotite and muscovite) and non-gneissic rocks.

Studying Bigogwe area, Moeyersons (2008) identified two types of rocks in the region:
- On the heights and the slopes, the prevailing rocks are granites. They are made up of undifferentiated gneissic granites composed by mica, feldspaths, quartz, muscovite and potassic minerals and granites, pegmatite, with mica (biotite and muscovite) as minerals.
- In the depressions and lowlands, there are volcanic rocks made up of: peridot, pyroxene, amphibole and biotite. They are part of recent quaternary lavas.

Peridot, pyroxene, amphibole and biotite are more alterable minerals while feldspar, muscovite and quartz are less alterable minerals (Kreit, 1979).

The resistant rocks and steep slopes that characterise the highlands of northwestern part of Rwanda determine the formation of a
thin layer of alterite based on a shallow bedrock and this leads to small and multiple landslides during the rainy season. Yet, alterability of the volcanic as well as magmatic rocks is a trigger which is the single event that finally initiated the landslide.

3.2. Nature of soil

The analysis of the nature of soils in northwestern Rwanda (Fig 1 and Fig 2) shows a variety of soils depending on topographic features (MINAGRI, 2002; Habarurema and Steiner, 1997; Birasa, Bizimana, Boucaert et al, 1990). On slopes, soils are thin and present a poor structure, except on the higher altitudes (over 2700m) where we find lithosols and kaolisols. In lowlands, there is a rich variety of soils and the most important are: soils made up of sandy, clay and loam developed on sedimentary rocks; andosols developed on volcanic ash, and ferrisols developed on basalts.

Figure 1: Northwestern Rwanda soils taxonomy. Source: Adapted from Birasa, Bizimana, Boucaert et al. (1990).

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Regarding the soils taxonomy (Fig.1), the andosols related to volcanic rocks are predominant in the extreme northwest part and the ferralsols, cambisols, alisols, gleysols and reosols elsewhere. Most catastrophic landslides and floods, for instance in Bigogwe, are related to soils developing upon pyroclastic materials. Ferralsols, cambisols, gleysols and alisols are predominant in the central and southern zones. Landslides in these zones are due to soil horizons stratification that favours water stagnation in lower horizons. This is mainly observed in Rulindo and Gakenke districts.

![Soil Type in Northwest Region](image)

**Figure 2**: Northwestern Rwanda soils texture.

Source: Authors.

Figure 2 shows a variety of soil textures: silty clay, silty loam, clay and clay loam. Sandy clay and sandy clay loam are the regular texture which characterize the soils. The soil texture represents the relative proportion of sand, silt and clay. Soils with high percentage of clay form very stable aggregate resistant to detachment (Byizigiro, 2016). Light soils like sandy or coarse loams are easy to detach as they have low organic matter content (Jim Ritter, 2015).
Therefore, soil with more sand observed in high slope zone and with intensive rainfall is exposed to soil erosion. Soils on steep slopes are easily eroded because of regular modification brought about by farmers. In lowlands, soils are not permeable because of clogging due to high proportion of clay, stamping of cows and the impact of splash. The nature of soils of heights and depressions is respectively responsible for mudflows, landslides, stagnation of water and flooding.

3.3. Topography

The topography has direct influences on the intensity and character of landslides and flooding. The direct influence encompasses slope, steepness, river valley morphology and talweg gradients. The most important relief characteristic is the steepness, which affects the mechanism as well as the intensity of the landslides. The greater the height, steepness and convexity of slopes, the greater the volumes of the landslides. Northwestern Rwanda is a high mountainous region with the volcanoes’ chain in the extreme north. The highest point is Kalisimbi with 4,507 metres. The remaining zone comprises a lot of hills and depressions. The elevation map shows this topographic contrast with altitudes ranged between 1,400 metres and 4,500 (Fig. 3). Flooding zones are observed in lower altitude areas located in Musanze and Nyabihu Districts and landslides in other zones.

There are abrupt slopes (15-50 %). As water flows down the slope, it accelerates under the force of gravity. If the percent of slope is increased four times, the velocity of water flowing down is doubled. Doubling the velocity quadruples the erosive power. Sediment transport capacity of runoff increases by 10 to 100 times at 1 % slope compared to 0.2 % slope. More so, during rainy season, the hills get saturated with water, resulting in instability of land mass. The complete surface portion of soil may slip down from its actual position causing landslides (Wischmeier and Smith, 1978). The steep slopes in northwestern region play a huge impact on landslides.
3.4. Vegetation cover

Deforestation, over use of land with inappropriate techniques on uncovered soil are responsible for soil erosion. Much of Rwanda’s natural rainforest - once covering a third of the country - has been cut down to make way for its ever-burgeoning population. The largest part area studied is located in the zones of deforestation instead of dense forest as substantiated by the validity index according to the formula of De Martonne (1970) below from Busogo weather forecast station data during 2013 and 2014:

$$I = \frac{1}{2} \left( \frac{P}{T+10} + \frac{12p}{t+10} \right)$$

where P: mean annual precipitation in mm, T: average of annual temperature in °C, p: precipitation of driest month (note that the driest month here is not necessarily the one where p is the smallest, but one where the p / t +10 is the smallest), t: average temperature of that month.

For the year 2013

$$I = \frac{1}{2} \left( \frac{1409.3}{15.8} + \frac{12 \times 12.5}{15 + 10} \right)$$

$$I = \frac{1}{2} \left( \frac{1409.3}{28.5} + \frac{150}{25} \right)$$

$$I = \frac{1}{2} (54.6 + 6)$$
The relationship of aridity index and the corresponding vegetation cover as established by De Martonne shows that the studied area fits in the fifth category (30 < I) that corresponds to the dense forest:

1. I < 5 corresponds to the desert
2. 5 < I < 10 corresponds to the steppe
3. 10 < I < 20 corresponds to savannah grassland
4. 20 < I < 30 corresponds to the forest
5. 30 < I corresponds to the dense forest

As conclusion, the northwestern part of Rwanda should experience dense forest as vegetation cover. However, due to the high population density (more than 400 inhabitants per km²), there is no more natural vegetation. There are only food crops on steep slopes and some of which such as Irish potatoes accelerate erosion. The effect of deforestation is not only the removal of vegetation cover which reduces erosion. Tree roots anchor the soil. Without trees, the soil is free to wash or blow away, which can lead to soil erosion. When trees are removed, the bare and exposed soil is left defenceless against the pulling force of gravity. Soil movement takes place more easily and rapidly resulting in landslides (Bradford, 2015). If the deforestation in northwestern area cannot be considered as the main cause of landslide, it can be at least a trigger. But it is one of the causes of flooding because it accelerates runoff on the slopes.

### 3.5. Rainfall

Rainfall is one of the key parameters of hydrogeological disasters. It supplies water flows which are the main cause of landslides and flooding. The rainwater eventually soaks the soil which also transmits depending on the weight of water contained.

The northwestern Rwanda is one of (if not the first) region which receives the highest rainfall, particularly in the northern part (>1200 mm). The establishment of Intensity-Duration-Frequency curves for precipitation in Rwanda remains a difficult task as adequate long-term data sets for short
aggregation times are not available. However, the data obtained from ISAE/Busogo weather forecast station (a regional station) gives indications on rainfall. It rains on average of 1487 mm per year in Birunga area (Table 1). The rain season is long, about eight months from September to May. The table below shows the annual distribution of rainfall at ISAE/Busogo weather forecast station. The lowest monthly rainfall is July with only 42.9 mm while the highest is September with 212.2 mm.

Table 1: Rainfall data from ISAE/BUSOGO weather forecast station/2014

<table>
<thead>
<tr>
<th>Values</th>
<th>Ja</th>
<th>Fe</th>
<th>Ma</th>
<th>Apr</th>
<th>M</th>
<th>Jn</th>
<th>Jl</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>T°C</td>
<td>16.4</td>
<td>16.5</td>
<td>15.8</td>
<td>16.2</td>
<td>16.0</td>
<td>15.5</td>
<td>15.4</td>
<td>16.7</td>
<td>16.3</td>
<td>15.1</td>
<td>15.8</td>
<td>15.8</td>
<td>15.9</td>
</tr>
<tr>
<td>Rain in (mm)</td>
<td>82.9</td>
<td>97.2</td>
<td>88</td>
<td>182</td>
<td>97</td>
<td>105</td>
<td>42.9</td>
<td>63.6</td>
<td>212.2</td>
<td>134.9</td>
<td>201.6</td>
<td>180.2</td>
<td>1487.5</td>
</tr>
</tbody>
</table>

Source: ISAE/Busogo weather forecast station, 2014.

The table 2 shows the calculations of hydrological, soil and atmospheric droughts of the area to analyse the duration of rain season and dry season according to Lambert (1996).

Table 2: Hydrological, soil and atmospheric droughts in the northwestern Rwanda

<table>
<thead>
<tr>
<th>Values</th>
<th>Ja</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>Jn</th>
<th>Jl</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>T°C</td>
<td>16.4</td>
<td>16.5</td>
<td>15.8</td>
<td>16.2</td>
<td>16.0</td>
<td>15.5</td>
<td>15.4</td>
<td>16.7</td>
<td>16.3</td>
<td>15.1</td>
<td>15.8</td>
<td>15.8</td>
<td>15.8</td>
</tr>
<tr>
<td>Rain (mm)</td>
<td>82.9</td>
<td>97.2</td>
<td>88</td>
<td>182</td>
<td>97</td>
<td>105</td>
<td>42.9</td>
<td>63.6</td>
<td>212.2</td>
<td>134.9</td>
<td>201.6</td>
<td>180.2</td>
<td></td>
</tr>
<tr>
<td>2 T</td>
<td>32.8</td>
<td>33</td>
<td>31.6</td>
<td>32.4</td>
<td>32</td>
<td>31</td>
<td>30.8</td>
<td>33.4</td>
<td>32.6</td>
<td>30.2</td>
<td>31.6</td>
<td>31.6</td>
<td></td>
</tr>
<tr>
<td>3 T</td>
<td>49.2</td>
<td>49.5</td>
<td>47.4</td>
<td>48.6</td>
<td>48</td>
<td>46.5</td>
<td>46.2</td>
<td>50.1</td>
<td>48.9</td>
<td>45.3</td>
<td>47.4</td>
<td>47.4</td>
<td></td>
</tr>
<tr>
<td>4 T</td>
<td>65.6</td>
<td>66</td>
<td>63.2</td>
<td>64.8</td>
<td>64</td>
<td>62</td>
<td>61.6</td>
<td>66.8</td>
<td>65.2</td>
<td>60.4</td>
<td>63.2</td>
<td>63.2</td>
<td></td>
</tr>
</tbody>
</table>

Source: Calculated by authors from ISAE/Busogo weather forecast station data, 2014.

The use of curves P/4T, P/3T and P/2T helps to check the duration of different types of droughts (Lambert, 1996): Atmospheric drought (4T), soil drought (3T) and hydrological drought (2T). Interpretation of droughts leads to the following results:

- Atmospheric drought lasts from July to August
- The soil drought covers a single month, that of July
- Hydrological drought does not exist.

Twelve months of 2014 have not experienced drought in the northwestern region of Rwanda, which makes this region to be exposed to the hydrological disasters. In addition, poor vegetation cover experienced in the region is not a consequence of droughts, rather of intensive human activity (See under 3.6. below).
3.6. Human features

- Population density and distribution

Figure 4: Population density and distribution in northwestern Rwanda.

Source: Authors.

The region encompasses the historical highlands of Rukiga and Buberuka and the volcano region. It is a mountainous and densely populated area (Fig.4). As put it Bart (1993), this fertile region is for a long period highly populated.

Table 3: Population density in the five districts of interest

<table>
<thead>
<tr>
<th>District</th>
<th>Population</th>
<th>Area</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rulindo</td>
<td>288,452</td>
<td>567</td>
<td>509</td>
</tr>
<tr>
<td>Gakenke</td>
<td>334,586</td>
<td>704</td>
<td>481</td>
</tr>
<tr>
<td>Musanze</td>
<td>368,563</td>
<td>530</td>
<td>695</td>
</tr>
<tr>
<td>Nyabihu</td>
<td>295,580</td>
<td>532</td>
<td>556</td>
</tr>
<tr>
<td>Rubavu</td>
<td>404,278</td>
<td>388</td>
<td>1041</td>
</tr>
</tbody>
</table>
Table 3 shows Rubavu as the most populated district while the low population density is in Gakenke district. However, in all districts, the density is more than the national average of 415 inhabitants per km² (MINECOFIN, 2012). This population is dispersed in hills. This is as well the most dominant type of rural settlement in Rwanda for a long time (Sirven, 1984). It consists of scattered homesteads. In such a setting, each homestead has its own farmland in the surrounds (Fig.5). However, since recently (2000), grouped settlement is being promoted in Rwanda (MININFRA, 2009; Twarabamenye and Schilling, 2008).

- Agricultural practices

The predominant type of agriculture is subsistence farming. Farmers produce crops or rear animals for their subsistence. This is mainly due to the fact that the farmers themselves are poor and cannot afford modern agriculture requirements. Farms are too small to raise a surplus. The farmers remain backward in their methods of farming.
Crops are mainly sweet and irish potatoes, cereals and beans. Livestock includes cattle, pigs, sheep, goats, chickens (poultry), rabbits and bees. The high population density coupled with dispersed settlements and poor / traditional land use practices and techniques are part of hydrological disasters factors as they contribute to land degradation and soil erosion.

4. Results: analysis of landslides and floods
The landslides and floods have been studied on nine sites presented in the table 4 and figure 7 below:

Table 4: Distribution of the studied landslides and floods

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Name of the site</th>
<th>Nature of disaster</th>
<th>District</th>
<th>Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bushoki</td>
<td>Landslide</td>
<td>Rulindo</td>
<td>Bushoki</td>
</tr>
<tr>
<td>2</td>
<td>Gashenyi</td>
<td>Landslide</td>
<td>Gakenke</td>
<td>Gashenyi</td>
</tr>
<tr>
<td>3</td>
<td>Busengo</td>
<td>Landslide</td>
<td>Gakenke</td>
<td>Busengo</td>
</tr>
<tr>
<td>4</td>
<td>Mugogo</td>
<td>Flood</td>
<td>Musanze</td>
<td>Busogo</td>
</tr>
<tr>
<td>5</td>
<td>Gatokoro</td>
<td>Landslide</td>
<td>Nyabihu</td>
<td>Rambura</td>
</tr>
<tr>
<td>6</td>
<td>Bigogwe</td>
<td>Landslide and Flood</td>
<td>Nyabihu</td>
<td>Bigogwe</td>
</tr>
<tr>
<td>7</td>
<td>Rusongati</td>
<td>Landslide</td>
<td>Rubavu</td>
<td>Kanama</td>
</tr>
<tr>
<td>8</td>
<td>Nyundo &amp; Mahoko</td>
<td>Flooding control</td>
<td>Rubavu</td>
<td>Nyundo</td>
</tr>
</tbody>
</table>
4.1. Landslides

1) Bushoki landslide

Bushoki is located in Rulindo District alongside Kigali-Musanze road, near Nyirangarama and the district headquarter. The landslide is recurrent in rainy season. The recent one occurred in 2013.

On this site, we analysed the soil profile on 270 m of length and 20 m of thickness. The soil profile presents an upper small dark organic layer of 20 cm covered by an herbaceous vegetation, then follow five layers of superficial materials named from top to down as follows:

1. Cover fine colluvial layer (7 m of thickness) composed of clay, silt and sand or loam;
2. First stone layer mainly composed of angular quartz fragments of 20-30 cm of thickness;
3. Saprolite (3 m) composed of clay and silt as well;
4. Second stone layer located above the bed rock at approximately 3 m from the first one. In terms of constituents, it is composed of approximately 100 cm of thickness of ferruginous coarser fragments accumulation from the destruction of lateritic duricrust;

5. The bedrock cover layer is mainly made up of clay on which small mudflows are visible. There are springs above this layer of clay which originate from the water which does not continue to infiltrate on clay. Water infiltration throughout the whole soil profile is very easy since it is composed of permeable materials such as colluvial accumulation and double stone layers.

In terms of land use, there are settlements on the top of the hill. The forest which would stop the soil movement is being removed and replaced by dispersed shrubs favoring water infiltration. It is important to note also that road construction made the slope unstable leading to acceleration of downward movement of soil materials.

All these factors lead to the following as the main causes of Bushoki landslide: soil texture (colluvial materials and stone layers) allows water to infiltrate and percolate straightforwardly and this leads to small springs which are responsible for landslides because different soil materials slide on clay materials. There are no trees (forest) with long roots to stop the soil movement. Slope instability due to human activities such as road construction is also another important factor of landslide.
The figure 9 shows a number of measures to control this landslide: re-forestation program should be undertaken; wall stones construction can favour easy water circulation, the population on the top of Bushoki hill should be relocated and resettled elsewhere.

2) **Gashenyi landslide**

This landslide occurred alongside Base River draining Base valley. The physical characteristics of the area are steep slopes on reforested hills. The hill is sparsely populated. The soil profile description in Gashenyi zone implies three distinct soil layers: thin colluvial cover composed of silt and clay, stone layer composed of quartzite or bed rock fragments and the weathered bedrock which is a quartzite. Water movement through the whole soil profile is responsible for springs between weathered bedrock and accumulated coarser materials composing the stone line.

The case of Gashenyi landslide is totally different from Bushoki landslide in that it is related to rock fall and road sinking as well. The causes associated to these hydrogeological disasters are the water percolation leading to suffusion process through the soil materials removing the fine soil particles from the hill top to the valley bottom. To prevent this landslide, it is important to construct a wall stone to limit falling rocks and also control suffusion process (percolation).
Busengo rotational landslide (slump)

Busengo landslide is located in Kajereri village, Kamina Cell, Busengo sector, Gakenke district at less than 100 m from the Gaseke river bed, near Cyabingo Bridge. The rounded fluvial blocks (around a diameter of 50 cm) observed around this bridge confirm the high capacity of river transportation during the rainy season. This landslide has occurred in loose materials accumulated on the steep slopes characterizing this zone. The upper nearest area of the landslide site is cultivated and located near the settlement observed from the first scarp of the landslide. Its measured extension is 36 m in width and more than 58 m in length. The slope on the marginal parts is 30%. The soil profile presents 3 layers which are not clearly identifiable: an upper grey layer composed of fine colluvial materials (clay and silt or loam) with 30/40 cm of thickness; a medium layer of coarser materials (30 cm) rich in quartz fragments which is a kind of stone layer; a lower layer composed of sandy materials. The bedrock is not identifiable.

There are small water-springs at the bottom of the main scarp which cause sliding of soil materials.

As it is at Bushoki site, there is a grouped settlement at the top of the hill and no vegetation cover to protect against soil erosion.
The causes of landslide are related to the gradient of the slope and the texture and consistency of the soil. The steep slopes and the river banks undermining make the soil materials unstable and this leads to landslides. The colluvial soils materials found on the site are unstable prone to landslides. The landslide is accelerated by the movement of water through small springs and rain water from houses located on the top of the hill. This urges to introduce a re-forestation programme and the integrated management of river banks and rain water at the top of the hill.

4) Gatokoro landslide (Rambura)

This landslide was observed on Gatokoro hill, in Rwinkingi village, Nyundo cell, Rambura sector, Nyabihu district. It is situated alongside the road Mukamira – Ngororero - Muhanga. It is located on a pegmatitic granite. It is on a steep terrain, with slope of 27 %. The soil is sandy. Its profile has 4 layers: upper layer of around 60 cm, the stone layer of 40 cm, the weathered pegmatitic rock and the parental rock. The weathering of parental rock results into white micas, quartz, and sand. The movement of land is about 7m.

The sandy and permeable soil is the main factor of landslide. The situation is hastened by rainwater and undrained water coming from the settlement located on the top of the hill. There are also many springs which circulate through the soil before the landslide takes place. Like in the other site, the preventive measures are the re-forestation programme, resettlement of people from the top of the hill and engineering works (gabions, stone walls) to avoid falling rocks.
5) **Bigogwe landslide**

Bigogwe landslide is found in Nyabihu District, Bigogwe sector, Arusha cell. This zone faces floods and landslides almost every year during the period of heavy rainfall in Rwanda. This landslide which occurred in 2009 was observed on the slope of incised Mizingo river.

The description of Bigogwe landslide reveals the presence of 8 landings (1.5 m of sickness) extended to 30 m in length and 15 m in width. The measured slope is 50%.

The soil profile texture is showing the predominance of silt and clay formed on granite (pegmatite). At the top of the soil profile, an artificial channel conducts the water to Mizingo river which saps its banks. The landslide is related to the high gradient of slope, type of rocks and soil in highlands and human activities as the deforestation, movement of domestic animals, poor cultivation methods and population pressure and settlement built on steep slopes.
The control measures which can be or has been taken are afforestation and re-afforestation to be practiced especially on steep slopes to hold the materials together; terracing which involves the cutting of the slopes into a series of wide steps on which crops are grown; restricting of some land use practices especially on steep slopes and engineering measures such as revetment of fencing of stones and sand bags to protect the wall and the construction of the drains to prevent the accumulation of water within the mass of material on the slope.

6. **Rusongati landslide (Kanama)**

This landslide was observed in Rubavu district, Kanama Sector, in the valley of Karambo River which collects water from the hills surrounding Sebeya River. The soil profile presents the following layers:

1. Dark colluvial layer or humus (1m of thickness);
2. First stone layer (60 cm of thickness) composed of heterogeneous materials mainly of quartz and lateritic concretions;
3. Homogeneous clay layer (4 m of thickness) corresponding to weathered micaschist or schist bedrock;
4. Second gravel layer;
5. Alluvial gravel or fluvial terrace;

There are many springs that result in gullies on the hillslopes. The landslide is accelerated by the soil texture and structure which facilitate the water percolation.

![Figure 15: Rusongati landslide. This landslide presents three landings: the upper one is characterized by a colluvial materials (A), the lower one by weathered bedrock (B) and the last the river banks undermining.](image)

4.2. **Floods**
I) Bigogwe and Mugogo floods

- **Bigogwe flood**

Bigogwe flood took place at Mizingo valley, Gaturo village, Bigogwe sector. The valley is surrounded by steep hills which are highly eroded by the flowing river systems towards lava plain. Mizingo flood occurred usually during rainy period and causes huge damages. For instance, on September 12th 2007, 42 persons lost their lives and 4 others disappeared.

The main factors contributing to flooding are:

- Escarped topography with steep slopes which does not allow water to infiltrate in the soil,
- Soil texture and structure: the soil is composed of clay and silt which also do not facilitate the permeability;
- Rainfall: it is with sufficient intensity to do damage without providing the water that would ensure a complete protective vegetation cover;
- The deforestation of hills which is accelerated by the crucial issue of firewood demand.
- High density and dispersion of the population: the region attracts people because of rich soils and good climatic conditions that favour agriculture. Density is high, more than 500 inhabitants/km². Moreover, the population is in majority scattered within the hills;
- Overgrazing and cultivation: the increasing number of livestock on too limited areas of pasture has been mentioned by farmers. This factor is a catalyser of runoff. Overcultivation is due to population pressures and fertile soil.

- **Mugogo flood**

Mugogo is the worst flood that occurred in the northwestern region. The site is located at Byangabo in Mugogo marshland, in Musanze District. The Kinoni River which drains waters of Mugogo watershed used to flood frequently and sweep away lives, crops and homes mainly in November and April. The site is bordered by the hills and mountain with steep slopes. As it is the case of Bigogwe, the fertile volcanic soil contributes to the high population density of the region. The situation is made worse by the high rainfall which causes excessive run off leading to flooding.
The recommended measures against Bigogwe and Mugogo floods are: afforestation and re-afforestation on steep slopes, terracing of slopes, restricting of some land use practices especially on steep slopes, resettlement of people, dam construction along the river, building of dykes along the banks of such rivers and widening river channel through dredging.

2) Nyundo and Mahoko: case study of flood control
The cases to be studied were flooding at Mahoko market and Nyundo center. The agent of floods at Mahoko market is Karambo River. This is the tributary of Sebeya River. Its source is in Gishwati forest. Sebeya River which takes also origin in Gishwati Mountain causes the flooding at Nyundo center. This river is part of the Kivu lake drainage system in northwestern Rwanda. It used to flood frequently and sweep away lives, crops and homes. Due to mountains, it does not offer possibility for navigation.

The topographic feature of the area is characterised by steep hills with slopes that go beyond 30 % and deep valleys. The last main floods occurred in April 2009. Nyundo Health Center and Mahoko market were bitterly flooded. The width of the flooded area was between 10 and 100m. Till 2009, there was no disposal to prevent flooding neither around the hills surrounding Nyundo, nor Nyundo, nor along the banks of Sebeya to the extent that Sebeya valley was totally flooded two times per year. That is in March-May and October-November.

The main factors contributing to flooding in this region are rainfall, topographic features, vegetation and human activities:
- Sebeya River is surrounded by mountains; it takes source under Muhungure mount (3,000 m). It drains waters of the whole watershed to Kivu Lake located at 25 km from the source;
Sebeya is sprinkled with many meanders and reaches. So, water expands the banks of the river when the flow is too huge;

- The region is too rainy with more than 1600 mm per year;
- Hills surrounding the valley are steep and have no water control systems;
- Nature of soil: pegmatites are often the parent material which underlies the superficial soil and it favours mass movements;
- The region is densely populated, land is highly fragmented and overused, and there is no protection against torrential rain.

The following measures have been taken to control floods on Sebeya River:

a) Nyundo Health Center has been abandoned. A new health center was built on the other site which is more secure.

b) Reeds, bamboos and other agroforest species have been planted along the banks of Sebeya river;

c) Sacks filled with soil and sand protect the banks of the river.

Figure 17: Nyundo, abandoned health center and protection against flooding

5. Conclusion

The issue of hydrogeological disasters is crucial in Rwanda particularly in the northwestern part. This study tried to analyse the main factors of landslides and floods causing huge damages in that region. The study concluded that all the nature of rocks, slopes, soil texture, rainfall intensity, vegetation cover and human activities work together to contribute to the landslides and floods in the northwestern region.

However, since landslides and floods recurrently happen during the rainy season, it
may be thought that rainfall is the main factor. Indeed, in this region even if all natural factors may relatively be the same, disasters do not happen in all slopes at the same extent. This explains the effect of human activities. Land use becomes therefore a triggering factor of disaster occurrence. Therefore, since it seems difficult to tackle natural factors, efforts are to be concentrated on land use. That is why all preventive measures to mitigate hydrogeological disasters that were proposed go in line with:

- Afforestation and re-afforestation on steep slopes;
- Terracing of slopes which involves the cutting of the slopes into a series of wide steps;
- Restricting some land use practices especially on steep slopes;
- Resettlement of people from high disaster zones to suitable and secure ones.

Some of similar measures taken in Bigogwe region have had positive impact and they should be extended to other regions. They include:

- Relocation of the inhabitants of Gaturo towards Kijote. Those who settled on Ngamba were relocated to Kanembo hill;
- Reafforestation of Ngamba hill. The planted species are eucalyptus, alnus, black wattle and Kikuyu grass (Cynodon dactylon);
- Ploughing on steep slopes is currently forbidden;
- Land use measures: the top of the hill is occupied by green pasture, the middle and low slopes of the steepy hill are reforested;
- The correction of Mizingo river: The caves which collected Mizingo river were closed with alluvial deposits. The river was diverted to another cave which pours its waters into Kivu Lake. This strategy limited the extent of flooding into the valley and facilitated agricultural and transport activities in Mizingo basin.

Now that we have experience on the causes, damages and preventive strategies of disasters, there is need to rethink about sustainable measures of land use. Villagisation policy is one of good ways to that end, but it is also important to carefully analyse where to locate a settlement because, as we have seen it, on the top of the slope where occurred a landslide there is a grouped settlement. The slopes of over 20° are not suitable for human activities (settlement and agriculture). The depression rounded by steep slopes as well as colluvial soils are not eligible for that either. The control of
population growth and its adequate distribution is another issue to handle.

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References


Nsengiyumva, J.B., (2012). Disaster high disaster zones on floods and landslides. MIDIMAR, unit of research and public awareness.


