Landslides hazards assessment using geographic information system and remote sensing: Gakenke District

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Abstract. Gakenke district is located in the Northern Province of Rwanda and is known as the district with several landslide events. Assessment of landslide in Rwanda has not been a problem until the weather changed frequently with heavy rainy season. The purpose of conducting this study was due to massive movement of earth having impacts on roads infrastructures, community, and negative impacts for the planners and decision makers. Remote sensing and Geographical Information system methods were used in the study for the assessment of landslide hazard occurrence, weighted overlay model was used where the different triggering factors were considered and scored according to the relationship between causative factor contribution to the landslides and then weighted for producing landslides vulnerability map. The results revealed that Gakenke is vulnerable to landslides and this is due to the most triggering factors: slope that present 40% with 30% of the land cover in addition to rainfall having 20% and 10% of Gakenke District soil type of this area. Landslide hazard map of Gakenke have been created using GIS by combining the causing factors. Hence, an updated map of exposed areas in Gakenke District to landslide could be prepared taking into account different points

1. Introduction

Earth’s surface is changing through both folding and faulting forces, triggering movements in the terrain’s crust and on its surface. Landslides are downward movement of slant materials such as rocks, debris or soils due to gravitational pull. Landslide is the one of the natural disasters in the world which causes loss of life, harms, and destroy properties in year [1]. Sideways plate boundaries people are to be exposed to earthquakes or volcanic activity, people who live close to the coast may be exposed to floods or tsunamis, and societies who live in hilly areas could be affected by sweeps. Landslides occur naturally in all parts of the world and are termed differently subject on factors such as material structure and rapidity of movement [2].

Rwanda is currently vulnerable to change of climate conditions as it takes more precipitation which is very significant in agriculture even rural and cities livelihoods met with irregular situation from drowning and landslides disasters. Rwanda is located in equatorial Africa, with a shortage of data to produce strong climate projections. Having realized that most of families in the affected areas are regularly living with agricultural and livestock activities, there is a need to know effects that caused
landsides on roads, where most bridges were totally or partial destroyed by avalanche, many roads were inaccessible with ten bridges connecting Gakenke to Muhanga and Musanze district were damaged [3].

Since the factors affecting occurrence of landslides can be geophysical or manmade, they may arise in developed or undeveloped zones, or any area where the topography was altered for construction of roads, houses, and services. To keep lives and goods, it is essential to evaluate landslide regions using archives from previous landslides in connection with landslide causes [4]. This study aimed at assessing landslides hazards in Gakenke District with the use of GIS and Remote Sensing by applying weighted method in order to identify vulnerable areas and mapping them. To identify factors that initiate or trigger mass movement in Gakenke district where through investigation the following factors were found: slope, rainfall, soil depth and lithology. Landslide hazard analysis focuses mainly on the spatial zoning of the hazard [5]. Two main types of mass movements occur in Gakenke District: Rainfall and slope, human activities occasionally cause mass movement on slope.

2. Data and method
2.1 Formatting the title
Gakenke District is one of the five districts of the Northern Province. It borders with Rulindo District at its Eastern side, Burera and Musanze Districts at its North, Nyabihu District at its West, at the South by Kamonyi and Muhanga Districts figure 1. This is divided into 19 sectors: Busengo, Coko, Cyabingo, Gakenke, Gashenyi, Mugunga, Janja, Kamubuga, Karambo, Kivuruga, Mataba, Minazi, Muhondo, Muyongwe, Muzo, Nemba, Ruli, Rusasa and Rushashi. This district covers 704 km2.

Figure 1. Study area location.
2.2 Data and Method

The scope of the primary data begun by identifying different factors that causes landslides in Gakenke District. The questionnaires were used during field surveying where the questions were answered by District authorities in charge of disaster management and local people. The study chose Gakenke District because currently is more affected by slope movements and their controlling parameters. The view of authorities was used to provide explanations regarding landslides activities. The questionnaires concentrated on recognising reasons of landslide and their influences to the community.

Remotely sensed data are used in solving several environmental tasks. This technology can be used as an actual aid in natural hazard study, as well as for the determination of environmental planning. Topography data, such as, land cover, geology, geomorphology and drainage could also be derived from it and existing thematic information can be updated to allow the quantification of human intervention on the earth’s surface [6]. This study used DEM to produce terrain analysis maps such as slope and aspect, and weighted overlay model in ArcGIS.

Rwanda, because of its geographical feature and climatic profile is one of the sub-Sahara African countries likely to suffer from disasters and especially localized landslides and floods. It experiences disaster cases resulting from natural hazard including flooding, landslides, strong winds, heavy rains and storms, the causes of vulnerabilities to disasters include geographic characteristics such as steep slopes and others [3]. Risks identification provides explicit facts on the environment and characteristics of the dangerous incident and the community.

It further studies possible events triggering injury to life or damage to property and the environment. Vulnerability identification takes advantage of the use of environmental modeling to describe threats and disaster impacts [7]. For the analysis of landslide hazard a large number of input were used. It is not always possible to collect all data. The main types of information or criteria were:

2.3 Slope

The constancy of the rise against sliding is defined by the relationship between the shear forces and the resistance to shear. On a flat surface the force of gravity acts downward and so long as the material remains on the flat surface it will not move under the force of gravity [8]. The core force responsible for mass wasting is gravity [9]. An important factor in the distribution of landslides is the slope gradient and mass activities first happen when a critical angle is exceeded. Slope were classified into classes in order to score it for showing slope which is in high risk, then weight for landslide hazard map in figure 3.

A Digital Elevation Model (DEM) is a specialized database that symbolizes the relief of a surface among points of well-known altitude. DEMs use remote sensing techniques to measure surface relations of adjacent real cells and the data are kept in grid of cells [1]. Table 1 represent classification and scoring of slope of how the terrain is formed in the District of Gakenke.

| Slope angle | Classes   | Score |
|-------------|-----------|-------|
| 0 - 2       | Flat      | 1     |
| 2 – 6       | Very Low  | 2     |
| 6 – 13      | Low       | 3     |
| 13 – 25     | Moderate  | 4     |
| 25 – 55     | High      | 5     |
2.4 Soil types

Naturally the most important type of data to be collected for landslide hazard assessment is the locations and characteristics of the landslides in the study area. According to latest studies, two basic varieties of residual soil occurred at Cyanika carbonatite in Burera. Soils play an important part because it is a by-product of soil mass movement process and at the same time it is a key factor [3]. Gakenke District have high clay content which is at the source of water holding capacity which mostly caused slump.

Landslides in Rwanda like in most of East Africa, are among the very deadly natural disasters that are killing people without warning and at the same time carrying the county’s most fertile soil [2].

Figure 2. Slope Map of Gakenke District
2.5 Rainfall

This can influence the runoff speed and creation of surface crusts, which affect loss and cause descent. Gakenke District is one of five Districts of Northern province of Rwanda which receives high rainfall. Climate had a dramatic effect on mass wasting events. The high monthly rainfall Gakenke received in period of three years from 2016 to 2018 is 461.2mm in year of 2016 at Rushashi station. Gakenke District receives heavy rainfall in March, April, May, October and November The wettest period of the year is from March till May. The interpolation technique was used for Gakenke District with ArcGIS especially by specifically Kriging method.

Rainfall is one of those factors that have been found to activate landslides as high rainfall events result in high water saturation in soils decreasing the strength of the soil figure 5. The rise in water content increases pore water force. The impact of rain is even more difficult because landslides are more common when precipitation is continuous and exceeds the field capacity of the soil [5]. As soon as the triggering rainfall situations of landslides have been quantitatively defined, levels are determined through more sophisticated methods claiming objectivity and reproducibility [10]. The higher rainfall amount during July is absorbed by the dry soil. Towards August these muds become saturated causing in a greater chance of slope failures. The main landslide types are debris flows that occur on concave slopes where rainwater concentrates in soil profiles.

| Average Rainfall | Classes   | Classification |
|------------------|-----------|----------------|
| <1200            | Low       | 1              |
| 1200-1400        | Moderate  | 2              |
| >1400            | High      | 3              |

Table 2. Rainfall classification.
3. Results and Analysis

Vulnerability analysis is an essential part of hazard assessment, which met with complication, uncertainty reasons and other characteristics. The total estimation of landslides exposure for the study area results from the combination of triggering factors including slope, rainfall, soil depth and lithology. From questionnaires the rainfall is the most triggering factor for landslides occurrence and it has 60% compared to other factors, slope has 25%, human activities have 5% and remaining others have 10%. The landslides vulnerability map was classified into three classes which are low, moderate and high landslides.

To recognize the information about landslide incident it is essential to illustrate landslides vulnerability analysis and landslides impacts assessment. Landslide inventory shows location, typology, activity and components of landslides for different period [8]. A landslide inventory, including shallow and deep-seated landslides, was prepared for the study area and landslides were overlapped with both lithological maps.

These activities have had a greater impact on Gakenke sector road with 22170.27 meters exposed to landslide hazard to 154446.79 meters of roads in Gakenke District. Any type of hazard has an impact this is the case of Gakenke District where not only roads are expose to landslide. Moreover, settlement and lives, infrastructure development, agriculture, forest, shrubs and many others are at risk figure 6 in the vulnerable map of Gakenke District. This due to triggering factors such as steep slope, rainfall, soil type and lithology of the area. In order to localize the landslide prone areas GIS environment was used. Therefore, slope is the main triggering factor together for landslide hazard in Gakenke District with rainfall and are likely to remain happening given that the population is still living in highlands.
4. General conclusions and recommendations

4.1 Conclusion
It is obvious that landslide is become a serious problem which could occur as natural processes, however, these landslides can be avoided. There is no reason to consider that the amount of natural hazards will soon start to drop, nor that we will witness a major change in the vulnerability of people. Gakenke District is characterized by a mixture of landscape which triggers the level of exposure to landslides. This area is very vulnerable and sometimes, both disasters cause several damages. Highlands areas present landslide events most frequently take place in years with exceptionally high rainfall.

All sectors are not hit at the same level. Geomorphic factors such as geology, topography and relief have also had an influence on landslide types in Gakenke District. In future a map of vulnerable zones to landslides should be updated frequently. Decision makers must be also aware of supplementary investment needed in constructing roads at the areas with high landslide risk.

4.2. Recommendations

- Determine hazard zones, as well as mapping and updating on a regular basis for each District or sector.
- The community necessities to be taught about Tragedy risk reduction at their places for actual Disaster Management and disaster risk reduction
- The existing coping mechanisms for Disasters like landslides and floods at the community levels must be supported by formal institutional.
- There is a critical need to determine all high risk zones for various hazards other than those of landslides
- Determine type of landslide event and consequent phenomena, such sliding debris, debris flow, or sedimentation.
5. References

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