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Mapping Landslide Susceptibility and Analyzing Its Impact on Community Livelihoods in Gakenke District, Northern Rwanda

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Abstract

This study spatially distributed landslide susceptibility and assessed its impact on community livelihoods in Gakenke district of Rwanda. The Global Positioning System (GPS) located recent landslides from which inventory map was built. Six conditioning factors: elevation, slope, land use and land cover, rainfall, soil texture and lithology were analyzed by Geographic Information System (GIS) to map landslide susceptibility. The results showed that Janja, Muzo, Kamubuga, Kivuruga and Muyongwe sector are highly susceptible to landslide. The elevation, slope, poor land management and rainfall are the key drivers to landslide in this area. The findings indicated that the residents are not aware of landslide causal factors due to low level of education and trainings. Also, rain harvest which could minimize the runoff is not yet practiced; this in turn impacts on people's livelihoods by killing/injuring people, damaging their infrastructures and natural resources. Therefore, it is suggested to empower rainwater harvest, deliver education and training to enhance community awareness, and ensure that the local community is involved in planning and execution of landside risk reduction schedule.

Keywords

Community, Gakenke District, GIS, Landslide Susceptibility, Livelihoods

1. Introduction

The occurrence of landslide cause considerable losses and damages to vulnerable people. This is mainly increasing due to the fact that the risk reduction policies are top-bottom while community involvement can help to empower their mitigation and adaptation capabilities (Anderson & Holcombe, 2013). It is reported that landslide causes 17% of all casualties of natural hazards in the world and it is predicted that in the future, with the increase in urbanization, deforestation, and changes in climate conditions, landslide occurrence will grow (Armaş, 2011; Ayalew et al., 2005; Akgün & Bulut, 2007). One of the main approaches for developing hazard reduction strategies is creating the landslide susceptibility maps (LSM) (Murillo-García et al., 2017). The landslide susceptibility mapping (LSM) has a significant role in risk mitigation of landslides since it can provide spatial distribution of potential slope failures (Felicísimo et al., 2013).

Future landslides are more likely to occur in the areas which were previously affected with landslides (Murillo-García et al., 2015; Claeys et al., 2017). Landslide susceptibility map identifies areas which are subject to landslides and is measured from low to high. The landslide susceptibility map takes into account where the landslides occur and the causes of landslide such as slope, soil type and the impact of the flow of water in a given area (Abdulwahid & Pradhan, 2017). Previous reports indicated that since 1960s, there have been disaster records in Rwanda such as flood, landslides, droughts, famine, earthquakes and volcanic eruptions. These hazards affected people's lives (killed, injured and homeless), damaged croplands, livestock loss, and destroyed infrastructures (Piller, 2016; Wagesho & Claire, 2016; Nsengiyumva et al., 2018). Today flood and landslides are the major concerns among others, and are largely being registered by the north-western zones of Rwanda (Bizimana & Sönmez 2015). Specifically, high rate of poverty and population density, elevated land, slope and frequent torrential rainfall are the major causes of landslide occurrence in Rwanda (Nsengiyumva et al., 2018).

In Rwanda, the north western is the largely affected zone by landslide. Hence, based on the fact that landslide is gradually causing damages and losses among people, it is good not only to map landslide susceptibility but also, to assess the local community's awareness on its exposure, and the extent to which their susceptibility impact on people's livelihoods would help to envisage appropriate risk reduction measures. In Gakenke district, the topography has direct influences on the intensity and character of landslides, high elevation and slope, deforestation and inappropriate land use are responsible for soil erosion in Gakenke district along with its frequent and torrential rainfall leading to usual occurrence of landslide (Benineza et al., 2019). In this area, only one study (Benineza et al., 2019) has been conducted to assess landslide hazard. The study only used elevation, slope, soil types and rainfall as conditioning factors and omitted assessing community disaster awareness. This expresses lack of scientific studies employing a series of factors and integrating community perception in order to enable both policy makers and community to realize the required hazard management measures. Therefore, this study aimed at mapping landslide susceptibility; and assessing community susceptibility awareness and its impact on livelihoods in Gakenke district of the northern province of Rwanda.

2. Methods and Materials

2.1. Study Area

This study was conducted in Gakenke district, one of five districts of Northern Province of Rwanda. The district borders with Rulindo district at its Eastern side, Burera and Musanze districts at its North, Nyabihu district at its West, and at the South, by Kamonyi and Muhanga districts (Benineza et al., 2019). The district is divided into 19 administrative sectors and occupies a surface area of 704.1 km^2, and a total population of 338,234. The population density of Gakenke District is 503 hab/km^2 (Benineza et al., 2019). **Figures 1(a)-(c)** illustrates the location of Gakenke district and its bordering districts, its sectors and landslide inventory.

2.2. Samples and Data Collection

Landslide Inventory

The study of van Western et al., (2008) suggested that for landslide susceptibility assessment, it is good to consider past distribution of landslide. This is due to the fact that factors that led to past landslide occurrence in the area of study if reoccurred, may result from the same factors. For the present study, historical record and field surveys identified 14 past landslides from which the landslide inventory map (**Figure 1(c)**) was prepared. The last events were recorded by using the Global Positioning System (GPS) with assistance of local residents. Furthermore, after building landslide susceptibility map, the local communities were approached in order to assess their awareness on their landslide susceptibility and its impact on their livelihoods. For this case, the dead and/or injured people, damaged infrastructures (roads, hospitals, and schools), affected livestock were

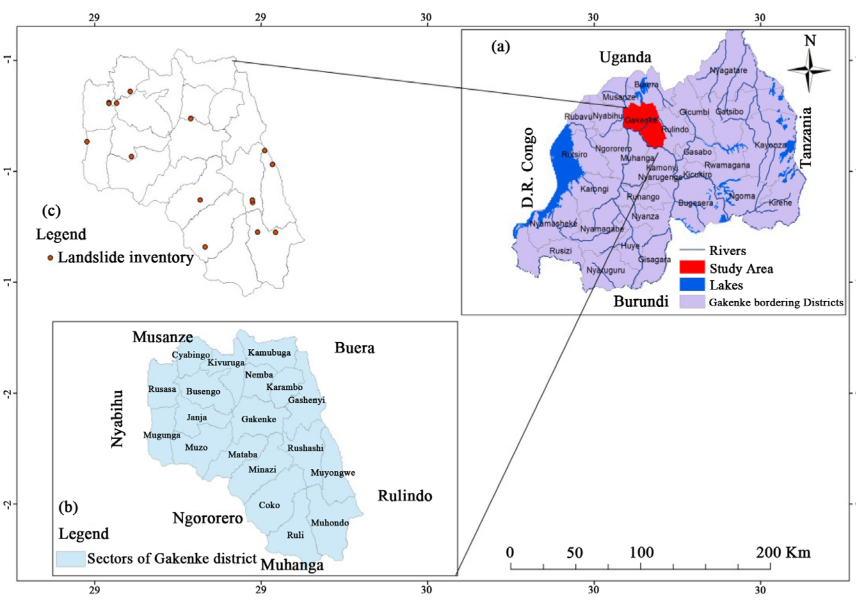

Figure 1. Location of Gakenke district in Rwanda (a), its sectors (b) and landslide inventory (c).

considered. The key informants were purposively selected such as leaders and other community representatives in order to assess their views on landslide susceptibility. In all sector, sample size was selected randomly by using the Yamane formula (Yamane, 1992), for calculating the sample from the population of Gakenke district, Equation (1):

$$n = \frac{N}{1 + Ne^2} \quad (1)$$

where n is the sample size, N is the population size, and e is the levels of precision. To minimize the risk that the sample size might not represent the true population, the margin error was fixed at 10%. Therefore, the sample became:

$$n = \frac{338324}{1 + 338324 \times 0.1^2} = 99.9 \simeq 100 \quad (2)$$

Thus, as indicated in the Equation (2), a sample of one hundred (100) was used. However, this number is too high to be covered; hence, the study were divided into the total 19 sectors in order to obtain the sample size per each sector. Thereafter, the authors calculated the sample per each sector considered by this study. The proportionate sampling method was used (Kim et al., 2014), to determine the number of respondents per sector, Equation (3):

$$ni = \frac{Ni * n}{N} \quad (3)$$

where ni is the sample size proportion to be determined, Ni is the population proportion in the sector, n is the sample size calculated in Equation (2) and N is the total population considered by the study. Therefore, the proportion of population in each sector is shown in Table 1.

Table 1. Sample size per sector.

Sector	Population	Sample size
Busengo	20,164	6
Coko	16,340	5
Cyabingo	17,544	5
Gakenke	22,670	7
Gashenyi	20,067	6
Janja	15,804	5
Kamubuga	20,758	6
Karambo	12,159	3
Kivuruga	18,226	5
Mataba	14,346	4
Minazi	13,527	4
Mugunga	19,361	6
Muhondo	20,125	6
Muyongwe	15,550	4
Muzo	21,378	6
Nemba	15,643	7
Ruli	18,516	5
Rusasa	18,250	5
Rushashi	17,806	5
Total	**338,234**	**100**

To collect the information from the sample size, a structured questionnaire was used. In order to collect data from residents of the district, from each sector, the respondents were purposively selected based on targeted women, youth representatives, socio-economic agents at sector level, local residents, schools, hospitals and church leaders.

2.3. Data Analysis

The collected datasets were processed and analyzed. The Statistical Index (SI) Model was used to estimate the contribution of the used causal factors to landslide occurrence. The Statistical Index (SI) is accepted as bivariate statistical method (Van Westen et al., 1997). The model has a basis requiring calibration from correlation between known incidents. In the model, the weighting value for each conditioning factor class is defined as the natural logarithm of the landslides density in a class divided by landslides density in the entire map (Van Westen et al., 1997). The statistical index is calculated using Equation (4).

$$\text{Wij} = \text{In}\left(\frac{\text{DensClasij}}{\text{DensMap}}\right) = \text{In}\left[\frac{\frac{\text{Npix}(\text{Sij})}{\text{Npix}(\text{Nij})}}{\frac{\sum_j \text{Npix}(\text{Sij})}{\sum_j \text{Npix}(\text{Nij})}}\right] \tag{4}$$

where Wij is the weight for class j within the triggering factor map I, DensClasij is density of landslides in class j within the triggering factor mapI, DensMap is the density of landslides in the entire map, Npix(Sij) is the number of pixels in class j within the triggering factor map I and Npix(Nij) is the number of pixels in class j within the triggering factor map i. Based on Equation (4), the landslide susceptibility map was produced.

$$\begin{aligned}\text{LSIsi} = {} & \text{Wsi}(\text{elevation}) + \text{Wsi}(\text{slope angel}) + \text{Wsi}(\text{rainfall}) \\ & + \text{Wsi}(\text{lithology}) + \text{Wsi}(\text{soil texure}) \\ & + \text{Wsi}(\text{Land use and land cover})\end{aligned} \tag{5}$$

where LSIsi is landslides susceptibility index with statistical index and Wsi is the weight of each landslides conditioning factor determined by the statistical index model. The map of landside susceptibility was built by using the Geographical Information System (GIS) in its Spatial Analysist Tools which helped to merge the SI values of all used factors and indicate the resulting landslide susceptibility. Furthermore, after building landslide susceptibility in this area, the data collected through the questionnaire were analyzed by using the Statistical Package for Social Sciences (SPSS) Software.

3. Results and Discussion

3.1. Landslide Susceptibility Conditioning Factors

The six landslide conditioning factors such as elevation, slope, rainfall, land use and land cover, soil texture and lithology were assessed. Elevation and slope angles used, (**Figure 2(a)** and **Figure 2(b)**) were derived from Digital Elevation Model (DEM) of 30 m resolution. These datasets were acquired from the United States Geological Survey Earth Explorer (USGS, 2018). The five elevation classes were: 1343 - 1595 m, 1595 - 1764 m, 1764 - 1934 m, 1934 - 2150 m and 2150 - 2654 m. The classes of slope in angles were from 0 - 15˚, 15˚ - 25˚, 25˚ - 35˚, and 35˚ - 45˚ and >45˚. The report on rainfall and disaster in Rwanda were considered, mainly northern part of Rwanda where Gakenke district is located, in this areas more than 70% of landslide occurrence and losses are rainfall-induced (MIDIMAR, 2014). Monthly precipitation data were interpolated by using 28 years data from 1990 to 2018, rainfall data collected from meteorological stations operating countrywide. The data were provided by the Rwanda Meteorology Agency (RMA, 2018). The mean monthly rainfall (**Figure 2(c)**) were in the range of 0 - 50 mm, 50 - 60 mm, 60 - 70 mm, 70 - 80 mm and >80 mm.

The type of the land coverage represents the likelihood of the land exposure to erosion and runoff risks including landslide. The land use and land cover (LULC) map of 2019 was produced from multispectral Landsat-8, Operational Land Imager (OLI) images. These images were acquired from the United States Geological Survey Earth Explorer (USGS, 2018). The land cover/use map was classified and five land use and land cover (LULC) classes, (**Figure 3(a)**) were produced based on the East African Classification of Regional Center for Mapping and Resources Development (Belle et al., 2014). Finally, the lithological and geological features used, (**Figure 3(a)** and **Figure 3(b)**) were derived from Rwandan geological, mining and soil databases (Rushemuka et al., 2014). The three lithology classes were schist, basic igneous rock and water bodies. Whereas four soil texture classes were sand clay loam, clay loam, sand clay and clay.

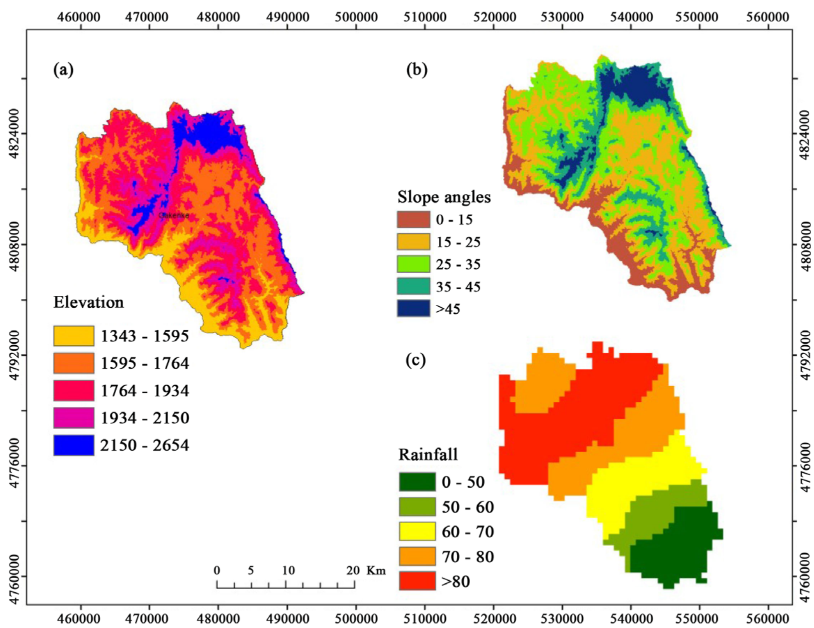

Figure 2. Elevation in meters (a); Slope angles in degrees (b) and Rainfall in millimeters (c) distribution in Gakenke district.

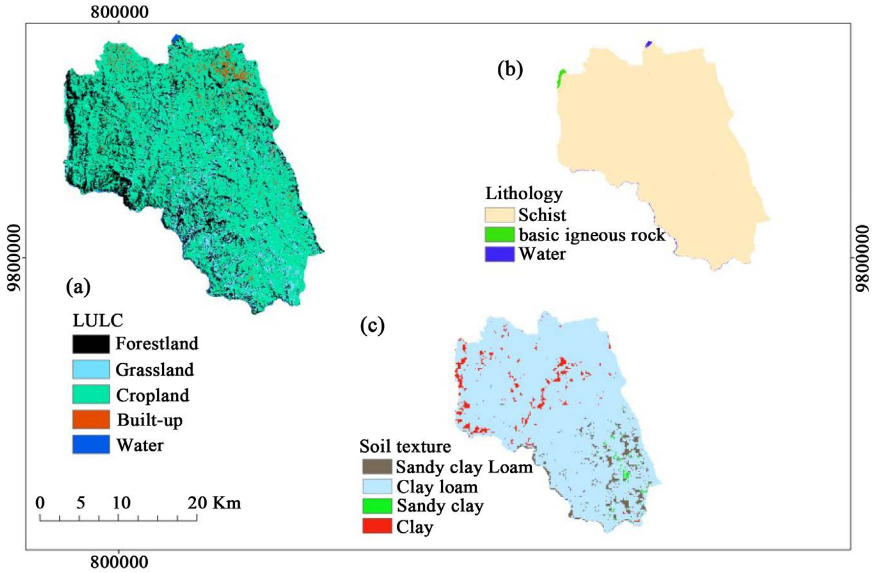

Figure 3. Land use and Land Cover (a), Lithology (b) and Soil texture of Gakenke district.

3.2. Landslide Susceptibility Mapping

The eight conditioning factors which likely cause the occurrence of landslide and exposure among people were identified. The results on the spatial relationship between each landslide conditioning factor and landslide occurrence by the SI Model are shown in Table 2. The results indicated that high SI values of elevation are mainly in the classes of 2150 - 2654 m (2.32) and the elevation classes of 1934 - 2150 m and 1343 - 1596 m which recorded an SI value of 1.82, respectively. With regard to slope angles, it was noted that high SI value are in the slope angles of 25 - 35 degrees and 15 - 25 degrees which recorded 0.39 and 0.31 SI values, respectively.For the rainfall, highest SI value was in the ranges of 50 - 60 mm (0.82) and 0.58 for >80 mm. Also, the results in Table 2 pointed out the schist as the dominating lithological class with high SI value (0.81). In addition, among other soil textures, the SI model indicated the clay (0.37) and sandy clay loam (0.24) as the major soil texture class which conditions landslide occurrence in this area. For the land use and land cover, the results in Table 2 revealed high SI values of 1.13, 0.86 and 0.62 for the land use classes of cropland, grassland and forest, respectively.

The results in Figure 4 indicated that in Gakenke district, the susceptibility to landslide is experienced differently. Some parts of the district are under high susceptibility while others are in the middle or low susceptibility to landslide. This expresses that the considered causal factors contribute to landslide occurrence at different extent within the district and that the risk reduction should consider each area's susceptibility class.

The results in Figure 4 indicated that Kamubuga sector is largely susceptible to landslide in this district followed by Janja, Muzo, Muyongwe and Kivuruga sectors. Similarly, regardless the types and number of conditioning factors employed, the results of the study conducted by Benineza et al. (2009) in this area

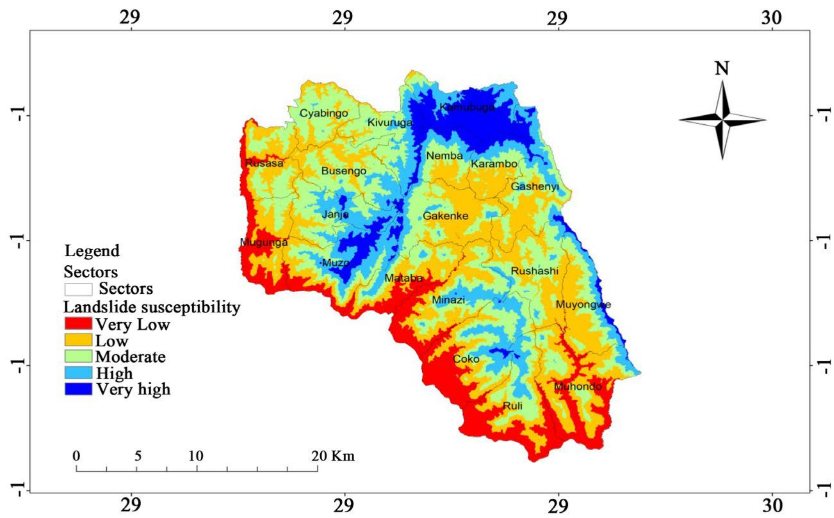

Figure 4. Landslide susceptibility map of Gakenke district.

Table 2. Relationship between landslide occurrence and conditioning factors by SI model.

Factors	Classes	Class domain (%)	No. landslides	No. landslide pixels	SI
Elevation	2150 - 2654	3.7	1	1036	2.32
	1934 - 2150	8.8	2	1372	1.82
	1764 - 1934	34	4	3468	1.42
	1595 - 1764	38.2	3	3196	0.67
	1343 - 1596	15.3	2	1372	1.82
Slope angles	>45	1.2	1	3069	0.26
	35 - 45	9.4	2	1427	0.21
	25 - 35	39.4	4	3791	0.39
	15 - 25	36	3	3548	0.31
	0 - 15	26	2	2978	0.12
Rainfall	>80	21.6	3	3114	0.58
	70 - 80	22.1	3	3320	0.54
	60 - 70	19.7	3	3219	0.54
	50 - 60	34.3	4	4201	0.82
	0 - 50	2.3	2	1123	0.26
Lithology	Basic igneous rock	0.8	0	193	0.11
	Schist	99.1	12	4642	0.81
	Water	0.1	0	179	0.04
Soil texture	Sandy clay loamy	12.1	3	2651	1.24
	Clay loamy	31.3	3	2519	0.19
	Sand clay	8.6	2	1242	0.12
	Clay	48.4	4	4984	0.37
LULC	Built-up land	6.2	1	1237	0.29
	Cropland	39.4	4	4328	1.13
	Grassland	26.2	3	1801	0.62
	Forest	26.1	3	1971	0.86
	Water Bodies	2.1	0	1003	−0.31

confirmed that Kamubuga sector is highly vulnerable to landslide. Thus, appropriate hazard management should prioritize this sector. The findings in Figure 5 confirmed this exposure to landslide of those sectors mainly due to their high elevation, slope, rainfall and poor land management. This expresses that landslide risk reduction initiatives should consider these key factors, primarily conditioning landslide occurrence and exposing the residents to the losses.

3.3. Impact of Landslide Susceptibility on Community Livelihoods

Landslide is among the major geological hazards which impact on community's livelihoods. However, it is reported (Shaw, 2012; Bhatta et al., 2016) that full involvement of local people in understanding the causal factors and the extent of their exposure can help to minimize the losses. This is mainly due to the fact that local people's indigenous knowledge enables them to better understand their living area's reality and can be based on while formulating relevant risk reduction.

Among the contacted respondents, the results in Table 3 showed that 36 percent are aged between 18 and 30 years old followed by 29 percent who are aged between 30 and 42 years old. And 58 percent of them are female while 44 percent and 32 percent attended secondary and primary schools, respectively. The local community in this area is at low level aware of exposure to landslide. The results revealed that the channels used to improve people's awareness on landslide occurrence and causal factors are mainly local meetings, radio and television (Table 4).

The delivery of trainings and courses on landslide in this area is still at low pace (Table 4). This can be the reason of the noticed gradual impact on community livelihoods mainly people dead and injured, destructed infrastructures, and damage of natural resources (Table 5). Accordingly, this expresses that the local community is approached but not provided with full information regarding the causes of landslide occurrence and their impact on life and livelihoods.

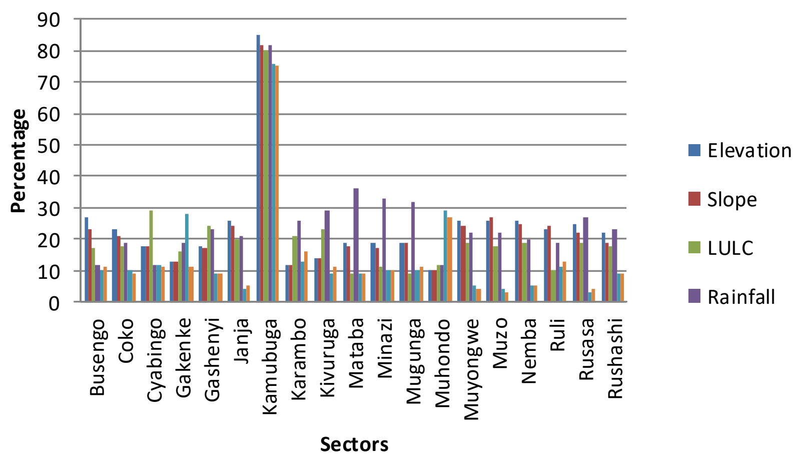

Figure 5. Key landslide causal factors per sector in Gakenke district.

Table 3. Description of Respondents by age, gender and education.

Age	Frequency	Percentage
18 - 30	36	(36)
30 - 42	29	(29)
42 - 60	21	(21)
60 above	14	(14)
Gender		
Female	42	(42)
Male	58	(58)
Education		
Illiterate	13	(13)
Primary	32	(32)
secondary	44	(44)
University	11	(11)

Table 4. Community Awareness on landslide occurrence.

Channels						
Information channel	Schools	Meetings	Radio and Television	Trainings		Total
Frequency	14	46	29	11		100
Percentage	14	46	29	11		100
Causal factors' awareness						
Awareness	Very high	High	Moderate	Low	None	Total
Frequency	3	12	22	31	32	100
Percentage	3	12	22	31	32	100

Table 5. Impact of landslide on community livelihoods.

Livelihood types	Frequency	Percentage
Human death and injury	17	17
Displacement	17	17
Lost livestock	13	13
Damage of resources	25	25
Destruction of Hospitals, schools, bridges and houses	28	28
Total	100	100

This was recently reported (Nahayo et al., 2018; Mamon et al., 2017) that lack of formal education and training among people leads to increasing risk due to the reason that basic information, knowledge and skills on drivers to disaster occurrence are not known at local level. This is likely similar to Gakenke district (**Table 4**) since only meetings and radio and television are the dominant channels used to share disaster information with local people without referring to formal education and trainings. In addition, the residents of Gakenke district are likely exposed to landslide because their indigenous knowledge is not valued (Table 6) while planning and executing the risk reduction activities. However, if the local people's knowledge is not recognized, their livelihoods might be affected since these people recognize their area better than anyone. Hence, it would be good to integrate people in planning and executing any activity related to their livelihoods. The results were presented in Table 4 where respondents asserted that landslide related information is, at high extent, communicated to the local community through the local meeting. This was confirmed by 46% of the population evaluated however, 29 of them mentioned that the information is gained through radio and television, Table 4.

The education and delivery of related education is still at low pace. This is confirmed by low level of awareness among respondents which was ranked at 32% in Gakenke district. The local people which manifested the awareness on landslide causal factors were 22%, which expressed low level of awareness on landslide which in turn, leads to the increasing hazards exposure since people are not aware of the main causal factors and the adaptation mechanisms.

The residents in Gakenke district are affected by landslide occurrence mainly due to the infrastructure damage such as hospitals, schools, bridges and houses. Apart from infrastructure damage, some resources were affected such as land and water, as confirmed with 25% informants. However, human death, injuries and displacement were both recorded with 17% of respondents, respectively. The findings indicated that some measures are implemented toward reducing community susceptibility to landslide in Gakenke district. As shown in Table 6, bench terraces and agroforestry practices are the main measures being implemented to minimize community exposure to landslide, as highlighted by 25% and 24%, respectively.

The future occurrence likelihood in Gakenke district was estimated by referring to recent events recorded. The results in Figure 6 indicated that Kamubuga as highly susceptible sector (Figure 4) recorded no event in 2019, which expresses low future occurrence likelihood. However, it was noted that Rusasa,

Table 6. Types and effectiveness of initiated exposure reduction measures.

Measures	Frequency	Percentage
Bench terraces	25	25
Agroforestry	24	24
Rain harvest	13	13
Enforced building code	13	13
Relocating to safe zones	15	15
Valuing indigenous knowledge	10	10
Total	**100**	**100**

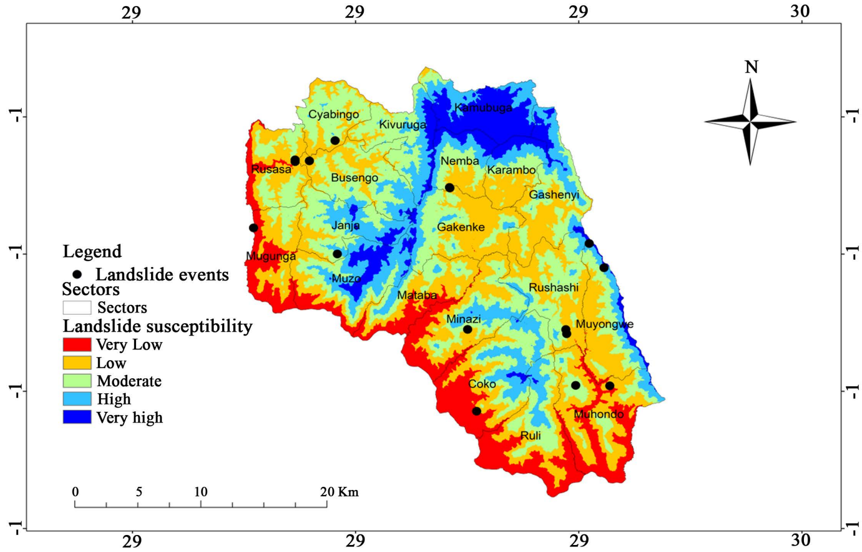

Figure 6. Predicted landslide occurrence.

Muhondo and Cyabingo sectors are likely exposed to future landslide. This is mainly the result of high rainfall across these sectors (Figure 2). Similarly, as recently reported (Ndayisaba et al., 2017), rainfall is among the drivers to landslide in the northwestern Rwanda, and rainfall was ranked among the primal causes of landslide occurrence in Gakenke district (Figure 4 and Figure 5).

However, among the initiated strategy for hazards reduction (Table 6), rain harvest is not highly prioritized compared to agroforestry and bench terraces (Table 6). This calls for strong interventions in mobilizing the local people to harvest the rain in order to minimize the runoff which increases the occurrence likelihood due to elevated land of the study area. This will results from the fact that, as indicated in Figure 6, future landslide occurrence is high in sectors recording high rainfall (Figure 2(c)). Thus, rain harvest would be one of the approaches to reduce future occurrence.

4. Conclusion

This study attempted to map landslide susceptibility and assess its impact on community's livelihoods. The authors employed six conditioning factors (elevation, slope, land use, rainfall, soil texture and lithology). The Geographic Information System was used to provide the resulting susceptibility map. It was noted that Kamubuga, Janja, Muzo and Muyongwe sectors are highly susceptible to landslide. The elevation, slope, rainfall and poor land management were ranked as key divers to landslide occurrence in Gakenke district. The results, by using questionnaire among the selected informants indicated that, the local people are still at low level, aware of their exposure to landslide mainly due to channels used to share related information with them. The delivery of education and training is not valued and the rain harvest is still not executed in this area regardless the fact that it is among landslide occurrence conditioning parameters. Based on the findings of this study, it is suggested to ensure delivery of formal education and training, rain harvest and valuing local people's indigenous knowledge while planning and executing landslide risk reduction schedule. This study can serve as guiding tool to policy makers and others interested in disaster risk reduction as well. Due to time and budget constraint, it was not easy to consider several factors, which comes to suggesting further research using many factors such as socio-economic, physical and environmental to assess community landslide vulnerability in this area.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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