Spatial Distribution of Landslides Vulnerability for the Risk Management in Ngororero District of Rwanda

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Abstract: Understanding people's hazard vulnerability magnitude enhances its risk awareness and preparedness as well. The objective of this study was to spatially differentiate landslides vulnerability toward relevant management of risk within Ngororero district, western Rwanda. The authors employed ten vulnerability triggering factors divided into social factors: population density, literacy rate, possession rate of mud houses and communication tools like mobile phone, radio or television, employment and rate of using unimproved drinking water. Whereas the ecological factors were rainfall, elevation, land use/cover and slope. The normalized weighting method in ArcGIS was employed to estimate and map landslides vulnerability and risk in the study area. The results indicated that the sectors largely inhabited with high elevation, slope, rainfall and limited communication tools along with low literacy rate record high landslides vulnerability and risk. This landslides vulnerability and risk mapping can help the vulnerable populations to understand the extent of their risk exposure. While policy makers can find out the way of formulating appropriate vulnerability lessening and risk reduction measures.

Key words: Landslides; Ngororero district; Risk; Rwanda; GIS; Vulnerability.

1. Introduction

The vulnerability to natural hazards is increasingly becoming exacerbated by the rapid human population growth and its daily life choices (Frodella et al. 2018; Narsimlu et al. 2013).Although poverty is consistently considered as the key community vulnerability driver, previous scholars (Asad 2015; Khunwishit et al. 2018; Kienberger 2012; Awal 2015) suggested to consider other society's socio-economic, political, cultural, environmental and physical factors including not limited to the age, education, information sharing systems, environmental and natural resources management, etc. These together, strengthen or weaken the community's ability to resist, cope and recover from the hazard, in case of occurrence. The vulnerability varies from individual, family to community level over time, and as previously reported (Askman et al. 2018; Jackson et al. 2017; Nirupama 2012) vulnerable groups are not only at risk because they are exposed to a hazard, but as a result of marginality of the above mentioned patterns within the society. Accordingly, it is becoming hard, specifically for the poor and densely populated areas to cope with the rising risks due to lack of appropriate mitigation and adaptation capabilities (Aitsi-Selmi et al. 2016; Gero et al. 2011; Amri et al. 2017).

This expresses the role of early warning and financial capabilities to enhance the vulnerable risk awareness and preparedness, which in turn, saves its life, protects long term development activities and strengthens the resilience over time. In Rwanda, the temperature recorded increasing trend within the last fifty years ago, and markedly led to incremental risk namely flood, mudslides, landslides and drought (Muhire and Ahmed 2015; Haggag et al. 2016).These hazards caused immense losses, among which there are more than one million people affected, 4,573 lost livestock, sixty thousand hectares of cropland and fifty thousand houses damaged. While the areas severely affected are poor and largely inhabited (Nahayo et al. 2017; Nsengiyumva et al. 2018; MIDIMAR 2017). Moreover, the incidence of this gradual vulnerability in Rwanda, is exacerbated by its rapidly growing population and predominantly young. It grew from 2.525 million in 1955 up to 7.235 and 11.917 million in 1990 and 2016, respectively (Muhoza et al. 2016; Petroze et al. 2015). This consequently leads to increasing vulnerability by the fact that people likely inhabit risk prone areas through better livelihoods searching.

Moreover, high elevation of the north and western parts receiving frequent high rainfall facilitate easy runoff then exposes the regions to severe mudslides, landslide and floods losses. Whereas the south and eastern parts are under limited rainfall causing crop failure, famine and droughts (Nsengiyumva et al. 2018; Haggag et al. 2016). The Ngororero district, one of seven districts of the western province of Rwanda is reported (Dawson and Martin 2015; Nahayo et al. 2017) to be shocked by both flood and landslides, mainly due to its location with high elevation and rainfall and the reason that, the district is among the densely populated districts of the western Rwanda. However, on the best of the authors' knowledge, there is no current vulnerability assessment carried within the district to reveal the factors with high priority to be considered for the vulnerability lessening and risk reduction. Only the field reports (Gakwerere et al. 2013; Bizimana and Sönmez 2015) were prepared after disaster occurred. This expresses the need of carrying out a systematic vulnerability analysis to strengthen the vulnerable risk awareness, preparedness and resilience as well. Hence, the objective of this study is to spatially distribute landslides vulnerability and suggest relevant measures for the resilience strengthening and risk reduction in Ngororero district of the western Rwanda.

2. Methods and Materials

2.1 Study area

Ngororero district is 54 percent rural with a total surface of about 678 Km^2 and a total population of 282,249. The Ngororero district (Fig.1.a) is composed by thirteen sectors: Bwira, Gatumba, Hindiro, Kabaya, Kageyo, Kavumu, Matyazo, Muhanda, Muhororo, Ndaro, Ngororero, Nyange and Sovu. The district (Fig.1.b) is bordered by the Nyabihu district in north, Karongi district to the south, Muhanga district to the east and Rutsiro district to the west (Gakwerere et al. 2013).

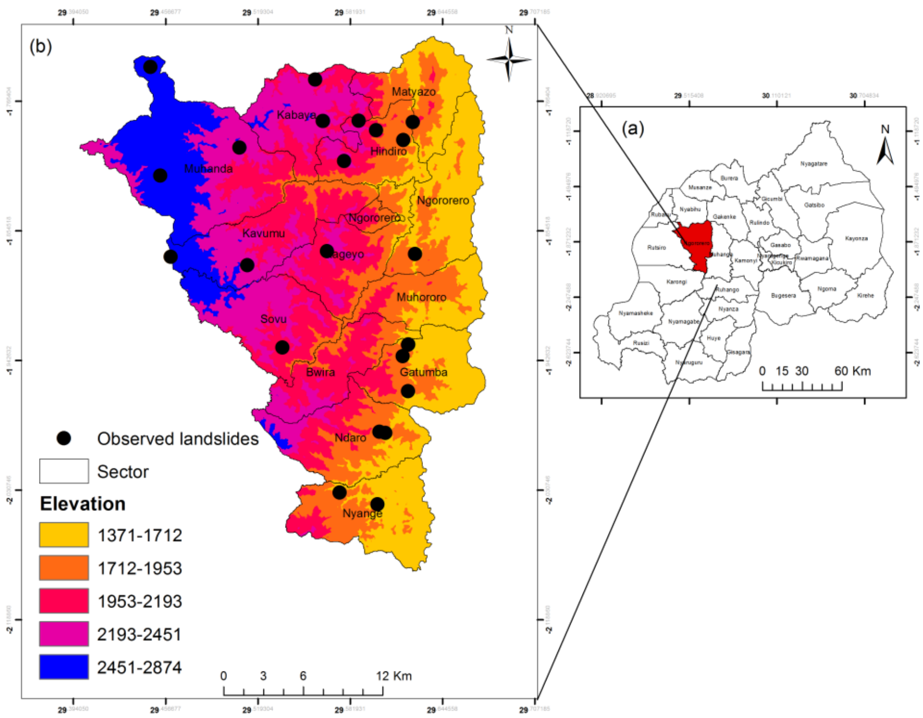

Fig.1. Landslides inventory map in Ngororero district (a), its location and neighboring districts in Rwanda (b).

2.2 Datasets

2.2.1Landslides inventory map

Previous scholars (de Loyola Hummell et al. 2016; Liangfeng et al. 2002) have suggested that for any disaster risk and vulnerability assessment, there should be the factual collection of past events to help in analyzing the likely future trends. Therefore, landslides inventory map (Fig.1 (a)) was produced for this study by using previous historical landslides records provided by the Rwandan Ministry of Disaster Management and Refugees (MIDIMAR 2017). The above landslides inventory map (Fig.1 (a)) identified 22 landslides, and used the affected people (killed, injured and homeless), cropland and houses damaged and lost livestock, and the occurrence frequency between 2010 and 2017 within Ngororero district.

2.2.2 Ecological factors

The Digital Elevation Model (DEM) related data and Landsat 8 images downloaded from the United States Geological Survey (USGS 2018) were used to estimate the aspects of elevation and slope (Fig.2 (a,b)), and land use and land cover (Fig.2 (d)) classes. These Landsat 8 images were radiometrically corrected, the cloud shadows were masked and the gap-filling algorithm was used to get a cloud-free image. After the images were classified using the supervised maximum classification method. Then the land use/cover was classified into six classes: forestland, grassland, cropland, built-up land, wetland and water bodies based on the East African classification of the Regional Center for Mapping and Resources Development (RCMRD 2017).

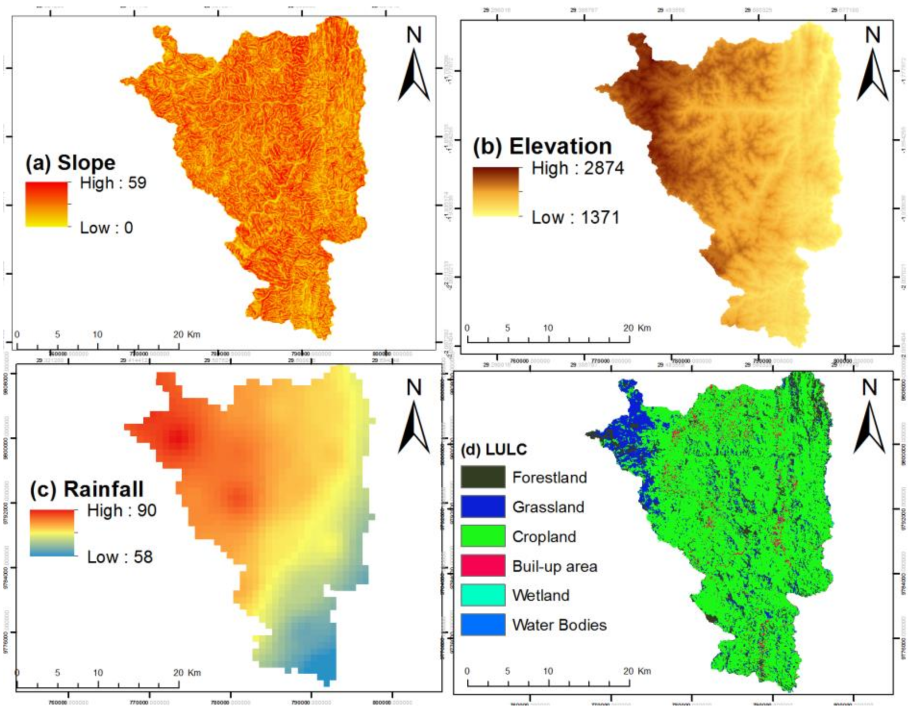

Fig.2. Study area's slope (a), elevation (b), rainfall (c) and land use and land cover (d).

Moreover, this study employed the rainfall due to the fact that, the change on rainfall frequency and intensity is among the landslides driving forces especially in highly elevated areas (Frodella et al. 2018; Moayedi et al. 2011). This is similar with the study area with high altitude and slope (Fig.2 (a, b)) as well as its land cover type with high proportion of cropland (Fig.2 (d)), the runoff drivers in case of rainfall. Thus, authors interpolated the mean monthly rainfall data ranging between 1990 and 2017 from the available meteorological stations. The rainfall data were provided by the Rwanda Meteorology Agency (RMA 2018).

2.2.3 Social datasets

Moreover, as illustrated in Fig.3, the authors employed the social datasets: population density, possession rate of mud houses and communication tools (mobile phone, radio or television) employment and literacy rate, and percentage of people consuming unimproved drinking water. These datasets were provided by the National Institute of Statistics of Rwanda (NISR 2017). These social datasets were used due to reason that, as previously reported (Birhanu et al. 2016; Khazai et al. 2014; Ratemo and Bamutaze 2017), they likely characterize the community's socio-economic function, and can strengthen or weaken the community's ability to resist a hazard. For example, lack of communication channels (access to mobile phones, radio and television) limits access to information. Similarly, literacy rate indicates the extent to which the community can read/transmit a message to others in case of warning.

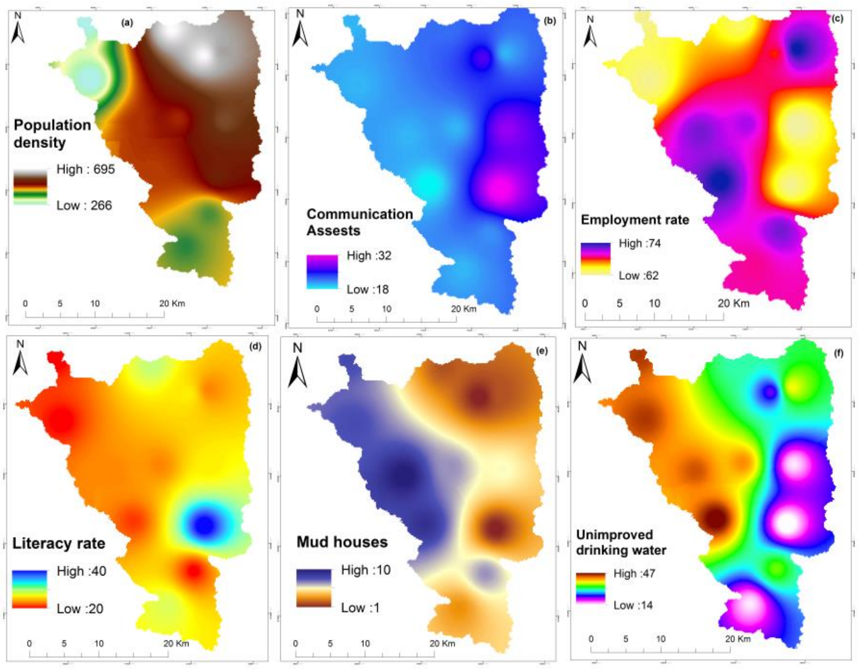

Fig.3. Spatial social factors distribution in Ngororero district namely the (a) population density, (b) communication assets representing the possession rate of mobile phone, television and radio, (c) employment rate as the percentage of adult people employed, (d) literacy rate as the percentage of people who easily can read and write, (e) mud houses, the percentage of population owning mud houses and (f) the percentage of people consuming unimproved drinking water.

2.3 Vulnerability analysis

This study estimated landslides vulnerability caused by the considered factors as shown in section 2.2. Nevertheless, authors recognized the fact that, each vulnerability factor considered likely contributes individually to landslides vulnerability. Thus, these factors were considered separately into: (1) social vulnerability resulting on the population density, communication assets (possession rate of mobile phone, television or radio), employment rate as the percentage of adult people employed, literacy rate indicating the percentage of residents in Ngororero district who easily can read and write, mud houses as the percentage of population owning mud houses and the percentage of people with unimproved drinking water. While the (2) ecological vulnerability was determined by using the study area's elevation, slope, land use and land cover and rainfall. In order to standardize these vulnerability causal factors, the percentage of each factor was calculated by using the normalized weighted vulnerability as follows:

$$TLV = \sum_{i=1}^{10} \left[\left(\frac{\%Ci}{\sum \%Ci}\right) \times \left(\frac{Ci}{p}\right) \right] \qquad (1)$$

Where TLV is the total landslides vulnerability, C_i is the category attribute; $\%C_i$ is the category attribute percentage and P is the total population of the Ngororero district. The above equation 1 was used to generate social, ecological and total landslides vulnerability. The authors adopted the above GIS-based normalized weighting method, as suggested by recent scholars (Smith et al. 2016; Wang et al. 2018; Hassaan et al. 2017; Armenakis et al. 2017) due to its application and good results in terms of spatial distribution of disaster risk vulnerability within an area of interest. The obtained landslides vulnerability was divided into five classes: very low, low, moderate, high and very high vulnerability with values ranging between 1 and 5 (Table 1) by using the natural break method.

Table 1. Vulnerability evaluation scale

Scale	Definition
1	The factors contribute equally to landslides vulnerability (**equal relative importance**)
2	The factors contribute more slightly to landslides vulnerability compared to other factors (**low relative importance)**
3	The factors contribute moderately to vulnerability compared to other factors (**moderate relative importance**)
4	The factors contribute highly to landslides vulnerability compared to other factors (**high relative importance**)
5	The factors contribute very highly to landslides vulnerability compared to other factors (**very high relative importance**)

2.4 Risk estimation

The spatial risk index for each spatial unit has been estimated by using the spatial layer operation between the hazard and vulnerability. This spatial intersection was performed with use of the raster multiplication operation. The index value for each grid raster cell was estimated and the ranked map based on the index value has been generated. Thus, the landslides risk map was produced as the intersection of the landslides inventory map and vulnerability spatial layers, as shown in the following equation 2.

$$LR = \text{LI} \cap \text{TLV} \qquad (2)$$

Where LR is the landslides risk, LH is the landslides inventory and TLV is the total landslides vulnerability.

3. Results

3.1 Social and ecological vulnerability

The results, as illustrated in Fig.4 (a), showed high social landslides vulnerability within the highly populated sectors. While the sectors recording high ecological landslides vulnerability (Fig.4 (b)) were those with high elevation, slope, land use and land cover and rainfall. However, sectors with low possession of communication assets (telephone, radio and television), high percentage of mud houses and low literacy rate revealed, at high extent, both social and ecological landslides vulnerability (Fig.4 (a, b)). This lack of appropriate communication tools, which could help in risk information sharing, expresses the likely increasing vulnerability, unless appropriate risk awareness enhancing mechanisms among the community are regarded.

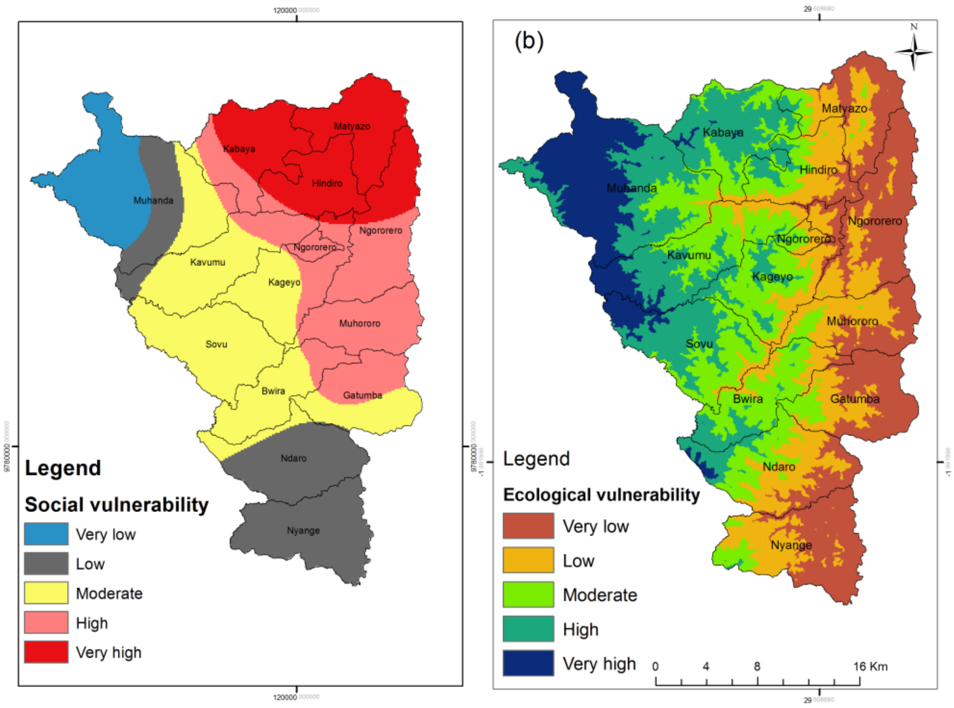

Fig.4. Spatial social (a) and ecological (b) landslides vulnerability indicated variation on the landslides vulnerability. The sectors with high vulnerability caused by the socio-economic (population density, literacy rate, communication system, employment rate, mud houses) are not the same as sectors vulnerable to landslides as a result of elevation, slope, LULC and elevation.

3.2 Total landslides vulnerability

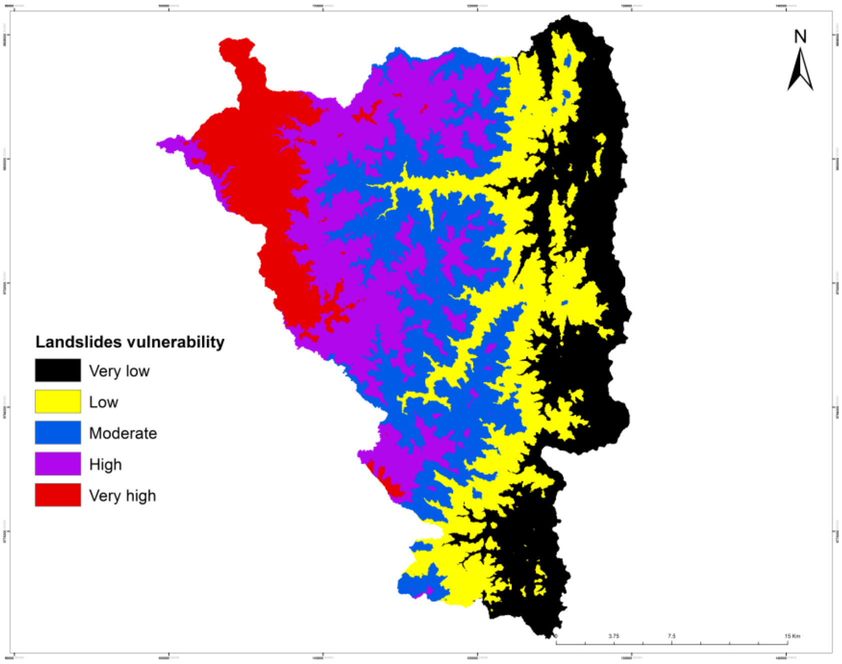

Fig.5.Total spatial landslides vulnerability in Ngororero district shows large extent of landslides vulnerability in the areas of the district with high elevation, slope and rainfall.

3.3 Landslides Risk

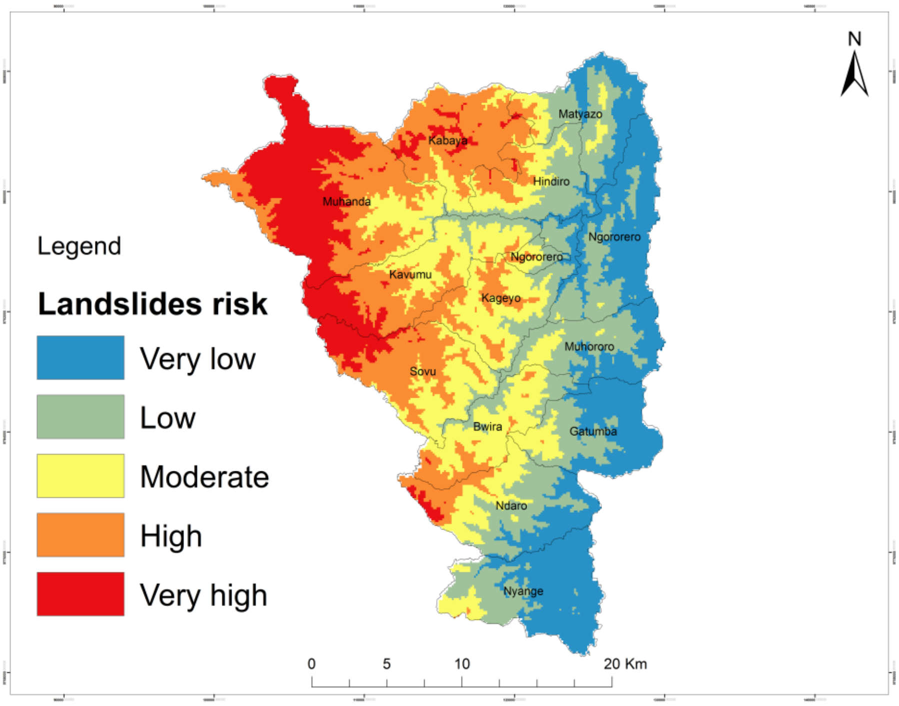

Fig.6.Spatial estimated distribution of landslides risk in Ngororero district, shows large extent of landslides risk within sectors with high slope, elevation, rainfall and land use/cover compared to their counterparts with low record.

The sectors highly vulnerable to landslides risk in Ngororero district register high population density, elevation and rainfall. To minimize the risk exposure, this population needs to be approached to enhance its risk awareness, and indicate to them how to wisely use and manage the available land in order to reduce the runoff likelihood. This requires, for example, promoting the use of bench terraces and rainfall harvest to minimize the rainfall-triggered runoff in high elevated sectors in order to reduce the resulting mudslides and landslides causing severe losses among the residents of Ngororero district. Moreover, as shown in Table 2, the total landslides vulnerability is not similar within all thirteen (13) sectors of Ngororero district; each sector experiences its level of vulnerability. The Kabaya Kageyo and Muhororo sectors are highly vulnerable while the Sovu sector is the least vulnerable to landslides with 4.8 percent. This vulnerability variation expresses the call for approaching each sector based on its vulnerability extent and the causal factors.

Table 1 Estimated landslides vulnerability and risk per sector (in %)

Sector	Vulnerability	Risk
Kabaya	11.4	11
Kageyo	10	8
Muhororo	9	11
Bwira	8	8
Hindiro	8	9
Matyazo	8	6.7
Muhanda	7.4	9.3
Ndaro	7.3	8
Ngororero	7.2	6
Kavumu	6.9	9
Gatumba	6	7
Nyange	6	3
Sovu	4.8	4
Total	100	100

The above Table 1 shows high landslides vulnerability within Kabaya (11.4%), Kageyo (10%) and Muhororo (9%) while the Sovu sector (4.8%) has the lowest landslides vulnerability record. The landslides risk is high in Muhororo and Kabaya sectors with 11 percent then Nyange sector records low landslides risk at 3 percent.

4. Discussion

The disaster losses do not only result on the magnitude and duration of the event, but also from the community's inability for the self-protection and recovery form the hazard. Vulnerability has been used in several fields including not limited to disaster risk, climate change, sustainable development and many more, However, its spatial variation makes it difficult to be well determined due to the reason that, one factor may contribute to vulnerability in one area but not to the other (Eiser et al. 2012; Birkmann et al. 2013). This therefore, expresses that considering each area's wide range of factors could help in better detecting its vulnerability extent. In addition, lack of information sharing tools such as radio, television, newspapers, and local meetings limit the access to the risk information among the vulnerable, and minimize the awareness and preparedness. This as consequence makes the community unaware of the way to use and manage the available resources and the kind of behaviour to adopt to reduce its exposure.

Based on the above, it is worthy note that, the population in Ngororero district is exposed to landslides risk due to lack of risk awareness mainly exacerbated by low level of possession of information sharing tools (Fig.3 (b)). In this area, residents possessing communication tools (radio, television and mobile phones) are not higher than 32 percent within Ngororero district. This limited risk information sharing is noticed amongst the vulnerability triggering factors, where the sectors with high landslides vulnerability in Ngororero districts (Fig.4 (a)) are among those with limited communication tools. For this, the community-based disaster risk reduction is suggested (Yin et al. 2011; Nahayo et al. 2017; Gero et al. 2011) to enhance the capacity of vulnerable groups to analyse and understand the vulnerability causal factors and ways of lessening the vulnerability.

This can be applied in Ngororero district (Fig.4 and 5) to strengthen vulnerable community landslides risk awareness and preparedness, and help policy makers to build a people-centred and equitable development and a resilient society. Moreover, it is good to note that, some sectors record high rainfall compared to others (Fig.2 (c)) with the resulting vulnerability as illustrated in Fig.4 (b). Hence, under climate change generating rainfall patterns and its resulting risk, the exposure to severe losses will likely be registered in Ngororero district. Therefore, it is good to ensure that the community is timely provided with climate related alert, prioritize the education, mainstream disaster risk reduction in science, development and environmental policies. While the identification of underlying drivers through the integrated and multidimensional approach would help to figure out key drivers, how vulnerability is generated, how it increases and how it builds up in this area.

4. Conclusion

This study applied the Geographic Information Systems (GIS) techniques and spatially estimated the landslides vulnerability resulting on the employed ecological and socio-economic triggering parameters within thirteen sectors of Ngororero district of Rwanda. The results indicate high vulnerability within Kabaya, Kageyo and Muhororo sectors highly populated with high elevation, rainfall and slope, low communication tools and literacy rate. Also, it is noted that, more than 50 percent of the land is under cropland, which reveals that the land is not well covered and expresses easy runoff facilitated by the study area’s high altitude, slope and rainfall, which in turn generate mudslides and landslides. In addition, the vulnerability to landslides risk is likely to increase in Ngororero district as long as the information sharing systems are not empowered, while those operating are not equally reaching the whole community for early risk awareness, preparedness and resilience. The analysis suggests to (1) approach the local community to strengthen its risk awareness and preparedness through education, local trainings and meetings, (2) ensure strong population growth control measures, and wise use and management of the available land, and (3) initiate/empower the practice of bench terraces, agroforestry and rainfall harvest to minimize the runoff .

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