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Spatial analysis of the impacts of landslides occurrence on community livelihood. A case study of Nyabihu district

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ABSTRACT
High slope angles bring more stress on the surface, creating movement that can lead to a landslide. Nyabihu district is one of Rwanda district which has high slope, high steepness and the topographical parameters area that is the main causes of landslides on community livelihood. The steep terrain and heavy rainfall patterns of the region exacerbate soil erosion and slope instability, leading to frequent landslides that endanger lives, disrupt communities, and damage critical infrastructure. Spatial datasets collected is Landsat imagery were downloaded from USGS website, which was used to analyze the land use land cover of the study area, Digital Elevation Model (DEM) data of 12.5 cm spatial resolutions were also downloaded from Alaska Satellite Facilities vertex (ASFV) used to analyze the slope, elevation and drainage density of study area and aspect analyzed by dem with helps identify slopes aspect that are more susceptible to landslides based on factors such as solar radiation exposure, soil moisture retention, and vegetation distribution is involves identifying landslide locations. By generating a Curvature map, you can identify areas with high positive or negative curvature, which may indicate potential landslide-prone zones. Rainfall data were obtained from Worldclimate.organd and soil types data from Rwanda Geoportal, soil moisture retention, and vegetation distribution is involves identifying landslide locations and proximity to roads network was used to identify distance to road vulnerability from landslides, calculating their spatial relationship, and assessing the vulnerability of landslide hazards respectively was also use as causative factors was rainfall,slope,elevation,aspect,lulc and proximity to road network to landslide in the study area.This research demonstrated how GIS tools can be used to produce map of landslide vulnerable areas using MCA and GIS. rainfall, Slope, soil types, elevation, drainage density and LULC taken as the causative factors for landslide in Western region. The finds of this map of landslide cover indicates that very high class covered 2.54 %, medium class covered 47.57 %, low class covered 0.12 % and high class covered 49.77 % of the total area.It is recommended that both local authorities and communities in the district pay much attention to the local land use planning rules, and policies governing settlement patterns and human activities distribution in order to keep people and their households away from landslide susceptible areas. In doing so, it directly contributes to reduction of soil erosion and vegetative cover removal, thereby helping in the stabilization of the slopes.

Keywords: Analytical Hierarchy Process, Community livelihood, GIS, remote sensing, Nyabihu Landslide.

I. INTRODUCTION

Landslides can be referred to as geological that cannot be easily predicted but lead to destruction of property and even deaths [1]. Landslides are the mostly common geological hazards during rainy seasons, which lead to deaths, destruction of property and huge financial losses not only in Rwanda but also in the rest of the world[2]. It is estimated that over seventeen percent of fatalities that result from natural causes in the world are as a result of landslides[2,3]. In recent years, the frequency and severity of landslides have increased in many parts of the world, posing a growing threat to communities and ecosystems[4]. Between 1998-2017, landslides affected an estimated 4.8 million people and cause more than 18 000 deaths[4,6]. Climate change and rising temperatures are expected to trigger more landslides, especially in mountainous areas with snow and ice[5]. As permafrost melts, rocky slopes can become more unstable resulting in a landslide. Mitigating this risk requires a combination of early warning systems, land-use planning, slope stabilization measures, and public awareness campaigns to reduce vulnerability and enhance resilience to landslides[6]. In the East African Community (EAC) region, landslides represent a significant natural hazard with profound socio economic and environmental implications[6,7]. The EAC comprises seven member states: Burundi, Somalia, Kenya, Rwanda, South Sudan, Somalia, Tanzania, and Uganda, each facing varying degrees of landslide ri sk due to diverse geological landscapes and climati c conditions[7]. The occurrence of landslides in the EAC is often associated with heavy rainfall, defore station,agricultural activities on steep slopes, and unplanned urbanization, which exacerbate soil erosion and slope instability[8]. Vulnerable communities in rural and peri-urban areas are particularly at risk, as landslides can result in loss of life, displacement, destruction of homes, disruption of infrastructure, and damage to agricultural land, leading to food insecurity and economic hardship[9]. In Rwanda, particularly in the Nyabihu district, landslides pose a significant threat to communities and infrastructure, primarily due to the region's steep terrain, heavy rainfall, deforestation, and agricultural practices on vulnerable slopes[,910]. Nyabihu district, located in the Western Province of Rwanda, is known for its hilly landscapes, making it susceptible to soil erosion and slope instability, especially during the rainy seasons[10]. The combination of these factors has led to frequent landslides, causing loss of life, displacement of populations, destruction of homes, and disruption of agricultural activities[10,11]. Vulnerable communities, often residing in rural areas with limited access to resources and infrastructure, bear the brunt of these disasters, facing challenges in accessing emergency services, shelter, and livelihood opportunities in the aftermath of landslides[11]. Efforts to mitigate landslide risk in Nyabihu district and other parts of Rwanda have included initiatives such as reforestation, terracing, soil conservation measures, early warning systems, and community-based disaster preparedness and response mechanisms[12]. However, addressing the root causes of landslide vulnerability, such as poverty, land tenure issues, and unsustainable land-use practices, remains a complex challenge that requires integrated approaches and sustained investment in resilience-building efforts[13]. Enhancing coordination among government agencies, local authorities, civil society organizations, and international partners is essential for effectively managing landslide risk, improving disaster preparedness, and promoting sustainable development in Nyabihu district and beyond[13,14].Nyabihu district, western province, there are the most frequent geological events resulting to deaths and, millions in damages to infrastructure yearly[15]. The frequency in the occurrences of landslides have been on the rise, a factor mainly attributed to the global changes in climate over the years [16].In Nyabihu district the soil eroded by the rainfall are deposited in the rivers, swamps and the valleys[17]. This study was conducted to that end[18]. It focused on landslides in North-western part of Rwanda[19]. 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 [1,19].The study proposes appropriate preventing measures[4,20]. Climate change exacerbates this risk by altering precipitation patterns and intensifying extreme weather events, which can trigger landslides in vulnerable regions[20].

II. METHODOLOGY

2.1. Study area description

Nyabihu district is located in the West province. The district has twelve sectors: Bigogwe, Jenda, Jomba, Kabatwa, Karago, Kintobo, Mukamira, Mulinga, Rambura, Rugera, Rurembo, and Shyira. Climate is generally mild, with an average temperature of 15^0C, and rain fall reaching 1,400 mm per year. A short dry season can be observed between January and February, while a big rainy season takes place between March and May, another dry season takes place between June and August and finally, a last rainy season between September and December.These sectors are subdivided into 73 cellules and 474 villages called imidugudu. The district’s surface is 512.5 km², and has a population of 280,210 (as for 2007), with a population density of 541 Inhabitants per km².Its geographical relief characterized by 90% rugged mountains with a slope of more than 55% creating a high risk of erosion so that the need for the establishment of effective mechanisms for control and prevention of erosion and other harms associated with climate change is very high. The characteristic of the soil is sandy and clay, laterite and volcanic, it is very fertile; Precipitation is almost uniformly over every month and close to 1400mm per year. It has a temperate climate with an average temperature of 15^0C favorable for the

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growth of the agro-pastoral products throughout the year with less risk of development of bacteria and diseases.

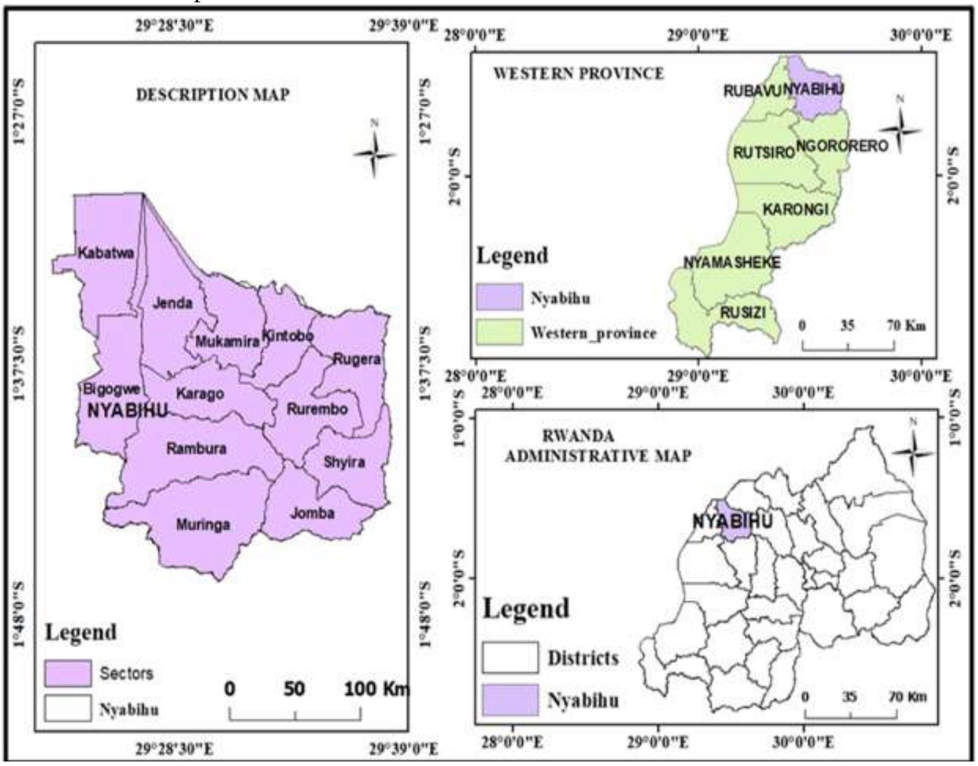

Figure1. Map of the Study Area

2.3. Data Collection and analysis

This research was using secondary data from the existing literature to different spatial datasets collected from various sources as following: Landsat imagery was downloaded from USGS website, which were to analyze the land use land cover of the study area, DEM data of 12.5 cm spatial resolutions was also downloaded from Alaska Satellite Facilities vertex used to analyze the slope and elevation, drainage density of study area aspect and curvature. Rainfall data was obtained from Worldclimate.organd, Soil data derived from Rwanda Geoportal respectively was also use as causative factor to landslide in the study area. All of these parameters were processed using ArcMap10.8.1 and ERDAS (Earth Resources Data Analysis System) Image 2015 software, the data was loaded in the computer. This research also used sources of data were including existing studies, reports, and socio-economic data from government agencies, research institutions, and non-governmental organizations. By triangulating data from multiple sources, this research aims to provide a comprehensive understanding of the spatial dynamics and socio-economic implications of landslides on community livelihoods in Nyabihu. The input data layers required for the multicriteria evaluation of spatial analysis of the impacts of landslides occurrence on community livelihood were derived from a variety of sources.

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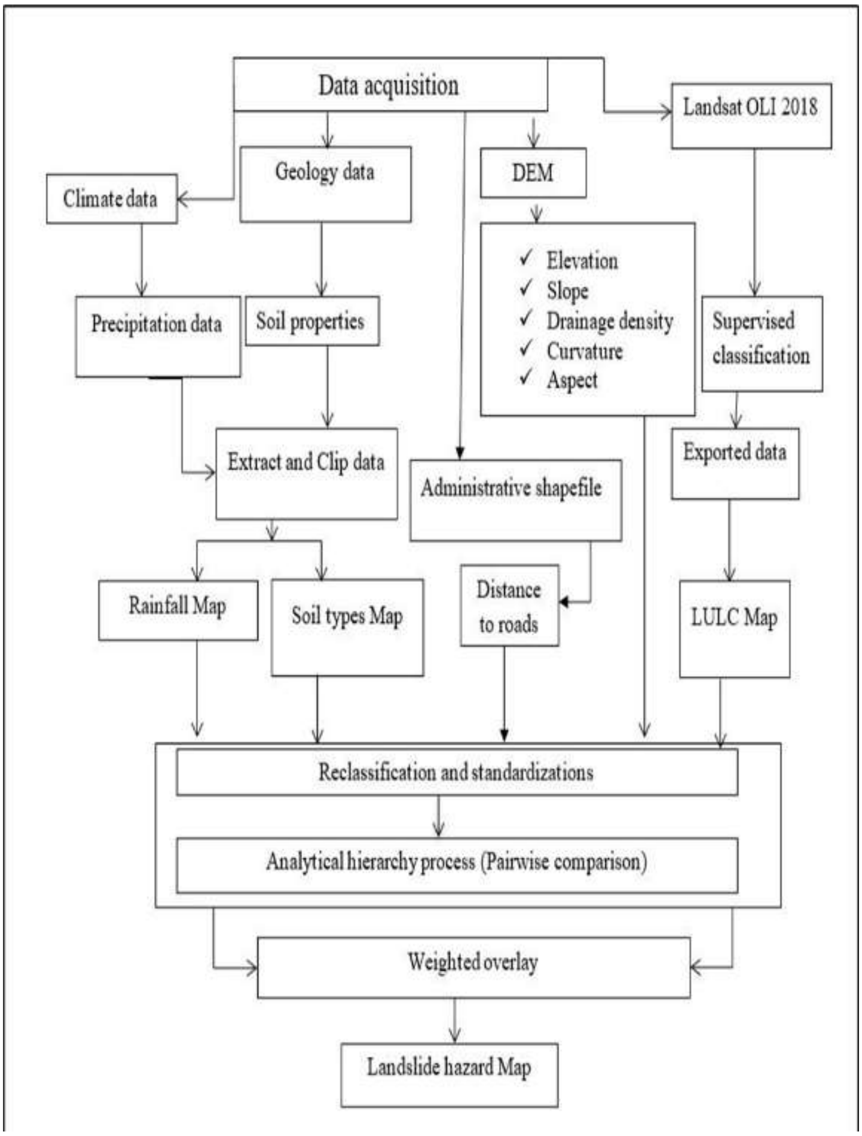

Figure 2. Methodological Framework

The needed dataset was consisting of different remote sensing data images including the Landsat images and digital elevation model. Moreover, the administrative boundaries (shape files) of the study area were also a great significance obtained and acquired from the Earth Resources Observation System (EROS) Data Centre of the U.S.G. S (United States Geological Survey) and Alaska Satellite Facilities vertex as it is cost effective free of charges). Using GIS involves several steps. Firstly, Digital Elevation Models (DEMs) are utilized to derive slope gradient and aspect information, providing insights into terrain characteristics that influence landslide susceptibility. Soil data, including properties such as texture, cohesion, and permeability, are integrated with DEMs to assess soil stability and shear strength. Historical rainfall data are then incorporated to identify areas with high rainfall intensity and prolonged precipitation events, which increase landslide risk. Land use and land cover data are utilized to evaluate the impact of human activities on slope stability, including deforestation, urbanization, and agricultural practices. By combining these datasets within GIS, spatial analysis techniques such as weighted overlay or multi-criteria evaluation are applied to generate a Landslide Hazard Map that delineates areas of varying susceptibility to landslide occurrences, providing valuable information for land-use planning, disaster risk management, and mitigation efforts.

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III. RESULTS

3.1. Criteria for AHP hazard map

During analyzing landslide hazard in Nyabihu district some key factors causing landslide was taken into consideration as numerous key factors have been considered as causal agents triggering Landslide occurrence in western province especially Nyabihu district. Among these include slope, elevation, rainfall, soil type, Drainage density and land cover/ land use, proximity to roads, curvature and aspect. The map of all those factors/ parameter was detailed bellow:

3.1.1 Rainfall

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. The rise in water content increases pore water forces. 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.

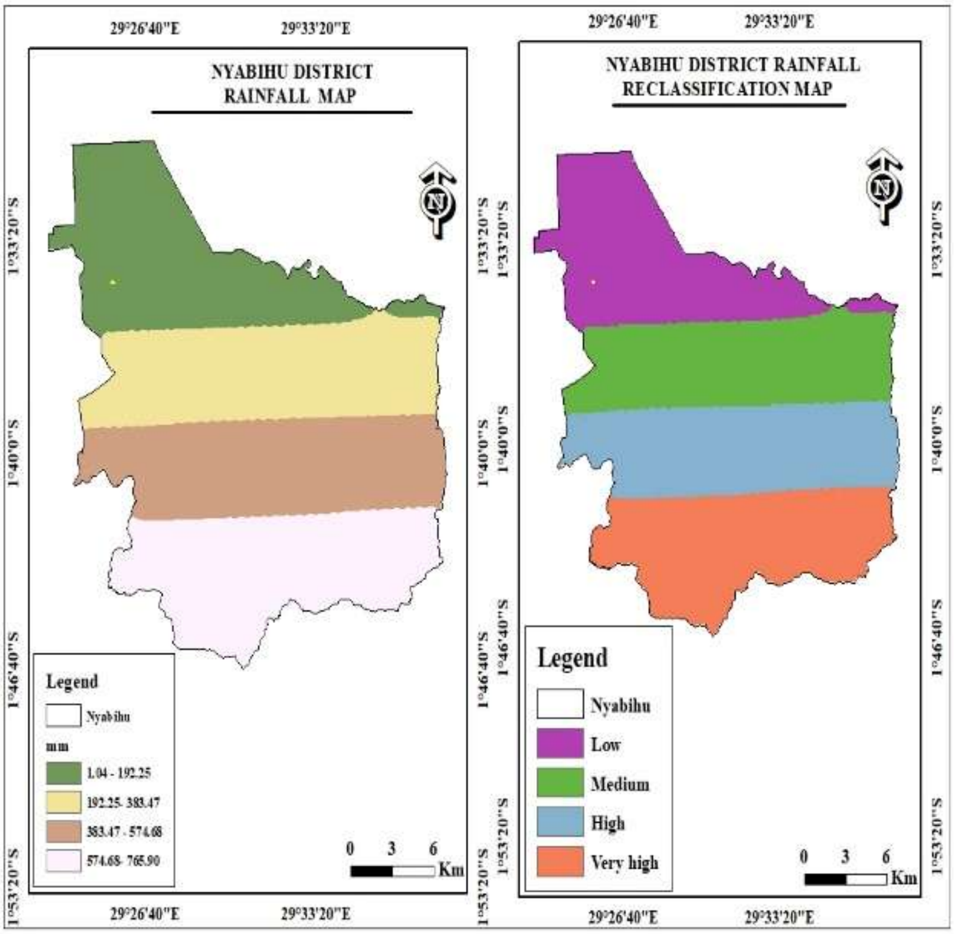

Figure 2. Rainfall map

As soon as the triggering rainfall situations of landslides have been quantitatively defined, levels are determined through more sophisticated methods claiming objectivity and reproducibility. The produced map was obtained from the classification of annual rainfall data taken from Meteo-Rwanda. As it is shown, the rainfall below 765.90 mm is considered to have the high level of influence to triggering landslides rather than the rainfall low 1.04-192.25 mm which has the greater influence. The rainfall is one of important factor influencing landslide disaster, this result shows that highly vulnerable class covered 24.97%, moderate vulnerable class covered 24.90%, low vulnerable class covered 24.63% and very highly vulnerable class covered 17.763% of the total area. This means that the landslide probability decreases with increasing rainfall.

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Figure 1.Size of rainfall classes based on vulnerability to landslide

Classes	Area in km²	%
Low	130.90	24.63
Medium	132.34	24.90
High	132.73	24.97
Very high	135.53	25.50
Total	**531.50**	**100**

3.1.2 Soil types

Soil plays a critical role in landslide occurrence and mitigation. Landslides are often triggered by factors such as heavy rainfall, earthquake activity, and human activities that destabilize slopes. Four soil types namely clay, Loam, silt and sand were generated from FAO classification and mapped to efficiently identify the distribution of each soil type in the entire study area. Basically, the soil type of Nyabihu district is highly dominated by sandy soil as it is shown in the figure below. As it clearly seen the second soil type highly dominated is clay, the last two are silt and loam. Sandy soil type dominated in Nyabihu district were regarded to be one of the causal factors leading to landslide because of its high plasticity and infiltration rate allowing the fast penetration and accumulation of water content, leading to slope failure and collapse.

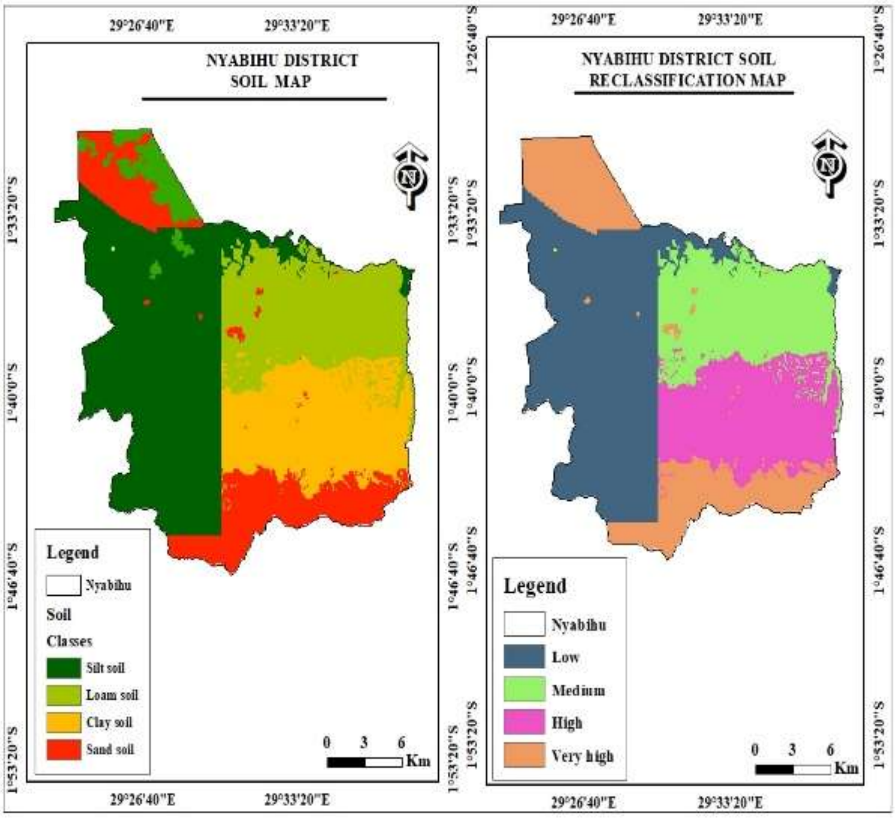

Figure 3. Soil types Map of Nyabihu district

Below table illustrates classified soil types used and their ratings based on their significance on landslides occurrence. The results shows that silt was 39.73%, loam was a 20.80%, Clay 20.27% and the next one was sand which occupy an 19.20 % of total area of whole study as respectively.

Table 2. Soil Types classification

Classes	Area in km²	%
Silt	211.19	39.73
Loam	110.54	20.80
Clay	107.72	20.27
Sand	102.04	19.20
Total	**531.50**	**100**

3.1.3Land Cover/Land Use

Poor land management practices such as deforestation, unsustainable agriculture, and urbanization can increase the susceptibility of an area to landslides by altering soil stability and water infiltration rates.

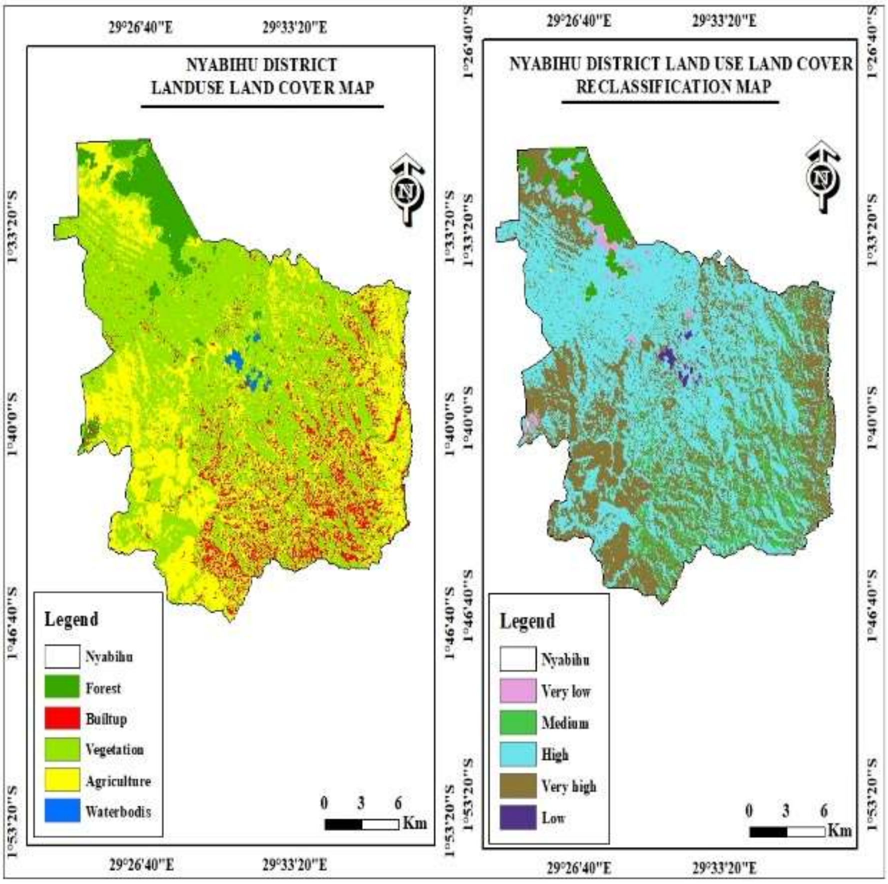

Figure 1. Land cover/ use map

This reclassified map of land use land cover map indicates that low class covered 0.39 %, very high class covered 33.50 %, high class covered 51.45 % and medium class covered of the total area 9.94 % and very low was occupied 4.71 % respectively (Table 3).

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Table 3. Land use lands cover classes

Classes	Area un km²	%
Very low	25.04	4.71
Medium	52.82	9.94
High	273.48	51.45
Very High	178.05	33.50
Low	2.10	0.39
Total	**531.50**	**100.00**

Conversely, strategic land use planning that incorporates techniques such as afforestation, slope stabilization measures, and the implementation of green infrastructure can mitigate landslide risks. By preserving natural vegetation, implementing erosion control measures, and regulating construction activities in landslide-prone areas, land use planning can reduce the vulnerability of communities to landslide hazards. Additionally, the use of Geographic Information Systems (GIS) technology facilitates the identification of high-risk areas and supports the development of targeted mitigation strategies, enhancing resilience to landslide events.

3.1.4 Slope

Slope factors are critical determinants of landslide susceptibility, with steeper slopes being more prone to instability due to increased gravitational forces. The angle of repose, beyond which materials are prone to failure, plays a significant role. Slope gradient interacts with factors like soil cohesion and water content, influencing landslide occurrence. Mitigation strategies for slope-related landslides include slope stabilization techniques such as terracing, retaining walls, and revegetation to enhance slope stability and reduce erosion. Additionally, drainage systems can manage water runoff, decreasing pore pressure and minimizing the likelihood of slope failure. Comprehensive slope monitoring and early warning systems further aid in risk reduction and disaster preparedness.

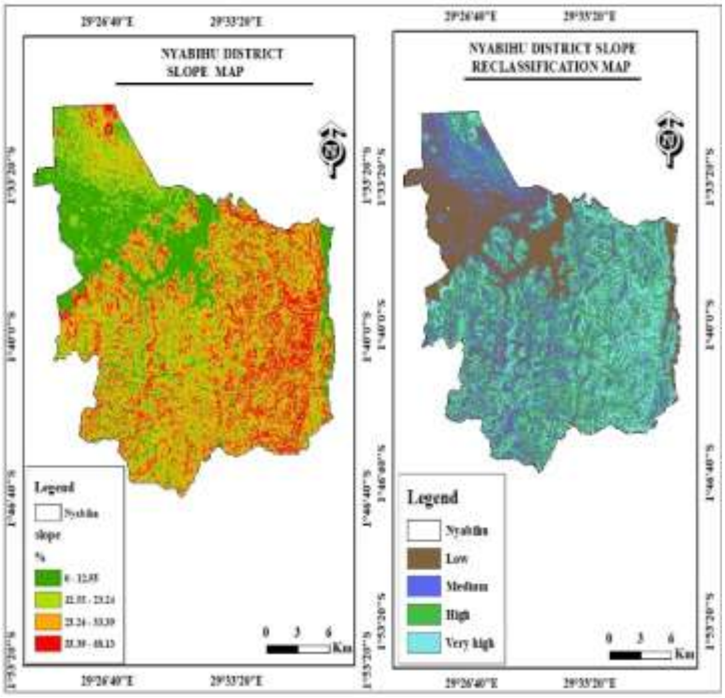

Figure 5. Slope map

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Generally, the steeper the slope, the higher the chance of landslide occurrence. The slope map was derived from DEM and the slopes were grouped in four classes: This reclassified map of slope indicates that very highly vulnerable class covered 16.63%, medium vulnerable class covered 27.70 %, low vulnerable class covered 24.91 % and highly vulnerable class covered 30.76 % of the total area (Table4). This means that the gully erosion probability decreases with slope decreases versa.

Table 4. Slope and percentage

Classes	Area un km^2	%
Low	132.40	24.91
Medium	147.21	27.70
High	163.51	30.76
Very high	88.38	16.63
Total	**531.50**	**100.00**

3.1.5 Elevation

Elevation is a key factor influencing landslide occurrence, as higher elevations often experience greater precipitation and erosion, leading to increased soil saturation and slope instability. Steeper elevational gradients can amplify the effects of gravitational forces on the terrain, making certain areas more susceptible to landslides. Mitigation strategies for elevation-related landslide risks include the implementation of erosion control measures such as vegetation cover and contour trenching to reduce surface runoff and soil erosion. Additionally, installing drainage systems and slope stabilization structures can help manage water infiltration and decrease pore pressure, thereby enhancing slope stability and reducing landslide hazards in elevated regions.

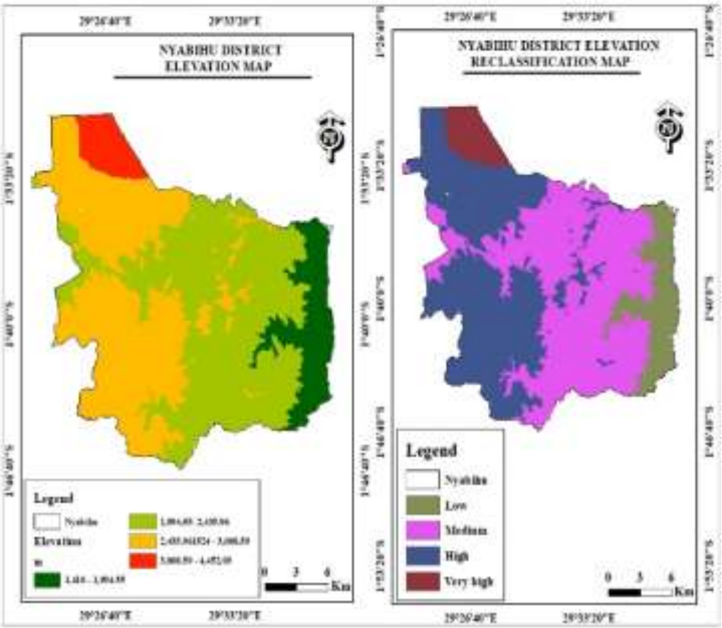

Figure2. Elevation map

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Elevation causes deposition of eroded mass on the soil surface. This reclassified map of Elevation indicates that very highly vulnerable to landslide class covered 4.48 %, moderate vulnerable class covered 44.29 %, low vulnerable class covered 10.24% and highly vulnerable class covered 40.99 % of the total area (Table5). This means that the landslide probability increases with slope decreases versa.

Table 5. Elevation and percentage

Classes	Area un km^2	%
Low	54.43	10.24
Medium	235.41	44.29
High	217.84	40.99
Very high	23.81	4.48
Total	**531.50**	**100.00**

3.1.6 Drainage density

Drainage density is a crucial factor influencing landslide susceptibility, as it directly affects the distribution and management of water within a landscape. Higher drainage densities indicate more channels and pathways for water flow, which can increase soil saturation and pore pressure, leading to reduced slope stability and heightened landslide risk. In areas with high drainage density, mitigation strategies focus on improving drainage infrastructure, including the construction of surface channels, culverts, and subsurface drainage systems to efficiently divert excess water away from vulnerable slopes. Vegetation management and soil conservation practices are also employed to minimize erosion and maintain natural drainage patterns, ultimately reducing the likelihood of landslides in regions characterized by high drainage density.

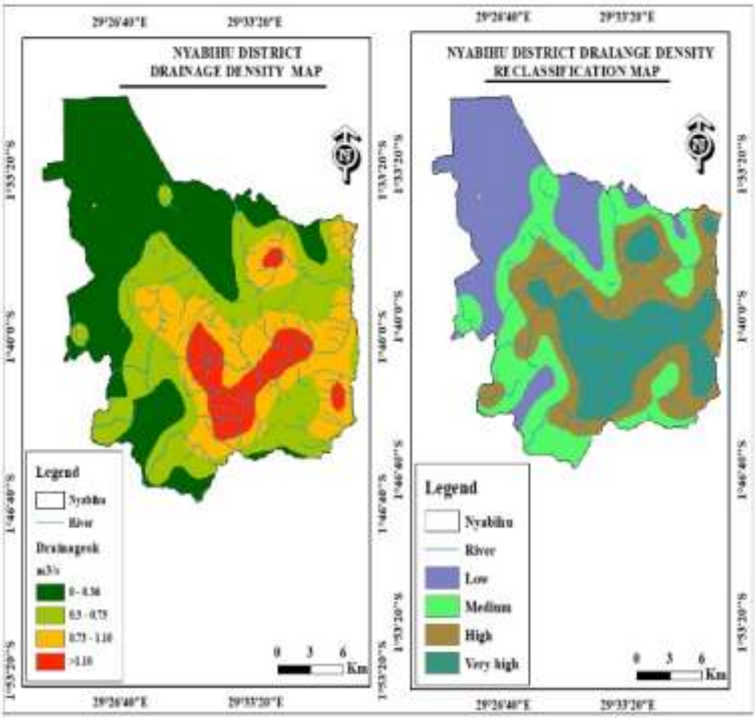

Figure 3. Drainage density

This reclassified map of drainage density indicates that very highly vulnerable class covered 20.84 %, moderate vulnerable class covered 26.05%, low class vulnerable covered 27.83% and highly vulnerable class covered 25.28 % of the total area (Table 6). This means that the landslide probability decreases with elevation decreases versa.

Table 6. Size of drainage density classes

Classes	Area un km^2	%
Low	147.93	27.83
Medium	138.48	26.05
High	134.35	25.28
Very high	110.74	20.84
Total	**531.50**	**100**

3.1.7 Curvature

In the context of landforms, curvature can help identify areas prone to landslides by analyzing changes in the terrain's shape. High positive curvature indicates convex slopes that are more stable, while high negative curvature suggests concave slopes that are at greater risk of failure. By examining curvature patterns and gradients, geologists and geotechnical engineers can gain insights into potential landslide hazards. For further information on using curvature analysis for landslide assessment. The curvature of the terrain plays a crucial role in determining the most vulnerable areas to landslide occurrence within Nyabihu district. Through spatial analysis, it becomes evident that regions characterized by steep slopes and concave landforms exhibit heightened susceptibility to landslides. These areas, typically found along the foothills and mountainous terrain of Nyabihu, experience increased gravitational stress and soil instability, exacerbated by factors such as heavy rainfall and inadequate vegetation cover. The curvature analysis underscores the urgent need for targeted intervention measures in these high-risk zones, including proactive land management strategies, slope stabilization techniques, and early warning systems, to mitigate the adverse impacts of landslides on community livelihoods and safeguard the well-being of the population.

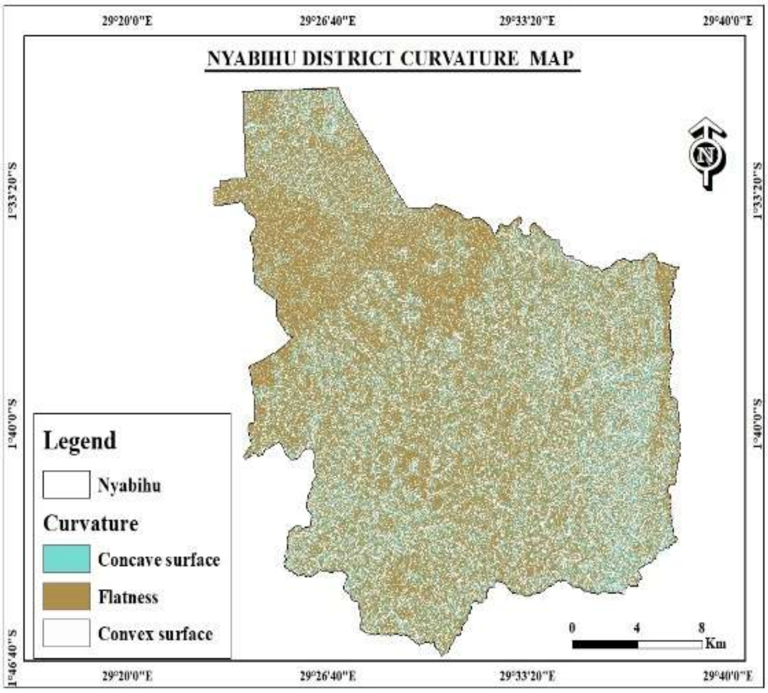

Figure4. Curvature map

3.1.8. Slope aspect

Slope aspect refers to the direction that a slope faces, typically measured in degrees from North. It provides information about the orientation of the landform and can have significant implications for various natural processes such as hydrology, vegetation distribution, and erosion patterns. For example, slopes facing south tend to receive more sunlight and warmth, which may affect plant growth and moisture retention. Slope aspect is an important consideration in fields like geography, geology, and environmental science.

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Slope aspect plays a critical role in assessing landslide susceptibility as it influences factors such as solar radiation exposure, moisture accumulation, and vegetation distribution. Typically, slopes with a northern aspect receive less direct sunlight and tend to retain moisture longer, making them more prone to landslides due to increased soil saturation and reduced evapotranspiration. Conversely, southern aspects receive more sunlight and often have drier conditions, which may lead to decreased landslide susceptibility. However, aspects vary regionally based on factors like local topography and climate, so it's crucial to analyze aspect alongside other terrain attributes such as slope gradient, curvature, and land cover to comprehensively assess landslide risk.

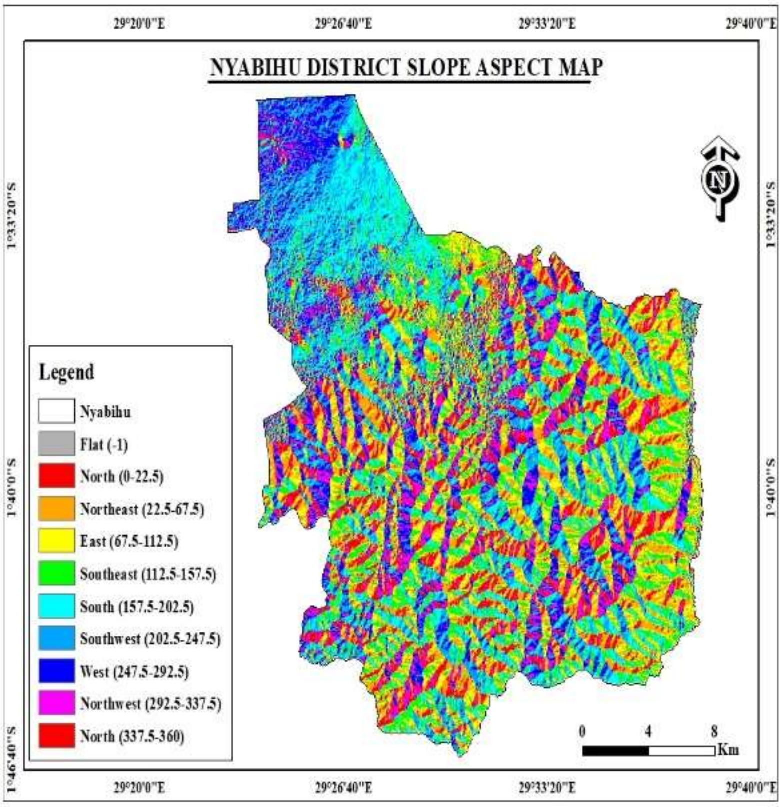

Figure 5. Slope aspect map

3.1.9 Proximity to Roads network

Assessing the proximity of landslide occurrences to road networks is crucial for understanding the potential impact of landslides on transportation infrastructure and human safety. By analyzing the distance from landslide-prone areas to road networks using GIS, it becomes possible to identify areas where roads are at higher risk of being affected by landslides. Closer proximity to roads suggests an increased likelihood of landslides causing road damage, traffic disruptions, or even hazards to travelers. Additionally, assessing the distance from roads to landslide-prone areas can aid in prioritizing mitigation efforts, such as reinforcing road infrastructure or implementing early warning systems. Integrating proximity analysis with other spatial data layers, such as terrain attributes, land cover, and historical landslide occurrences, enables a comprehensive assessment of landslide risk and its potential impact on road networks, guiding effective decision-making for landslide risk management and infrastructure planning.

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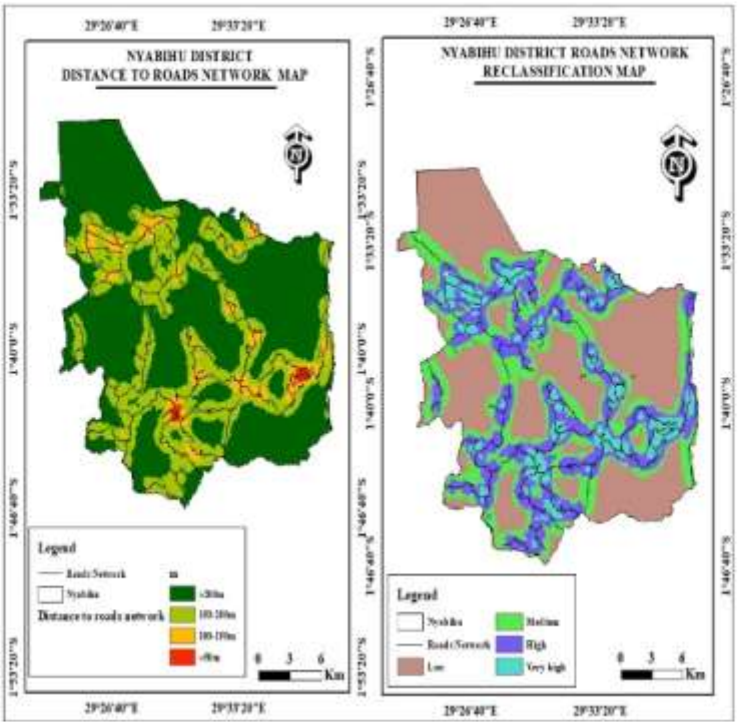

Figure 10. Proximity to Roads network

3.2 Landslide hazard map

Nyabihu district being located in hilly and mountainous regions of the country give it higher chances of absorbing the greater portion of precipitation and associated existing soil conditions dominated with sandy clay soil type, together leading to high infiltration and accumulation rate finally resulting in slope failure and collapse. Referring to the analysis resulted from the computation of various essential parameters and criteria necessary for its occurrence, landslide hazard map of Nyabihu district has been generated using Spatial Multi-Criteria Evaluation in Arc Map. For mapping high risk zones of the study area, nine factors namely rainfall, drainage density, soil type and Land Use/Cover and aspect, slope, elevation and curvature have been considered. Each causal factor with its level of influence has been analyzed and the outcome demonstrates how enorm ously landslide hazards are distributed across the entire region of Nyabihu district.

✓ According to above table, the pair-wise comparison matrix for this criterion are assigned as follow

Table 7. Pair wise comparison matrix for criteria

Criteria	Rainfall	Slope	Elevation	Drainage	Aspect	Curvature	Proximity to roads	Soil types	Lulc
Rainfall	1	2	3	4	5	6	7	8	9
Slope	1/2	1	2	3	4	5	6	7	8
Elevation	1/3	1/2	1	2	3	4	5	6	7
Drainage	1/4	1/3	1/2	1	2	3	4	5	6
Aspect	1/5	1/4	1/3	1/2	1	2	3	4	5
curvature	1/6	1/5	1/4	1/3	1/2	1	2	3	4
Proximity to road	1/7	1/6	1/5	0.25	1/3	1/2	1	2	3
Soil type	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2
LULC	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1

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✓ The fraction value could be converted into decimal value and the sum for each column Could be calculated, see table bellow

Table 8. Pair wise comparison matrix in decimal value

Criteria	Rainfall	Slope	Elevation	Drainage	Aspect	Curvature	Proximity to roads	Soil types	Lulc
Rainfall	1	2	3	4	5	6	7	8	9
Slope	0.5	1	2	3	4	5	6	7	8
Elevation	0.33	0.5	1	2	3	4	5	6	7
Drainage	0.25	0.33	0.5	1	2	3	4	5	6
Aspect	0.2	0.25	0.33	0.5	1	2	3	4	5
curvature	0.17	0.2	0.25	0.33	0.5	1	2	3	4
Proximity to road	0.14	0.17	0.2	0.25	0.33	0.5	1	2	3
Soil type	0.125	0.14	0.17	0.2	0.25	0.33	0.5	1	2
LULC	0.11	0.125	0.14	0.17	0.2	0.25	0.33	0.5	1
Total	2.83	4.72	7.59	11.45	16.28	22.08	28.83	36.5	45

✓ By converting the fractional values into decimal values, we get the following results

Table 9. Normalized pair wise matrix in decimal value and Assigned weights to factors

Criteria	Rainfall	Slope	Elevation	Drainage	Aspect	Curvature	Proximity to roads	Soil types	Lulc	Criteria	Weight%
Rainfall	0.35349	0.42392	0.39511	0.34934	0.30706	0.2717	0.24277	0.21918	0.2	2.76257	30.6953
Slope	0.17674	0.21196	0.26341	0.26201	0.24565	0.22642	0.20809	0.19178	0.17778	1.96383	21.8204
Elevation	0.11783	0.10598	0.1317	0.17467	0.18424	0.18113	0.17341	0.16438	0.15556	1.3889	15.4323
Drainage	0.08837	0.07065	0.06585	0.08734	0.12282	0.13585	0.13873	0.13699	0.13333	0.97993	10.8882
Aspect	0.0707	0.05299	0.0439	0.04367	0.06141	0.09057	0.10405	0.10959	0.11111	0.68798	7.64424
curvature	0.05891	0.04239	0.03293	0.02911	0.03071	0.04528	0.06936	0.08219	0.08889	0.47978	5.33087
Proximity to road	0.0505	0.03533	0.02634	0.02183	0.02047	0.02264	0.03468	0.05479	0.06667	0.33325	3.70283
Soil type	0.04419	0.03028	0.02195	0.01747	0.01535	0.01509	0.01734	0.0274	0.04444	0.23351	2.5946
LULC	0.03928	0.0265	0.01881	0.01456	0.01228	0.01132	0.01156	0.0137	0.02222	0.17023	1.89141
Total	1	1	1	1	1	1	1	1	1	9	100

Next step is to calculate the criteria weights (CW) by averaging the entire element in the row and divided it by the number of criteria for example the criteria weights for rainfall are as follow

(2.76257)/9 = 0.306

After obtaining the weights for each criterion, we have calculated the Eigen value (Lambda max) which will help us to determine the consistency index and the consistency ratio. The consistency index (CI) is expressed by (λ max-n)/n-1 where n is the number of criteria. The consistency ratio can be interpreted as the probability that the croak is completed in a random manner. In fact, the responses often have a certain degree of incoherence. The AHP method does not require

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that judgments are consistent or transitive, indeed, Saaty (1980) has defined the value of consistency ratio (Danumah et al., 2016). The consistency ratio is equal to the consistency index divided by the random index. If the CR is equal to or less than 0.1, the comparisons are considered consistent, otherwise it would be revised.

So λ max=9.16
CI= (9.16 -9)/9-1= 0.02
CR=0.02:1.49=0.013 which is less than 0.1
Since the value of CR is less than 0.1 which is standard, we have to conclude that the matrix is reasonably consistent.

Table 10. Random index matrix of the same dimension

No criteria	1	2	3	4	5	6	7	8	9
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Number of criteria = number of parameters compared

The weighted overlay tool is a tool found in spatial analyst tools under overlay. It allows the calculation of multiple criteria analysis between several raster. In the weighted overlay table, the input was the raster being weight. The influence of the raster compared to the criteria as a percentage of 100. Values are rounded down to the nearest integer. The sum of influence must be equal to 100. In the scale value place is where I specify the weights calculated for each parameter.

3.2.1 AHP hazard map

Various parameters including slope, river proximity, soil type, elevation, land cover and rainfall are the various factors taken into account in the mapping of the hazard. The hazard map will show all areas that are susceptible to flood hazards.

Based on Saaty scale, the following weights were given to the five factors. Table above shows how each causal factor, contribute to landslide occurrence, has been assigned in the weighted overlay function as adopted on the basis of various researches regarding landslide susceptibility specifically in Rwanda Nyabihu district. On this basis rainfall assigned high level of influence of 45.30 % as it is regarded to be the most triggering factor among others. However, the impact of soil depth was considered to have the low level of influence approximately to 2.60 %. These different parameters were analyzed and combined using weighted overlay function in order to produce landslide hazard map. The produced map provides three classes of landslide hazard zones namely low hazardous, moderate and high hazardous zone are demonstrate in Fig11.

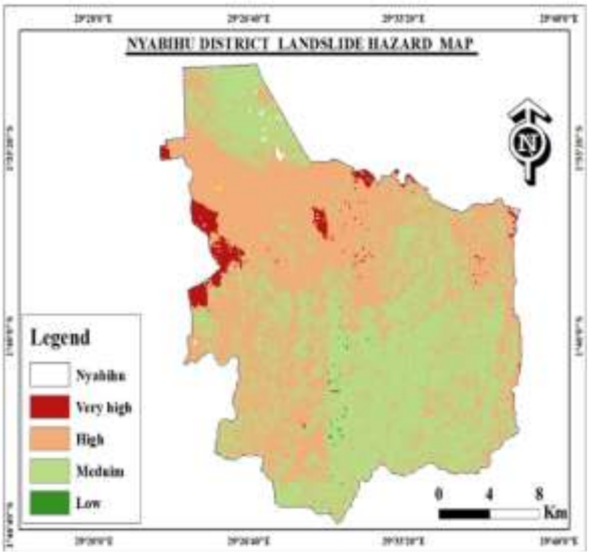

Figure 11. Landslide hazard map of Nyabihu district

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The main goal of this study was to identify areas prone to landslides in Nyabihu district, it is clearly shown that areas located in the East-western of the district are highly susceptible to landslides although the rest of the district can also be affected. Table below shows the areas in Nyabihu district affected categorized on the basis of susceptibility to Landslide hazard.

Table 11. Categorized area affected

Classes	Area un km^2	%
Very high	13.52	2.54
High	264.53	49.77
Medium	252.83	47.57
Low	0.62	0.12
Total	**531.50**	**100.00**

This research demonstrated how GIS tools can be used to produce map of landslide vulnerable areas using MCA. rainfall, Slope, soil types, elevation, drainage density and LULC taken as the causative factors for landslide in Western region. The finds of this map of landslide cover indicates that very high class covered 2.54 %, medium class covered 47.57 %, low class covered 0.12 % and high class covered 49.77 % of the total area. In modeled and mapped results are insignificant and acceptable considering the manual landslide management interventions which are beyond the capability of models to represent. Thus, this method is robust enough to develop map shelter sites for landslide management.

3.2.2 Assess the direct and indirect impacts of landslides on community livelihoods, including loss of lives, displacement, damage to infrastructure, loss of agricultural land, and disruption of economic activities using spatial analysis techniques

Assessing the direct and indirect impacts of landslides on community livelihoods requires a comprehensive spatial analysis approach that integrates various data sources and techniques. Firstly, utilizing remote sensing imagery and Geographic Information Systems (GIS), we can map the extent and severity of landslides in the affected areas of Nyabihu District, Rwanda. This spatial analysis allows us to quantify the immediate consequences of landslides, including the loss of lives, displacement of populations, and damage to infrastructure such as roads, bridges, and buildings. Additionally, by overlaying land cover and land use data with landslide occurrence maps, we can assess the indirect impacts on agricultural land, identifying areas where soil erosion and land degradation have occurred due to landslide activity, leading to reduced productivity and loss of livelihoods for local farmers. Furthermore, spatial analysis enables us to analyze the spatial distribution of economic activities and identify sectors most affected by landslide-induced disruptions, such as tourism, transportation, and trade. By quantifying these impacts spatially, policymakers and stakeholders can prioritize resources and interventions to mitigate the negative effects of landslides on community livelihoods, enhance resilience, and promote sustainable development in Nyabihu District.

3.2.3To provide mitigation measures on landslide risk exposure in the Nyabihu district to the decision makers on landslides

Mitigating landslide risk exposure in Nyabihu District requires a multi-faceted approach that integrates both structural and non-structural measures. Firstly, investing in engineering solutions such as slope stabilization measures, retaining walls, and drainage systems can help mitigate the immediate risks posed by landslides, particularly in high-risk areas identified through spatial analysis. Secondly, implementing land-use planning regulations that restrict construction in landslide-prone zones and promote sustainable land management practices, such as reforestation and erosion control, can reduce vulnerability over the long term. Furthermore, enhancing early warning systems and community-based disaster preparedness initiatives can improve resilience and enable timely evacuation in the event of landslide threats. By combining these measures and integrating them into decision-making processes, policymakers can effectively reduce landslide risk exposure in Nyabihu District and safeguard the lives and livelihoods of its residents.

IV. CONCLUSION

Landslides pose significant threats to both human lives and livelihoods, particularly in regions characterized by steep terrain and intense rainfall, such as Nyabihu District in Rwanda. The occurrence of landslides in this area has profound implications for the local communities, impacting their socio-economic well-being and environmental sustainability. Understanding the spatial dynamics and impacts of landslides on community livelihoods is crucial for effective risk management and resilience-building efforts. Therefore, this study aims to conduct a spatial analysis of the impacts of landslide occurrences on community livelihoods in Nyabihu District. By employing Geographic Information Systems (GIS), remote sensing, and spatial statistical methods, we seek to identify vulnerable areas, assess the direct and indirect impacts of landslides, and propose mitigation measures to reduce risk exposure and enhance community resilience. Through this case study, we aim to provide valuable insights and recommendations for policymakers, local authorities, and community stakeholders to develop informed strategies for sustainable land use and disaster risk management in landslide-prone areas of Nyabihu District.

4.1Summary of findings

The study was conducted to analyze Vulnerability assessment of landslide using geospatial techniques in northern region. Based for objectives our research has been achieved by using Multi criteria analysis technique in integration with the Geographical Information System (GIS) was used for the analysis of vulnerability area to landslide hazard in northern region. This research demonstrated how GIS tools can be used to produce map of landslide vulnerable areas using MCA. rainfall, Slope, soil types, elevation, drainage density and LULC taken as the causative factors for landslide in Western region. The finds of this map of landslide cover indicates that very high class covered 2.54 %, medium class covered 47.57 %, low class covered 0.12 % and high class covered 49.77 % of the total area. In modeled and mapped results are insignificant and acceptable considering the manual landslide management interventions which are beyond the capability of models to represent. Thus, this method is robust enough to develop map shelter sites for landslide management. Therefore, through the provision of possible landslide relevant information to decision makers, engineers, scientific researchers and the general public on how enormous landslides are this research highlights possible long term mitigation measures on how to efficiently control the risk of landslides occurrence. Some of them include measures on the stabilization of the slope through afforestation and building retaining walls. Policy makers in charge of disaster management also should find ways to relocate the local community living in high-risk zones to areas of less impact so as to allow the sustainable development free from landslide hazards.It is recommended to the Ministry of Emergency Management (MINEMA), Ministry of Environment, Ministry of Agriculture (MINAGRI) and their related institutions in charge, to take urgent actions in the contribution to the reduction of landslides effects and other natural hazards that have negative impacts on Rwandan society especially Nyabihu district.

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