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Analysis of Residence Suitability Under Landslide Occurrence in Rwanda

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Abstract

Landslide occurrence is at large extent, negatively impacting on poor societies especially those located in disaster prone areas. This study analyzed the residence suitability with regard to the occurrence of landslide in Kamubuga sector of Gakenke district in the Northern Province of Rwanda. The authors used six landslide causal factors: land use and land cover, rainfall, slope, elevation, soil texture and lithology. These factors were collected from the United States Geological Survey (USGS), Rwanda Geoportal and Rwanda Meteorological Agency (RMA). The data on population density and built-up areas were collected from the National Institute of Statistics of Rwanda (NISR). The extraction by mask technique in Spatial Analyst Tools of the Geographic Information System (GIS) produced maps of landslide conditioning factors. Then Math Algebra of GIS differentiated landslide hazard while Microsoft Excel and GIS indicated areas suitable to residence in regard to landslide hazard in Kamubuga sector. The results showed that elevation, slope, rainfall and poor land management are the major causes of landslide occurrence. Rukore, Kamubuga and Kidomo cells were classified within high and very high landslide hazard. Regarding residence analysis, Kamubuga cell occupies large land of 10.2 Km^2 and is densely populated with 824/Km^2 but highly prone to landslide. However, Mbatabata cell, second large land (8.4 Km^2) is the least densely populated with 584/Km^2 people and not prone to landslide. Thus, areas densely populated are almost prone to landslide and recognizing this fact would help to minimize losses among people and select the best residence areas. Therefore, local people are suggested to recognize the contribution of land use and land cover (human activities) in landslide occurrence and then act responsibly. Also, relocating people from prone to safe zones would minimize loss on lives and livelihoods as well.

Keywords

Landslide, Residence, GIS, Kamubuga Sector, Gakenke District

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1. Introduction

The damages due to the occurrence of landslides are also predicted to rise in the subsequent decades with population growth, progression of residential areas and infrastructure in high-risk areas, continuing deforestation, and the increase in regional precipitation [1]. The resilience of people to choose living in disaster-prone areas can be lately set in making decisions, whether they remain in the area or choose to stay [2]. The choice to stay and settle in a disaster-prone location is influenced by certain factors, mainly the socio-economic conditions of the community that do not allow them to move [3, 4, 5]. The risk from landslides and their consequences are, at large extent affecting the developing areas with poor adaptation capabilities [6]. In order to minimize landslide risks among highly populated areas, local government must

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arrange a list of requirements for land using and safety building codes in land with landslide hazard. In case landslide occurs questions like (a) how can areas re-development bring out in order to return people living back?, and (b) how can hazard mitigation adopted in areas redevelopment to minimize the risk, if landslide occurs in the future? should be considered [7, 8, 9].

In Rwanda, the occurrence of landslide significantly has negative impact on development initiatives and areas largely impacted are the densely inhabited with low adaptation capabilities. This causes severe losses and damages among people, their belongings and natural resources degradation as well [10, 11]. Recent reports on landslide in Rwanda suggested that assessing the local community awareness on its landslide exposure, and the extent to which their susceptibility impact on livelihoods would help to envisage appropriate risk reduction measures.

The northwestern Rwanda where Gakenke district is located is reported to be among areas impacted by landslide [12, 13, 14]. The study of [12] indicated that Kamubuga sector is highly susceptible to landslide mainly due to high rainfall, elevation, poor land use and management. However, despite its exposure to landslide, in the literature, there is no study which considered this sector (Kamubuga) to analyze the settlement suitability to identify safe areas with regard to landslide occurrence.

This expresses that scientific study would be useful in this area in order to minimize settlement's exposure to landslide. The uniqueness and contribution of this study is that it considers a small unity of research and that its findings can be easily put into practice at the considered research area. Therefore, this study aimed to analyze the suitability of settlement location under landslide occurrence at Kamubuga sector of Gakenke district in the northern Rwanda.

2. Methodology

2.1. Description of Study Area

This study focused on Kamubuga sector, one of nineteen (19) sectors of Gakenke district in the Northern Province of Rwanda. The Kamubuga sector is bordered by Musanze and Burera districts in the north, Kivuruga sector is located at its eastern side, Nemba and Karambo sectors of Gakenke district border the southern part of Kamubuga sector and Rulindo district at its western side. The sector is subdivided into four cells namely: Kamubuga, Kidomo, Mbatabata and Rukore, and occupies a total surface of 34.7 Km^2 with a total population of 24,220 and a population density of 699 people per Kilometer square.

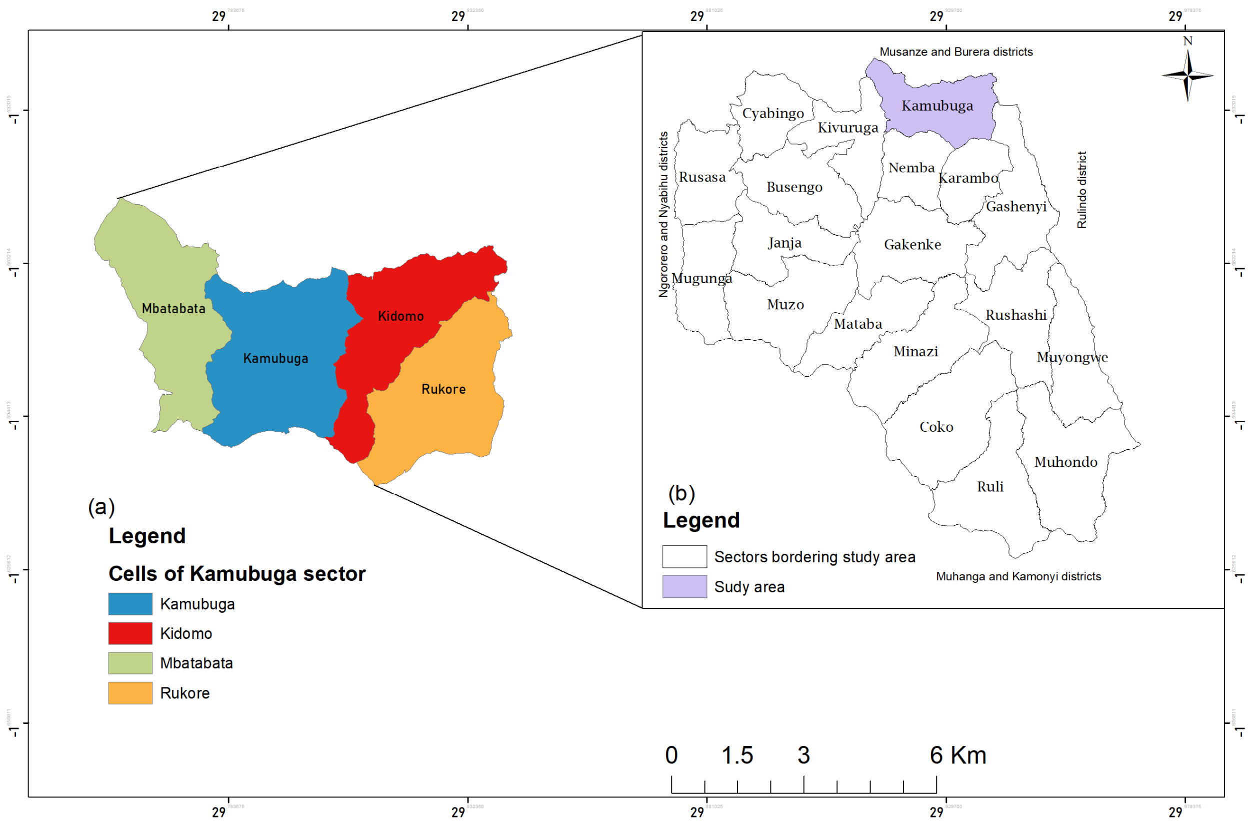

Figure 1. Map indicating Kamubuga sector and its bordering sectors in Gakenke district.

2.2. Datasets and Their Sources

This study employed two types of data namely those related to landslide occurrence and residence suitability in Kamubuga sector.

2.2.1. Landslide Causal Factors

In order to produce the map of landslide hazard, the authors utilized several conditioning factors such as land use and land cover, rainfall, slope, elevation, soil texture and lithology. These factors were collected from the United States Geological Survey [15], Rwanda Geoportal and Rwanda Meteorological Agency. The Geographic Information System (GIS) and Remote Sensing tools were employed to process and map the above landslide causal factors.

The study took into consideration previous researches which highlighted some key factors that cause landslide occurrence in Rwanda [10, 12, 16]. Furthermore, the authors considered the Rwanda national disaster risk management policy, and contingency plan for flood and landslide [17, 18] and the landslide hazard and risk assessment approaches of the United Nations Office for Disaster Risk Reduction [19] as expert opinion.

The study utilized the elevation measured in meters and slope calculated in angles which were derived from Digital Elevation Model (DEM) of 30 m resolution. These datasets were acquired from the United States Geological Survey Earth Explorer [15]. The monthly precipitation data were interpolated by using the 2020-year rainfall data collected from meteorological stations operating countrywide. These data were provided by the Rwanda Meteorology Agency [20]. The employed rainfall was the average monthly rainfall data since hourly or daily rainfall could not be available as some years had incomplete datasets. Thus, it was preferred to employ monthly data which were complete from the specified chosen period (year 2020).

For this study, land use and land cover (LULC) map of 2020 was produced from multispectral Landsat-8 Operational Land Imager (OLI) images. These images were acquired from the United States Geological Survey Earth Explorer [15]. The produced map of land cover/use map of Kamubuga sector was classified into five LULC classes with reference to the East African Classification of Regional Center for Mapping and Resources Development [21, 22].

Finally, the authors employed the lithological and geological features from which both soil texture and lithology were derived and used by the study. Both soil texture and lithology employed by this research were derived from Rwandan geological, mining and soil databases [23].

2.2.2. Residence Status

The authors employed the datasets on population density and built-up areas. These data were taken from the Integrated Household Living Conditions Survey of the National Institute of Statistics of Rwanda [24] and report of Ubudehe 2020 survey.

2.3. Data Analysis

After the collection of data, the collected datasets were processed and analyzed as follows.

2.3.1. Mapping Landslide Hazard and Its Causes

In order to produce landslide map, the study judged it necessary to firstly provide the maps of its causal factors indicated in section 2.3.1. In order to produce the individual map of each landslide causal factor across Kamubuga sector, the authors utilized the same maps of the entire Rwanda territory from which those of Kamubuga sector were extracted by using the shapefile of the study area.

The extraction by mask technique in Spatial Analyst Tools of the Geographic Information System (GIS) was employed. Thereafter, the Math Algebra also found in the Spatial Analyst Tools of GIS was approached in order to merge the above conditioning factors (section 2.3.1) and distribute the resulting landslide hazard within the study area.

In order to estimate the spatial distribution of landslide hazard in the study area, the authors applied the following equation.

$$LH = \frac{E_v + S_v + ST_v + L_v + R_v + LU_v}{6} \quad (1)$$

Where LH is landslide hazard, Ev is the Elevation value, Sv is the Slope value, STv is the Soil Texture value, Lv is the Lithology value, Rv is Rainfall value and LUv is the Land Use value. This value was estimated from very low to very high classes of each conditioning factor. This exercise facilitated the authors to differentiate landslide hazard from very high to very low hazard within cells of the study area.

The obtained landslide hazard was classified in the range of very low (1), low (2), moderate (3), high, (4) and very high (5).

2.3.2. Community Residence Analysis

In order to analyze the residence in Kamubuga sector, the authors employed the Raster Processing technique of the Data Management Tools in GIS. This helped to distribute the population density in every cell and cells' size across Kamubuga sector. For this part of data analysis, the authors additionally employed the data on built-up land which were analyzed form the land use and land cover map in order to indicate the land used for settlement within the study area.

In order to ensure that built-up land is well distributed within cells of Kamubuga sector, the authors approached the sensitivity analysis methods by which the entire map of Kamubuga sector was supposed to be occupied by settlements only and then each cell was appropriated with its settlement percentage.

2.3.3. Landslide Occurrence and Residence Suitability Analysis

The authors finally performed a residence suitability analysis under landslide occurrence by using the Microsoft Excel tool. The study considered each cell' landslide hazard, population density, total land size and built-up land which were estimated in percentage. The authors applied the following equation in order to estimate the residence suitability of each cell by taking into consideration the cell's total size, population density, settlement (built-up land) and landslide hazard.

$$RS = \frac{TL+PD+S+LH}{400} \quad (2)$$

Where RS is the cell's percentage of residence suitability, TL is the cell's total land, PD is the cell's population density, S is the cell's settlement and the LH is the cell's landslide hazard. The authors divided the obtained value by 400 due to the reason that each considered factor in equation 2 was estimated in percentage.

The residence suitability was expressed in percentage and the cell with low percentage was scored as suitable area for community settlement. This exercise enabled the authors to identify cells which are safe for residence and those that are likely to record high risk of landslide due to their residence status.

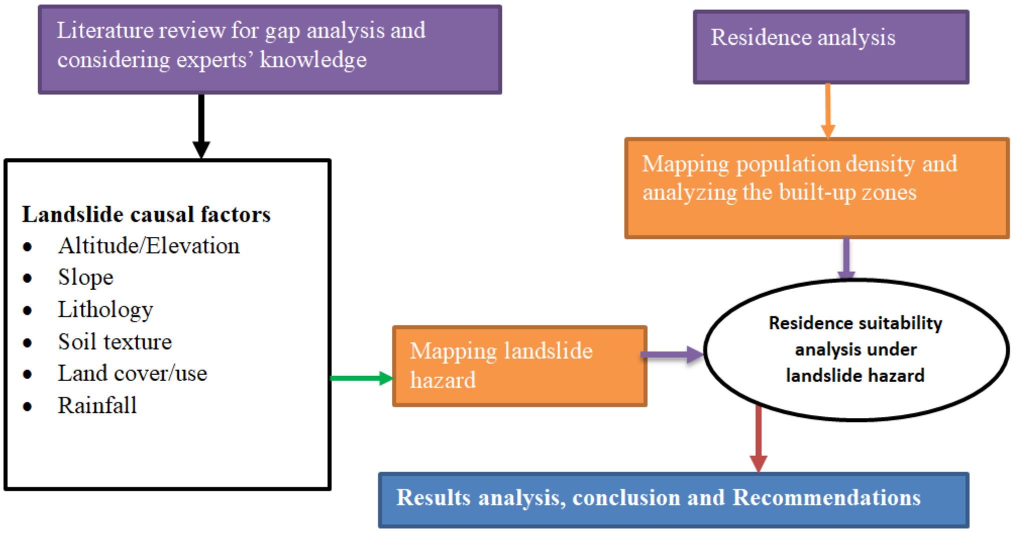

Figure 2. Proposed methodological flowchart.

3. Results

3.1. Mapping Landslide Hazard and Its Caul Factors

As detailed in section, 2.3.1, this section presented the maps of the selected factors which likely cause landslide occurrence and its hazard map in Kamubuga sector.

3.1.1. Landslide Causal Factors

The results in Figure 3 showed that each cell of Kamubuga sector has its value in elevation analyzed in meters. The analysis in Figure 3(a) demonstrated that some parts of Kamubuga, Rukore and Kidomo cells are localized within very high elevation of more than 2,500 meters. However, it was realized that a large area of Mbatabata cell is situated within low and moderate elevation ranging between 1,748 and 2,249 meters (Figure 3).

The spatial distribution of slope in degrees across cells of Kamubuga sector (Figure 3(b)) showed that slope within all cells of the study varies from very low to very high slope. The obtained slope angles ranged from 0-9 degrees (very low slope), 9-16 degrees (low slope), 16-22 degrees (moderate slope), 22-29 (high slope) and 29 – 62 degrees (very high slope).

Regarding the rainfall distribution in Kamubuga sector, the analysis in Figure 3(c) revealed that high rainfall ranging between 76 and 76 mm is recorded by Kidomo and Rukore cells. The low rainfall is largely registered within Kamubuga cell in the range of 73 and 74 mm whereas low rainfall of 70 – 73 mm is predominantly recorded within Mbatabata cell.

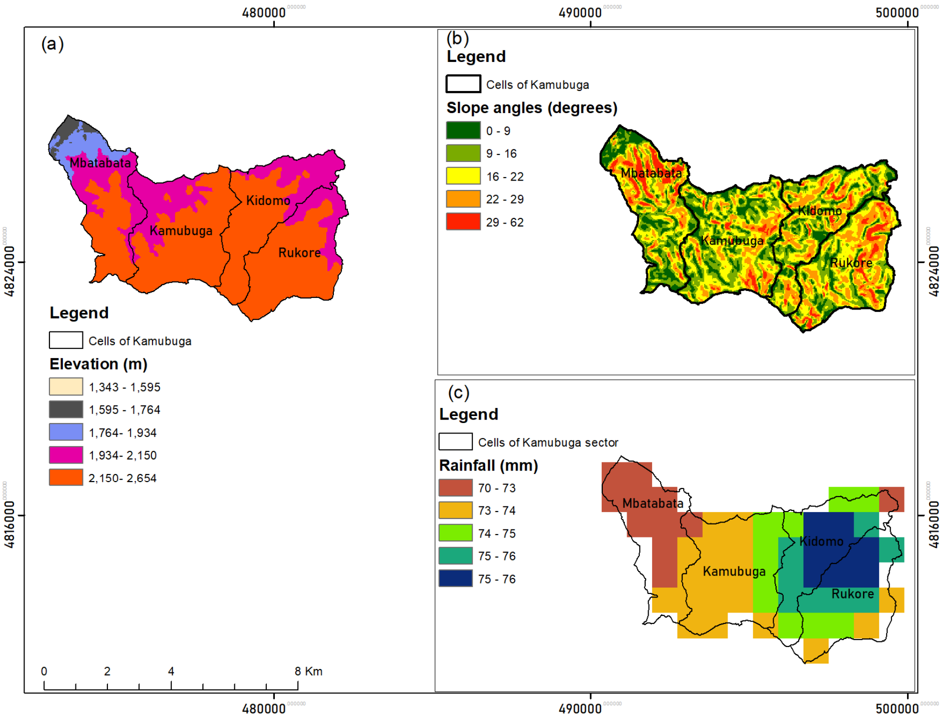

Figure 3. Distribution of (a) elevation in meters, (b) slope in degrees and rainfall in millimeter across Kamubuga sector

The results in Figure 4(a) generated five classes of land use and land cover namely: forestland which occupied 15.37 percent of the total land, grass land seized 14.30 percent of the entire land of the sector; cropland occupies more than half of the study area (58.29 percent). The same Figure 4(a) indicated that built-up land scored 1.85 percent whereas water bodies recorded 6.12 percent of the land of Kamubuga sector. It was noticed that cells of Kidomo and Rukore are the mostly populated cells of Kamubuga sector. This was based on to mention that in case landslide occurs within the study area resulting from land use and land cover, those areas highly built-up would record immense losses as the results of the occurrence of landslide.

For the employed lithology and soil texture, the results in Figure 4(b) showed that the Schist is the dominating lithological class in this area. The same Figure 4(c) revealed that the clay loam is the major class of soil texture within Kamubuga sector.

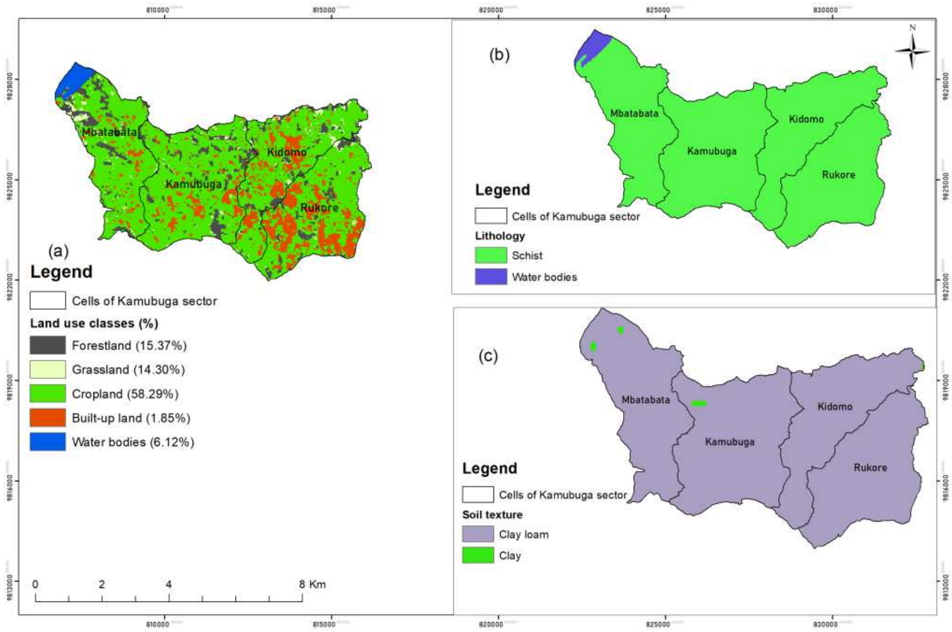

Figure 4. Distribution of land use, lithology and soil texture classes in Kamubuga sector.

3.1.2. Mapping Landslide Hazard

The authors mapped landslide hazard by using the above six causal factors. The results in Figure 5 showed that Kidomo and Rukore cells are classified as highly prone to landslide hazard compared to Kamubuga and Mbatabata cells. The large part of low and very low landslide hazard is localized in Mbatabata cell while Kamubuga cell is largely classified within low and moderate landslide hazard.

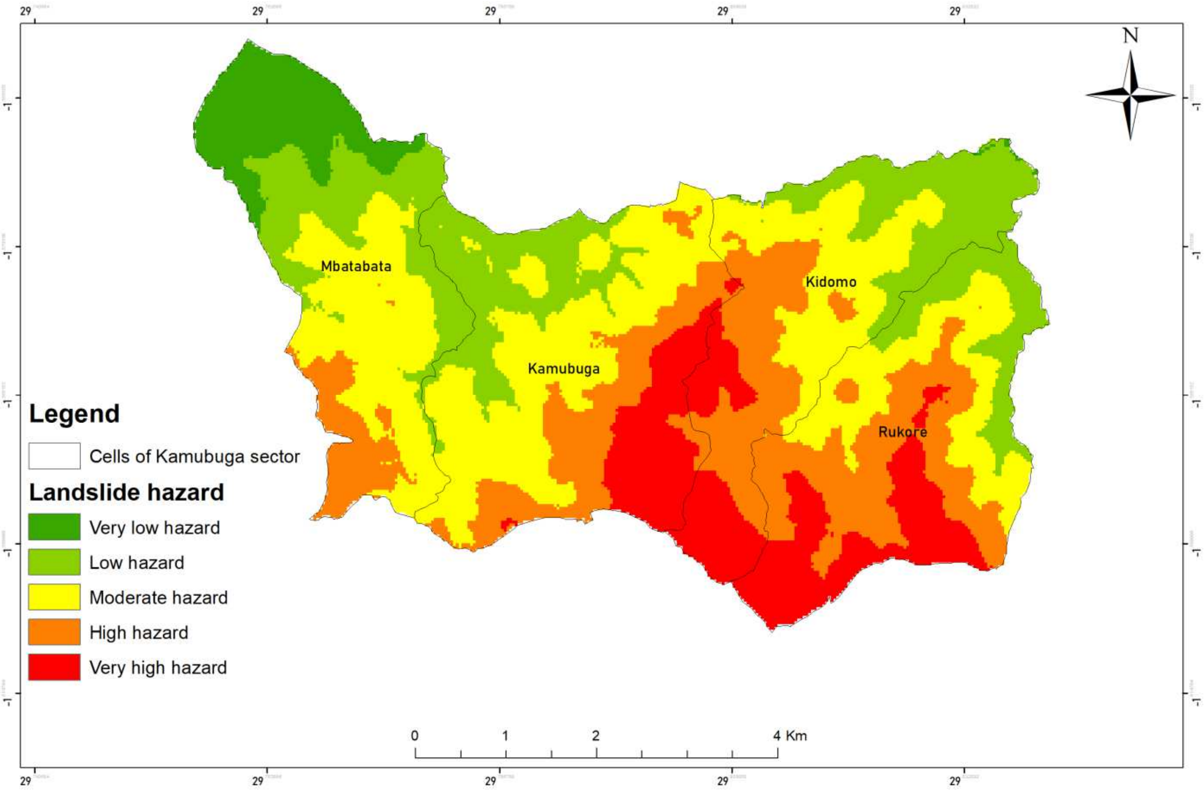

Figure 5. Spatial distribution of landslide hazard across Kamubuga sector.

The estimated landslide hazard in percentage across each cell of the study area was illustrated in Table 1. The results indicated that Mbatabata cell occupies high percentage of very low landslide hazard (31.12 percent) followed by Kidomo cell which occupies 4.3 percent. The analysis in Table 1 also revealed that Kidomo and Rukore cells are very highly exposed to landslide hazard at 16.37 and 23.73 percent, respectively.

Table 1. Estimated landslide hazard per cell.

	Hazard classes				
Cells	**Very low**	**Low**	**Moderate**	**High**	**Very high**
Mbatabata	31.12	12.74	14.29	9.7	0
Kamubuga	0	34.1	28.13	23.17	9.78
Kidomo	4.3	29.41	23.6	19.7	16.37
Rukore	0	24.13	34.12	21.4	23.73

Furthermore, regarding the selected landslide causal factors, the analysis in Table 2 showed that elevation, slope, rainfall and poor land management are the major factors which drive the occurrence of landslide in this area. The Rukore and Kidomo cells record high percentage of the causal factors (Table 2).

Table 2. Estimated contribution of causal factors to landslide occurrence per cell.

	Causes					
Cell	**Elevation**	**Slope**	**Land use**	**Rainfall**	**Soil Texture**	**Lithology**
Mbatabata	11	27.25	14.2	12.85	98	98
Kamubuga	23	21	17.8	15.3	100	98
Kidomo	24.71	18	31	34.6	100	100
Rukore	34.93	33.12	32.19	36.31	100	100

3.2. Residency Analysis

The results in Figure 6 showed that the cell which occupies the largest size in Kamubuga sector is Kamubuga cell (10.2 Km^2) and Kidomo cell is the smallest cell at 7.8 Km^2. The results in Figure 6 revealed that Kamubuga and Mbatabata cells, large in size but record low landslide hazard (Figure 5) would be areas to settle in due to the reason that landslide hazard is low within both cells. Kidomo and Rukore cells with limited land area (Figure 6) are largely exposed to landslide (Figure 5).

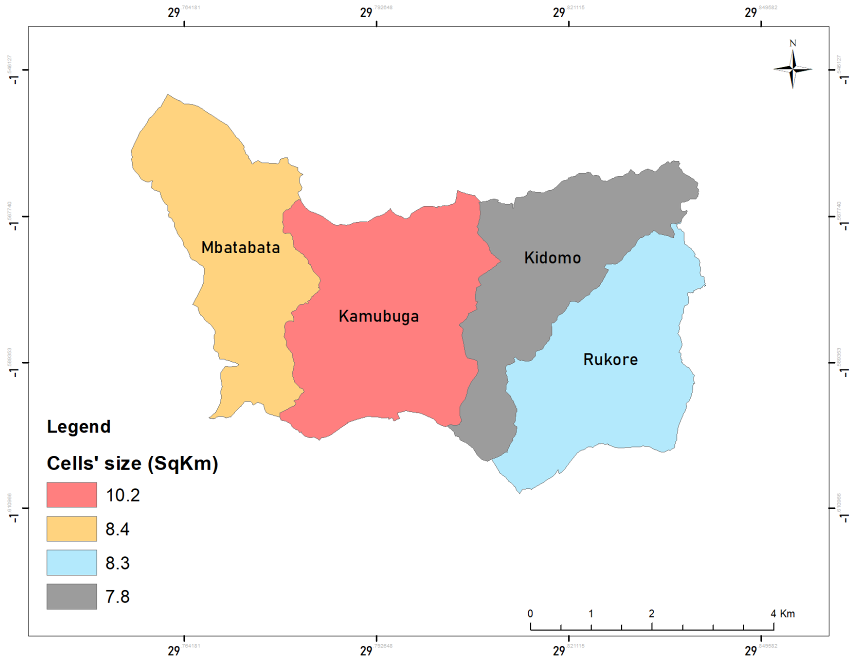

Figure 6. Cells' size at Kamubuga sector.

In addition, regarding the population density per each cell, the results in Figure 7 showed that Kamubuga cell is densely populated at 824 people per square kilometer followed by Kidomo cell which records 689 people per square kilometer. However, it was noted that Rukore and Mbatabata cells record low population density of 668 and 587 people per square kilometer, respectively (Figure 7).

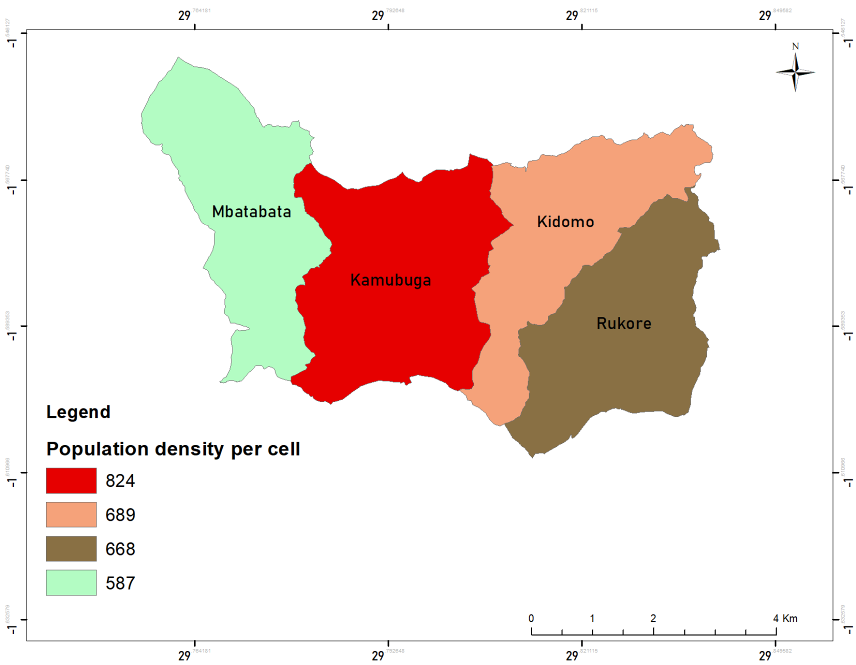

Figure 7. Population density per each cell of Kamubuga sector.

According to Figure 7, Mbatabata cell which records low population density is also not exposed to landslide hazard (Figure 5). Nevertheless, Rukore and Kidomo cells which are highly prone to landslide hazard (Figure 5) are also highly populated (Figure 7). This expresses that people in these two cells are highly prone to losses while if they move to safe cells like Mbatabata, less populated (Figure 7), losses would be minimized amongst people and residents will be living in safe areas as well.

3.3. Analyzing Residence Suitability Under Landslide

In order to analyze the suitability of current residency under landslide hazard in Kamubuga sector, the authors considered both landslide distribution within the study area (Figure 5) and its population density along with built-up land (Figures 7 and 4(a)).

Based on the findings in Table 3, Rukore cell is densely populated (24.14 percent) and highly built-up at 39.87 percent. The cell is also highly exposed to landslide hazard at 20.67 percent and occupies the second small land size of 23. 99 percent after Kidomo cell which seizes 22.37 percent of the total land of Kamubuga sector.

Regarding the residence suitability in Kamubuga sector, cells mainly Rukore and Kamubuga which scored high percentage of 27.16 and 25.03 percent, respectively, are highly exposed to landslide hazard and not suitable to residence. The Mbatabata and Kidomo cells were classified as areas likely suitable to residence compared to their counterparts Rukore and Kamubuga (Table 3). Thus, people settled in Rukore cells which is highly exposed to landslide may be relocated to Mbatabata and Kidomo cells which are safer to landslide.

Table 3. Residency suitability under landslide hazard.

Cells	Factor (percentage)				
	Total land	Population density	Built-up land	Landslide hazard	Residence suitability
Mbatabata	24.23	21.19	17.7	13.57	19.17
Kamubuga	29.39	29.76	21.97	19.036	25.03
Kidomo	22.37	24.88	20.17	18.67	21.52
Rukore	23.99	24.14	39.87	20.67	27.16

4. Discussion

In most cases, landslide losses are increasing among the community due to the fact that people build their houses near steep slope, close to mountain and/or near drainage areas and do not assess their properties' ground status, and areas which recorded landslide in the past are at the same time likely exposed to future occurrence [25].

The authors recognized the above facts and judged it necessary to conduct a research by focusing on Kamubuga sector, recently highlighted among sectors largely exposed to landslide in Gakenke district. The district was pointed to be prone to landslide mainly due to elevation, slope and rainfall along with poor land use and land management [12]. These factors were similarly highlighted by this research in Table 2.

The results in Figure 5 indicated that landslide hazard is distributed differently within cells of Kamubuga sector. The cells of Rukore, Kidomo and Kamubuga record high percentage of landslide hazard (Table 1) compared to Mbatabata cell. However, it was noted that the latter (Mbatabata cell) is populated with 587 people per square kilometer (Figure 7). This is the lowest population density compared to other cells which are densely populated and highly prone to landslide (Figure 7).

The results of this study confirm with recent studies [6, 26] that areas densely populated are likely exposed to disaster since the land is not well managed and human settlements might be located in hazard prone areas. This comes from the fact that people will modify the natural landscape and expose it to easy runoff from which disasters like flood and landslide may result from. In addition, poor land management and inappropriate building locations cause people to record disaster losses. This is the same case to Kamubuga sector where cells highly built-up mainly Rukore and Kamubuga are at the same time highly exposed to landslide hazard (Table 3).

The authors based on this and confirmed that differentiating landslide hazard distribution can contribute to suitable settlement location at Kamubuga sector. This can also help to minimize losses among people and select the best residence areas of Kamubuga sector like Mbatabata which is very lowly prone to landslide (Figure 5) and records low population density as well (Table 3). Therefore, it can be mentioned that people settled in Rukore cells highly exposed to landslide should be relocated to Mbatabata cell which is safer to landslide than Rukore cell.

5. Conclusion

This study aimed to assess the extent to which current settlements are safe with regard to landslide hazard in Kamubuga sector of Gakenke district, Northern Province of Rwanda. The authors used the 2020 datasets in order to ensure that update information is utilized from which future policy making can be formulated from. The results showed that elevation, slope, rainfall and poor land management are the major causes of landslide occurrence within cells of Kamubuga sector. The Rukore, Kamubuga and Kidomo cells were classified within high and very high landslide hazard. Regarding residence analysis, Kamubuga cell occupies large land of 10.2 square Kilometer and is densely populated with 824 people per square Kilometer. However, Mbatabata which occupies the second large land size (8.4 Km^2) is the least densely populated with 584 people per square Kilometer and prone to landslide at low extent. Thus, the authors found that landslide may lead to severe losses among people since they are largely located in cells highly prone to landslide. The study suggests community relocation from landslide prone areas.

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