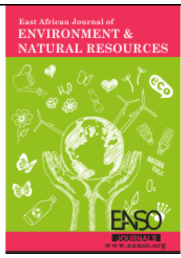


East African Journal of Environment and Natural Resources
eajenr.eanso.org
Volume 8, Issue 1, 2025
Print ISSN: 2707-4234 | Online ISSN: 2707-4242
Title DOI: https://doi.org/10.37284/2707-4242

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Landslide Susceptibility Mapping and Its Driving Factors in Kamonyi District of Rwanda

Aimable Nizeyimana[1], Narcisse Hakizimana[1], Emmauel Wede Karekezi[1], Richard Mind'je[1] & Christophe Mupenzi[1]*

[1] University of Lay Adventists of Kigali, P. O. Box 6392, Kigali, Rwanda.
[*] Correspondence Email: mindjerichard@gmail.com

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Date Published:

02 June 2025

Keywords:

AHP, Driving Factors, GIS, Kamonyi, Landslide Susceptibility, Remote Sensing, Rwanda.

ABSTRACT

This study investigates the use of remote sensing and GIS techniques to generate a landslide susceptibility map and examine the factors contributing to landslides in the Kamonyi district located in the Southern Province of Rwanda. The Weighted Overlay Analysis (WOA) approach has been applied, enhanced by the Analytic Hierarchy Process (AHP), to combine various geospatial factors influencing landslide occurrence. These factors include elevation, slope angle, aspect, curvature, the topographic wetness index (TWI), stream power index (SPI), proximity to roads, proximity to rivers, land use and land cover (LULC), normalized difference vegetation index (NDVI), soil texture, and rainfall. GIS and remote sensing tools were employed to carry out a multi-criteria analysis, assign appropriate weights to the factors, and produce the final landslide susceptibility map. The findings emphasized the key factors that contribute to landslide susceptibility and were ranked based on the assigned weights. The slope (22.5%), rainfall (18.3%), land use and land cover (LULC) (13.6%), and soil texture (10.4%) were identified as factors mostly influencing landslide occurrence in the area while factors such as proximity to roads (7.8%), elevation (6.3%), topographic wetness index (TWI) (5.2%), and proximity to rivers (4.6%) were found to have a moderate influence. NDVI (3.9%), stream power index (SPI) (3.1%), curvature (2.8%), and aspect (1.5%) were found to have a lesser influence on landslide susceptibility in the Kamonyi district. The landslide susceptibility map displayed varying degrees of risk across the district, with 2.5% categorized as very high susceptibility, 16.9% as high susceptibility, 52.7% as moderate susceptibility, 27.2% as low susceptibility, and 0.7% as very low susceptibility. The areas with high and very high susceptibility were predominantly located in the northern and central regions of the district, whereas the southern areas mainly exhibited low and very low susceptibility. The results of this study provide crucial information for land use planning, risk reduction, and disaster management in both Kamonyi district and Rwanda overall. It is recommended that policymakers and local authorities focus on the high-risk zones for focused and effective interventions.

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

APA CITATION

Nizeyimana, A., Hakizimana, N., Karekezi, E. W., Mind'je, R. & Mupenzi, C. (2025). Landslide Susceptibility Mapping and Its Driving Factors in Kamonyi District of Rwanda *East African Journal of Environment and Natural Resources*, *8*(2), 45-72. https://doi.org/10.37284/eajenr.8.2.3074.

CHICAGO CITATION

Nizeyimana, Aimable, Narcisse Hakizimana, Emmauel Wede Karekezi, Richard Mind'je and Christophe Mupenzi. 2025. "Landslide Susceptibility Mapping and Its Driving Factors in Kamonyi District of Rwanda". *East African Journal of Environment and Natural Resources* 8 (2), 45-72. https://doi.org/10.37284/eajenr.8.2.3074

HARVARD CITATION

Nizeyimana, A., Hakizimana, N., Karekezi, E. W., Mind'je, R. & Mupenzi, C. (2025) "Landslide Susceptibility Mapping and Its Driving Factors in Kamonyi District of Rwanda", *East African Journal of Environment and Natural Resources*, 8 (2), pp. 45-72. doi: 10.37284/eajenr.8.2.3074.

IEEE CITATION

A., Nizeyimana, N., Hakizimana, E. W., Karekezi, R., Mind'je & C., Mupenzi "Landslide Susceptibility Mapping and Its Driving Factors in Kamonyi District of Rwanda", *EAJENR*, vol. 8, no. 2, pp. 45-72, Jun. 2025. doi: 10.37284/eajenr.8.2.3074

MLA CITATION

Nizeyimana, Aimable, Narcisse Hakizimana, Emmauel Wede Karekezi, Richard Mind'je & Christophe Mupenzi. "Landslide Susceptibility Mapping and Its Driving Factors in Kamonyi District of Rwanda". *East African Journal of Environment and Natural Resources,* Vol. 8, no. 2, Jun 2025, pp. 45-72, doi:10.37284/eajenr.8.2.3074

INTRODUCTION

Landslides are well-documented and recognized globally as significant geomorphic hazards due to their impact on slope development in mountainous areas, along with their substantial economic, social, and environmental consequences (Bizimana, 2015). These events arise from the intricate interplay of factors, including local and regional geology, geomorphology, topography, and seismic activity (Khasanov *et al.*, 2021). Many studies on landslides have been conducted globally, including in Central and East Africa, where unstable slopes are prone to a combination of natural and human-induced triggers, such as rainfall, land use, and earthquakes (Hussein Bizimana, & Osman Sönmez, 2015).

In Europe, catastrophic landslides have caused an estimated average annual economic loss of 4.7 billion Euros, with the greatest concentration in mountainous areas. These events resulted in 1,370 fatalities and 784 injuries from 476 landslides, with Turkey recording the highest number of deaths, totalling 335. A rising trend in fatalities was noted, especially between 2008 and 2014. Most of these landslides were triggered by extreme natural events such as storms (heavy rainfall), earthquakes, and floods, while fewer incidents were linked to human activities like mining and excavation (Haque *et al*., 2016). High seismic activity often exacerbates the impact of destructive earthquakes by triggering landslides, which can significantly contribute to the death toll (Julian *et al*., 2002). While many African countries are frequently affected by severe, multi-year landslides, not all regions on the continent are equally vulnerable (MINEMA, 2012).

Rwanda, with its steep terrain, heavy rainfall, and extensive human activity, is particularly prone to landslides, which present significant risks to lives, infrastructure, and the environment (MINEMA, 2012).

Between 16% and 40% of Rwanda's land features steep slopes, making it vulnerable to soil erosion, which leads to the loss of approximately 1.4 million tons of fertile soil annually (Lamek *et al*., 2016). A study by Mind'je *et al*. (2020) in Rwanda employed a frequency ratio (FR) approach along with GIS and remote sensing technologies to explore the spatial relationships between landslides and various contributing factors. The study identified the western, northern, and parts of the southern provinces as areas most prone to landslides, with slope, land use, rainfall, and elevation being the primary factors. In March 2024, the New Times reported that the Rwanda Water Resources Board (RWB) is closely monitoring landslide-prone areas

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

in several districts following new incidents of landslides in Kamonyi, Karongi, and Rusizi. Kamonyi, located in southern Rwanda, has been particularly affected by frequent landslides that have caused loss of life, property destruction, and environmental degradation (REMA, 2021). The region's vulnerability to landslides is exacerbated by the combination of topography, heavy rainfall, and human activities such as deforestation and improper land use practices (Petley *et al*., 2007). In 2021, as part of the National Adaptation Planning (NAP) process, the Rwanda Environment Management Authority (REMA) partnered with the Global Green Growth Institute (GGGI) to conduct a study evaluating the risks of floods and landslides in the sub-catchments of the City of Kigali, as well as Kamonyi, Huye, and Rusizi districts (REMA, 2021). In Kamonyi, the study focused on the Bishenyi sub-catchment, which includes areas such as Bishenyi, Runda, Ruyenzi, Sheli, and Rugarika. Agriculture is the primary land use, but there has been significant residential construction on hilltops and slopes in recent years, particularly in the Ruyenzi area (REMA, 2021).

The study identified landslide-prone zones in Kabagesera, Muganza, and Ruyenzi Cells of Runda Sector, as well as in Sheli, Kigese, Bihembe, and Nyarubuye Cells of Rugarika Sector. The average landslide hazard rate in these areas was 365m²/year/km², with some areas experiencing a rate of 90 m²/year/km² (REMA, 2021). In February 2024, a landslide occurred in Kamonyi district’s Nyarubaka sector despite the absence of rainfall at the time, with locals noting heavy rainfall on February 14, 2024, before the incident (New Times, 2024). Another landslide in March 2024 damaged the road connecting Kigali City to the Kamonyi's Rugalika Sector, in Nkoto Village (Teradignews, 2024).

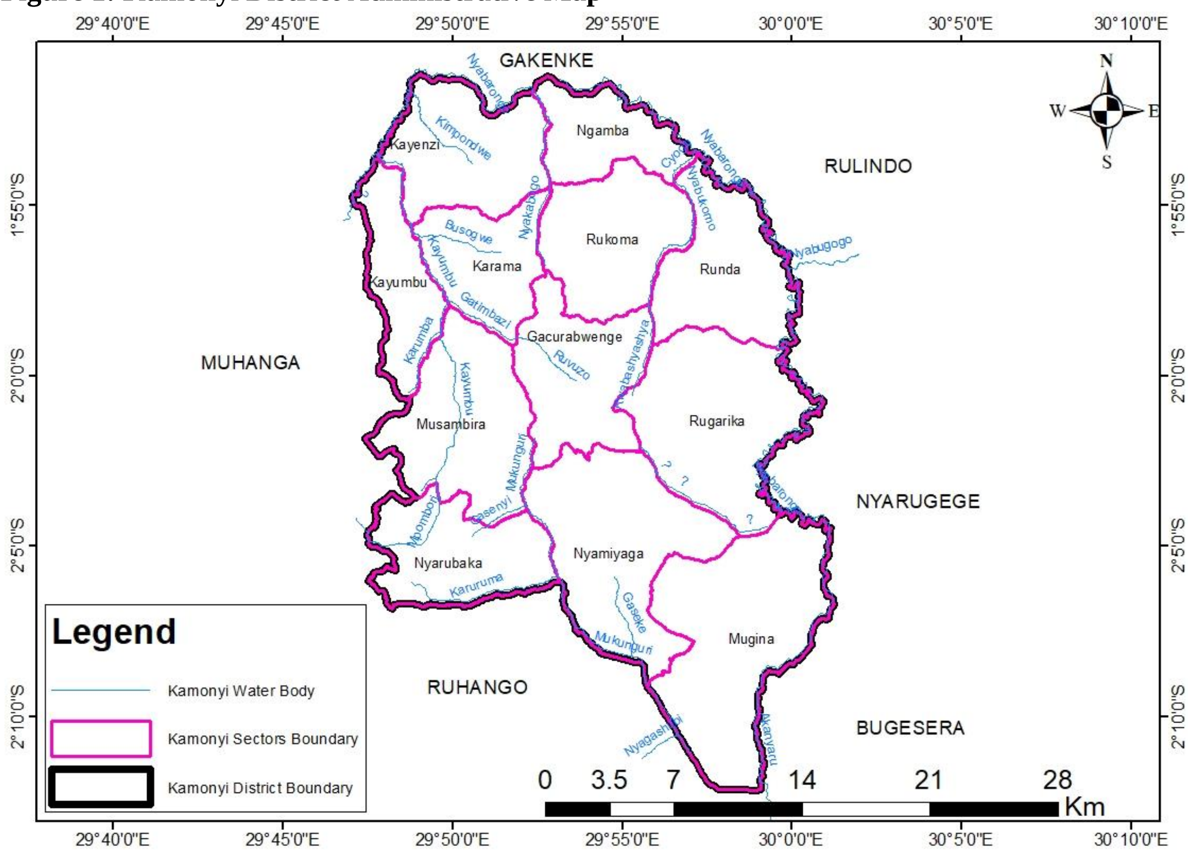
In recent years, advancements in Remote Sensing (RS) and Geographic Information Systems (GIS) have greatly improved environmental management by offering tools for effective disaster risk assessment and mitigation. RS and GIS technologies have proven to be effective for modelling landslide susceptibility (Ayalew, & Yamagishi, 2005), providing essential data on terrain, vegetation, land use, and geological features critical for understanding landslide dynamics (Guzzetti *et al*., 2005). However, despite these technologies' availability and their proven effectiveness in other regions, there is a noticeable gap in the application of these techniques in Rwanda, particularly in Kamonyi district, where landslides are more prevalent. Developing a comprehensive landslide susceptibility map using GIS and RS methods is crucial for proactive disaster management and sustainable land-use planning in the region. Thus, this study sought to explore the application of remote sensing and GIS techniques to analyze and geo-visualize landslide susceptibility in Kamonyi District of Rwanda. The specific objectives of the study are to: (1) analyze the main driving factors contributing to landslides in Kamonyi District, (2) geo-visualize a susceptibility map exhibiting landslide-prone areas in Kamonyi District, and (3) analyze the relationship between the driving factors and landslide susceptibility level in Kamonyi district.

MATERIALS AND METHODS

Study Area Description

The Southern Province of Rwanda has eight districts, including Kamonyi District. Gacurabwenge, Karama, Kayenzi, Kayumbu, Mugina, Musambira, Ngamba, Nyamiyaga, Nyarubaka, Rugarika, Rukoma, and Runda are its twelve sectors. These sectors are further divided into 317 villages (Imidugudu) and 59 cells (Utugari). With 50,848 residents overall, the district occupies 655.5 km² and has a population density of 683 people per square kilometre (NISR, 2023). Kamonyi district is bordered to the north by Gakenke and Rulindo Districts, to the south by Ruhango District, to the west by Muhanga District, and to the east by Bugesera and Nyarugenge Districts. The district has a moderate climate with an average temperature of 20°C and enough rainfall, ranging from 1,200 to 1,400 mm per year. Except for the western area, which is more mountainous, the landscape is mostly a low-lying plateau. The Nyabarongo River to the east and north, and the Akanyaru River, which forms part of the district's northern and eastern limits, are the main rivers that drain Kamonyi. There are roughly 843 water sources in the district, including a number of smaller ones like Kayumbu, Bakokwe, Gikoro, Mukunguri, Nyabuvomo, Bishenyi, Gatimbazi, and Ruvubu. The elevation of the district varies from 1,500 to 2,000 meters. Mukunguri and Kona ka Mashyuza are the lowest points, while the vast Nyabarongo Valley dominates the eastern and northern regions. Notable highland peaks include Ijuru rya Kamonyi and Cubi na Marenga. Kamonyi's soil is mostly fertile, permeable, and humus-rich, which helps to boost agricultural output with contemporary land management practices (DDS, 2018).

Figure 1: Kamonyi District Administrative Map



Data Collection and Preparation

The study relied on a variety of geospatial datasets, including remote sensing data and conventional geospatial sources. High-resolution satellite imagery from providers like Digital Globe was used to obtain detailed insights into terrain features, land cover, and land use patterns, serving as a basis for understanding the physical landscape. The study also leveraged the topographic and cartographic sources, including digital elevation models (DEMs) and topographic maps from the United States Geological Survey (USGS) retrieved from (https://www.usgs.gov/). Additionally, rainfall records were sourced from the Rwanda Meteorology Agency (https://meteorwanda.gov.rw/index.php?id=2) and interpolated to generate a spatial distribution of precipitation, enabling an assessment of climatic influences on landslide susceptibility. To analyze soil types and geological conditions, the study

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

incorporated soil maps, geotechnical surveys, and geological reports from the Ministry of Natural Resources of Rwanda (https://www.environment.gov.rw/) and academic institutions.

Moreover, LULC maps and spatial datasets from the National Land Center and Mapping in Rwanda (https://www.lands.rw/land-use-and-mapping) were considered to evaluate the exposure and vulnerability of human settlements to landslide hazards. A Government Agency such as the National Land Authority (NLA) was consulted to obtain geological data, including soil types as well as historical records of landslide vulnerability. Existing databases and published literature have also been explored to gather relevant datasets. The selection of these factors was guided by a comprehensive literature review and expert insights.

Table 1: Constructed Spatial Database for Used Datasets

Datasets	Pixel size	Source	Processed factor
Shapefiles	National scale	Ministry of Infrastructure (MININFRA) of Rwanda	Study area
DEM	30 m	USGS, Earth Explorer, (http: www.dwtkns.com/ srtm30m)	Elevation, slope, aspect, curvature, TWI, and SPI
Road networks	30 m	RTDA (www.rtda.gov.rw)	Distance to roads
River networks	30 m	DIVA-GIS (www.diva-gis/Data)	Distance to rivers
Landsat	30 m	https://earthexplorer.usgs.gov/	LULC and NDVI
Pedological data	250 m	Ministry Land Authority (https://www.lands.rw/home)	Soil texture
Climate data	30 m	Rwanda Meteorology Agency; (https://meteorwanda.gov.rw/index.php?id=2)	Rainfall

Data Processing and Analysis

The data processing and analysis phase utilized a combination of techniques that integrated both GIS and Remote sensing. Using the bands from the Landsat 8 operational land imager (OLI) at 30 m spatial resolution, which were assembled by the United States Geological Survey Earth Explorer (USGS, 2025), the NDVI was calculated in GIS to show the differences in vegetation spectral responses at the red and near infrared bands (NIR representing band 5 and R representing band 4). By dividing the difference between the red (RED) and near-infrared (NIR) reflectances by their sum, the NDVI is calculated (Hyndavi, 2019). It always falls between -1 and +1 (Eq.1). When calculation gives negative values, it is likely water. On the other hand, if it gives an NDVI value close to +1, there is a high possibility that it is dense green leaves. But when the value is close to 0, there are likely no green leaves and it could even be an Urbanized area (Agenagnew, & Melesse 2019).

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

Other two topographic factors, TWI and SPI, which were hardly employed in landslide susceptibility mapping in Kamonyi district, were used to add inputs in the landslide susceptibility model. The TWI measures the influence of topography on hydrological processes. It is a hydrological index that calculates a place's propensity to retain water based on its topography. One metric used to identify hydrological processes involving the buildup of water flow based on the regulation of the slope factor in a region is the Topographic Wetness Index (TWI) model. (Rohan Kumar, & R. Anbalagan,

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

2016). The Eq.2 is a mathematical model that has been used to calculate TWI.

$$TWI = ln\left(\frac{A_s}{\tan\theta}\right) \quad (2)$$

Where A is the specific catchment area, θ is a local slope in radians, and ln is the natural logarithm. Moreover, the SPI was also employed. It is a geomorphological and hydrological indicator that calculates the possible erosive force of flowing water. Its foundation is the idea that the slope and the contributing drainage area both affect how easily water may erode and move debris. The SPI is calculated by the Eq.3.

$$SPI = ln(A_s * \tan\theta) \quad (3)$$

Where: As is Specific Catchment Area; θ is slope in radians.

In this study land use map was produced from the Landsat 8 OLI/TIRS satellite image and applied an object-based classification scheme. After applying atmospheric and radiometric corrections to minimize distortion, we implemented a supervised classification approach using the Random Forest algorithm, which was trained on carefully selected ground truth data representing eight distinct LULC classes (forest, cropland, grassland, wetland, urban, barren land, water bodies, and others).

To process distance to rivers and distance to roads using Euclidean Distance in ArcGIS was used to calculate the straight-line (as-the-crow-flies) distance from every cell in a raster to the nearest feature (road or river). The steps involved in loading vector and raster data in GIS and computing the distance using raster analysis tools.

The analysis of landslide susceptibility and its driving factors in Kamonyi District has incorporated a multi-criteria decision-making method that has systematically evaluated and prioritized factors contributing to landslide vulnerability. The process has involved constructing a hierarchical decision structure, beginning with the overarching goal of landslide resilience planning, followed by criteria and sub-criteria representing various landslide vulnerability factors.

The AHP was used to produce the final vulnerability map and consists of the following five steps: (i) break down a decision problem into component factors; (ii) arrangement of these factors in a hierarchic order; (iii) assignment of numerical values (Table 2) to determine the relative importance of each factor according to their subjective relevance; (iv) set up of a comparison matrix; and (v) computation of the normalized principal eigenvector, which gives the weight of each factor (Saaty, & Vargas, 2001). The advantages of using AHP as an expert-based method in landslide susceptibility analysis are (Long, & De Smedt, 2012): (i) all types of information related to landslides can be included in the discussion process; (ii) judgment is structured so that all information is taken into account; (iii) discussion rules are based on expert's knowledge and experiences; (iv) when a consensus is reached, weights for each relevant factor are obtained automatically by eigenvector calculation of the comparison matrix; and (v) inconsistencies in the decision process can be detected using consistency index values (Table 3) and, hence, corrected if needed. The main disadvantage of this method is that subjective preference in the ranking of factors may differ from one expert to another (Kayastha *et al*., 2013).

The AHP method utilized a pairwise comparison matrix to assess the relative importance of each criterion. The authors assigned ratings on a scale from 1 to 9, where 1 indicated equal significance, 3 represented moderate significance, 5 denoted strong significance, 7 indicated very strong significance, and 9 signified extreme significance. Intermediate values (2, 4, 6, and 8) were used to capture varying degrees of significance (Ezzat, & Hamoud, 2016).

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

These numerical ratings were then incorporated into the comparison matrix, which was subsequently normalized to derive the relative weights of each criterion.

Table 2: Ordinal Scale Represents Preference of Judgement

Preference/ordinal l scale	Degree of preference	Remarks
1	Equally	Factors inherit equal contribution
3	Moderately	One factor moderately favoured over other
5	Strongly	Judgement strongly favours one over other
7	Very Strongly	One factor very strongly favoured over other
9	Extremely	One factor favoured over others in the highest degree
2, 4, 6, 8	Intermediate	Compensation between weights 1,3,5,7 and 9
Reciprocals	Opposites	Used for inverse comparison

Source: Saaty (1990)

Table 2 displays an ordinal scale based on Saaty (1990) to represent the judgment preferences. The scale ranges from 1 to 9, where 1 indicates equal importance, 9 represents extreme preference, and the intermediate values (2, 4, 6, and 8) indicate varying levels of preference. This scale helps assess the relative significance of different factors, supporting the decision-making process within the research framework.

Table 3: Random Consistency Index (RI)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty (1990)

Table 3 displays the Random Consistency Index (RI) values, as introduced by Saaty (1990), for different numbers of criteria (N) in the AHP. The RI serves as a benchmark for evaluating the consistency of pairwise comparisons during the AHP process. These values correspond to specific N values, which define the maximum allowable level of inconsistency. Researchers compare their consistency ratio (CR) with the RI values to ensure the reliability and consistency of their judgments in the decision-making process. In this study, the RI values act as a reference point for assessing the consistency of the pairwise comparisons conducted during the AHP.

One of the important aspects of the AHP principle is the calculation of consistency index (CI) and consistency ratio (CR), (Rohan Kumar, & R. Anbalagan, 2016). Saaty (1990) formulated the consistency index as

$$\mathrm{CI} = \frac{\lambda_{max} - \mathrm{N}}{(\mathrm{N}-1)} \quad (4)$$

where λ_{max} is the maximum eigenvalue and N is the number of elements present in the row/column of the matrix. The Consistency Ratio (CR) can be calculated by ratio:

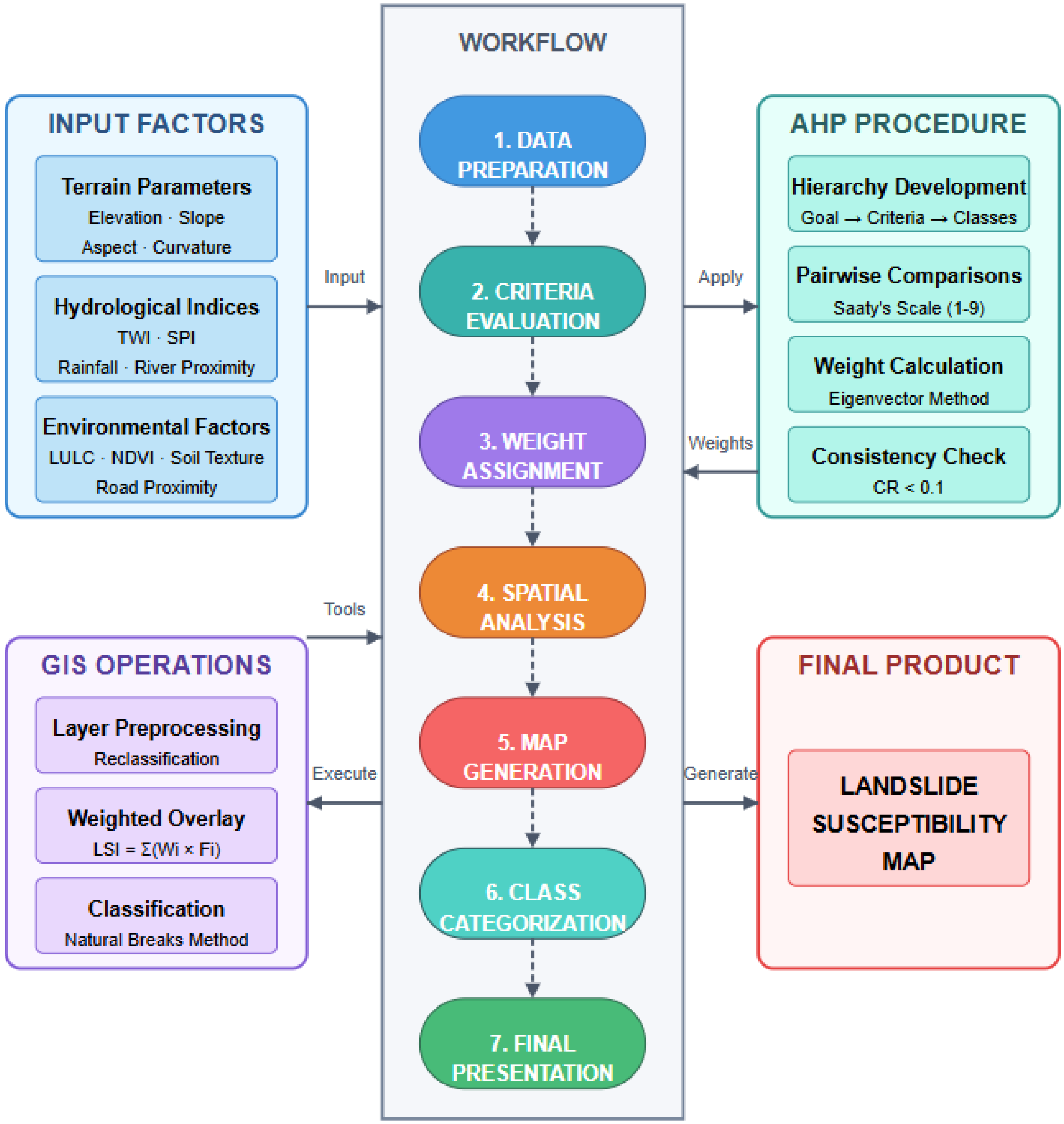
$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \quad (5)$$

where RI stands for random index (Satty, 1980). The random index (Table 4) was compiled by Satty (1980) based on several random samples.

CR value of 0.1 is the maximum threshold of consistency of the matrix. CR value >0.1 is thought to be inconsistent where whereas value 0 indicates a perfectly consistent comparison result (Rohan Kumar, & R. Anbalagan, 2016).

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Figure 2: Methodological Flowchart Adopted for the Study



RESULTS

The Driving Factors Contributing to Landslide Susceptibility in Kamonyi District

In Kamonyi District, a range of driving factors interact to influence landslide susceptibility, significantly affecting the local community. Understanding these factors is crucial for addressing the challenges posed by frequent landslide events.

This section outlines the findings from a comprehensive analysis of the main factors contributing to landslide susceptibility within the district. By identifying and evaluating these factors, a clear understanding of the underlying causes of susceptibility is gained. This knowledge forms the basis for developing targeted and effective mitigation strategies and supports informed

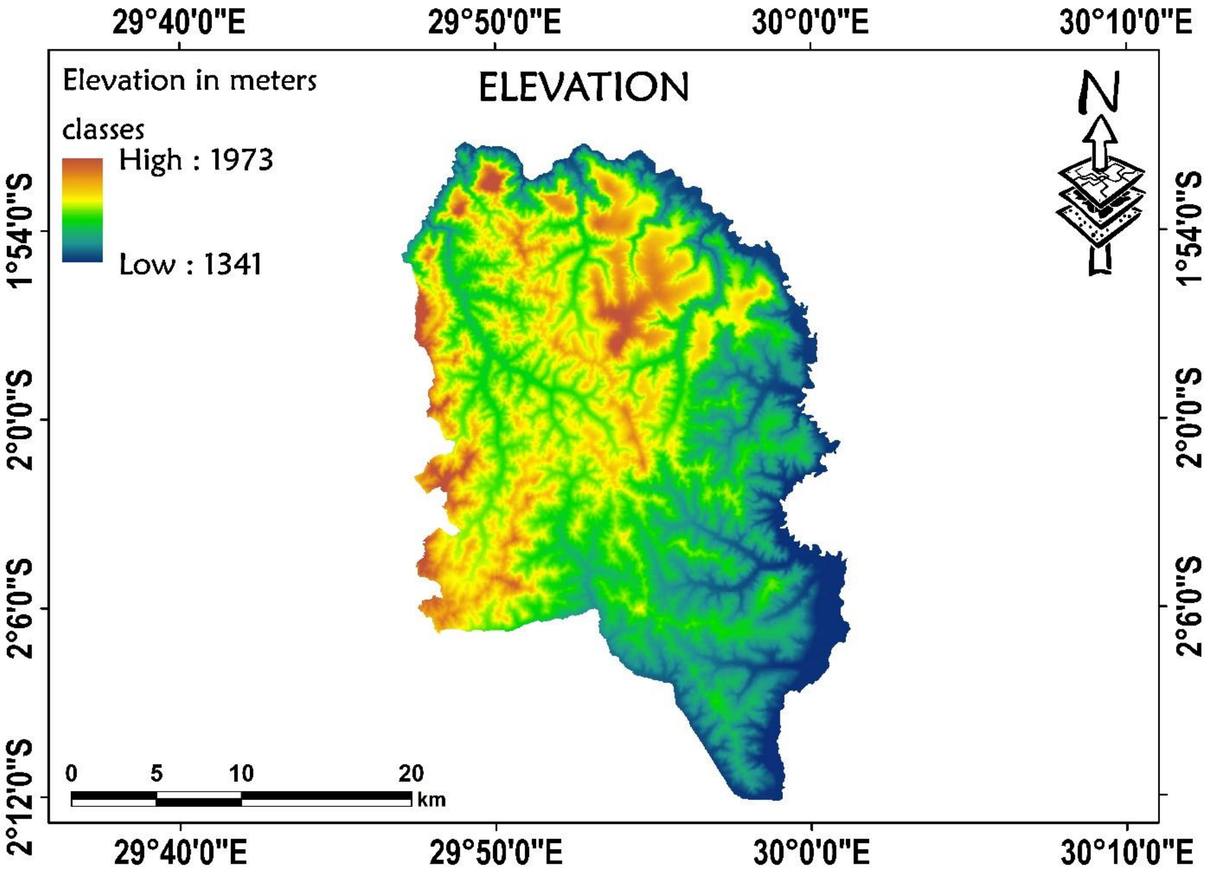
Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

decision-making for disaster risk reduction and resilience-building efforts. The study identified twelve key factors that contribute to landslide susceptibility in the district, including elevation, slope angle, aspect, curvature, the topographic wetness index (TWI), stream power index (SPI), proximity to roads, proximity to rivers, land use and land cover (LULC), normalized difference vegetation index (NDVI), soil texture, and rainfall patterns.

Elevation

Elevation plays a crucial role in determining landslide susceptibility in any region, being an important input for modelling dynamic natural processes such as landslides, mass movement, and soil erosion. Elevation provides insights into the topographical features of the landscape. The elevation map revealed significant variation across the study area, ranging from the lowest point at 1341 m to the highest at 1973 m, as shown in Figure 3. The western and northern parts of the district exhibited higher elevations, which are typically more prone to landslides. In contrast, the lower elevations in the eastern and southern parts were less susceptible to landslides. Moderately elevated areas were found in the northwestern and central-western portions, presenting a varied topography that suggests moderate landslide susceptibility. This diverse elevation profile highlights the need for targeted mitigation measures tailored to different elevation zones, offering a more nuanced understanding of landslide susceptibility within Kamonyi District.

Figure 3: Thematic Layer of Elevation in Meters

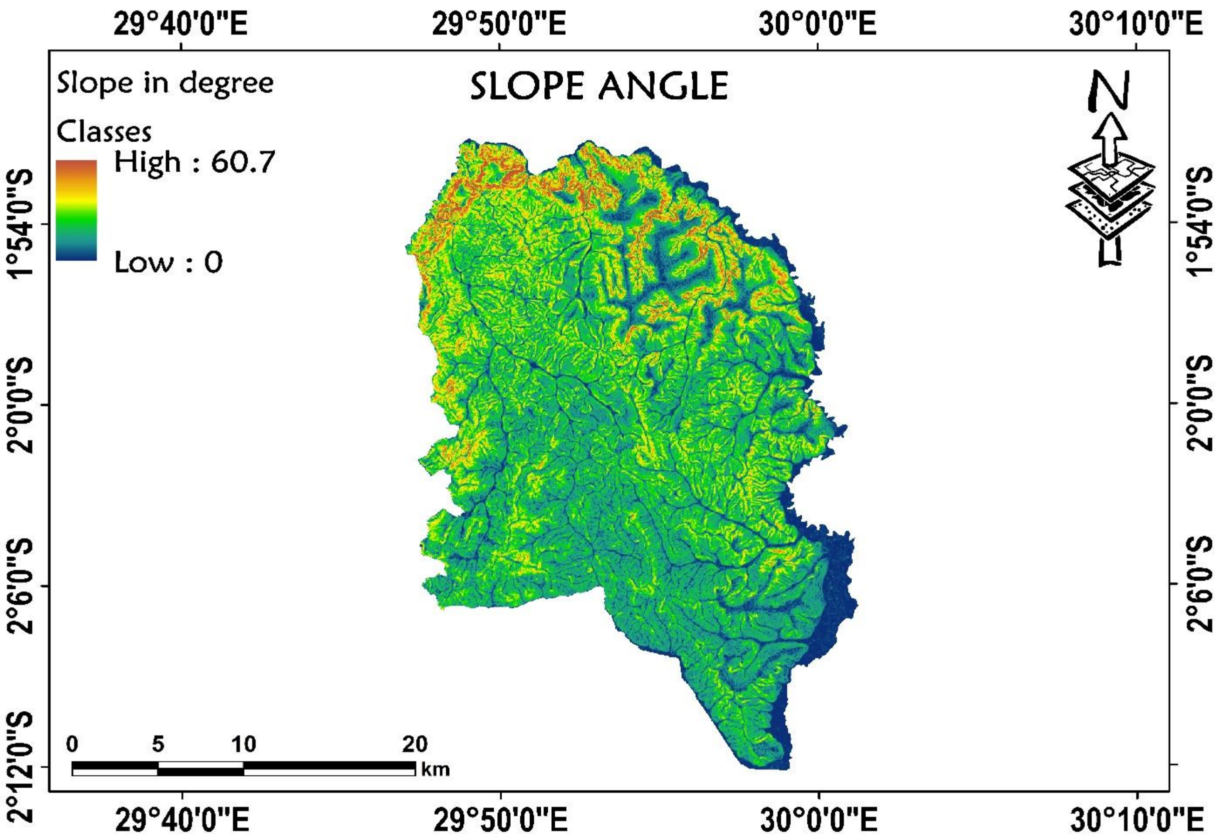


Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Slope

The assessment of slope within a study area is crucial for understanding the dynamics of landslide susceptibility. Slope, as a key topographical feature, has a significant impact on the gravitational forces acting on soil and rock, which increases the likelihood of landslides. While steep slopes tend to accelerate shallow landslides, gentler slopes are generally more stable, but they can still be prone to landslides due to prolonged weathering or external factors such as earthquakes. In this study, the slope analysis revealed that Kamonyi District is mainly characterized by high, moderate, and low-gradient areas. The results indicated that steep slopes are concentrated in the northern part of the district, particularly near the borders with Muhanga, Gakenke, and Rulindo districts. Areas with moderate and low slopes are more evenly distributed across the entire district. The slope angle map for Kamonyi District (Figure 4) spans from 0 degrees (flat) to 60.7 degrees (very steep).

Figure 4: Thematic Layer of Slope (Degrees)

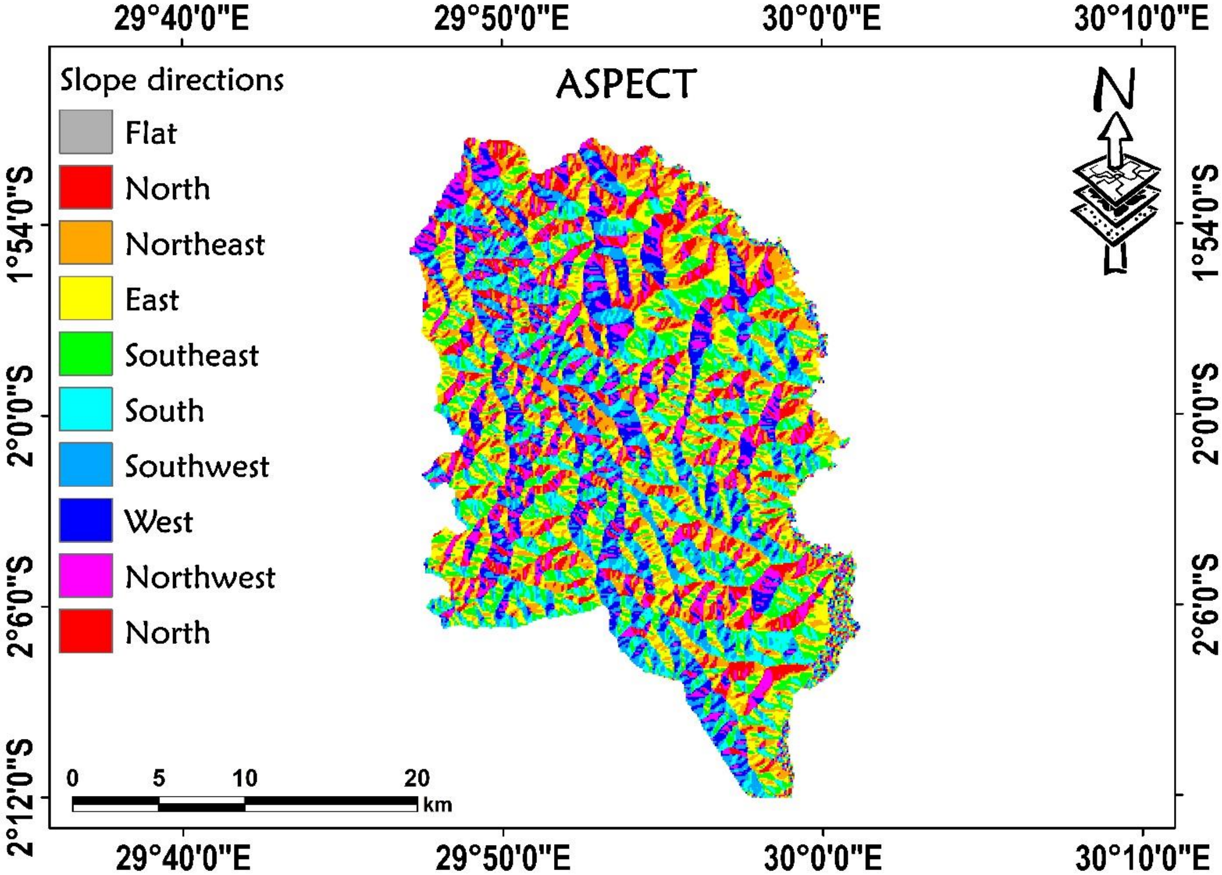


Aspect

The aspect refers to the direction a slope faces, measured in degrees from north (ranging from 0° to 360°). This factor can significantly influence soil properties such as moisture content, erosion, landslides, and vegetation growth. Aspect plays a key role in soil classification, land use planning, and environmental modelling. The direction of slopes in Kamonyi District includes north, northeast, east, southeast, south, southwest, west, and northwest. It affects soil characteristics such as moisture retention, erosion potential, and vegetation growth. Flat areas are recorded as having no aspect data (-1). Figure 5 displays the soil aspect map of Kamonyi District, showing that the district does not contain any flat areas.

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Figure 5: Thematic Layer of the Aspect

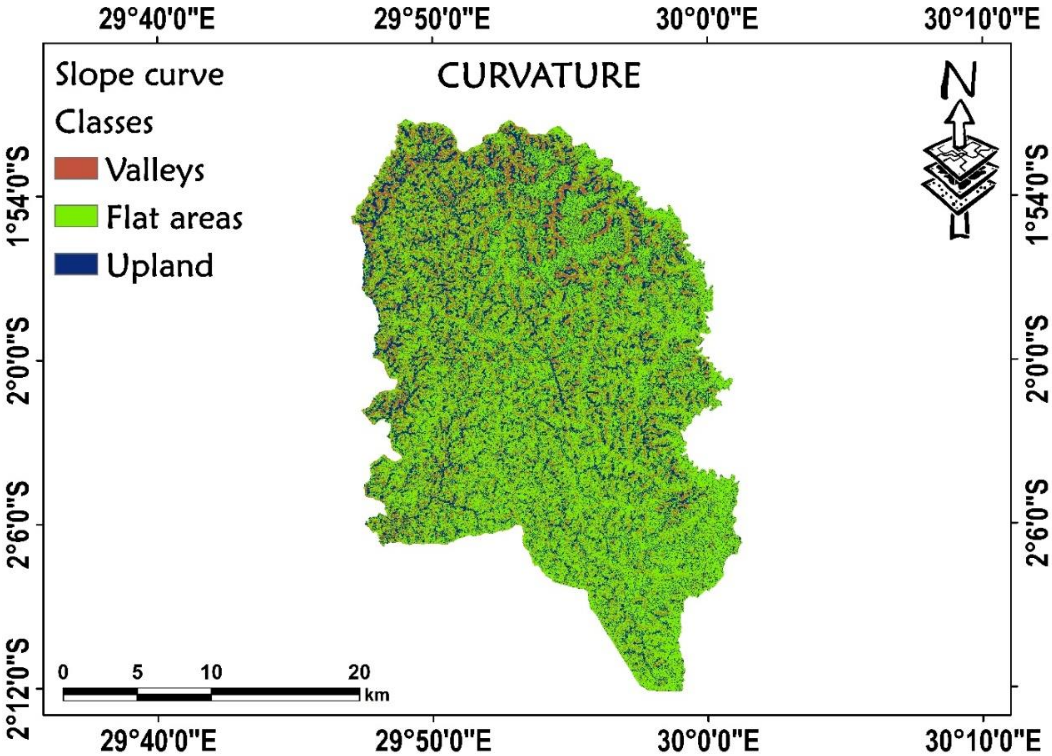


Curvature

Curvature analysis is a valuable tool in landslide assessments as it helps evaluate the stability of terrain by examining the land's surface shape. Different curvature classes, such as valleys, uplands, and flat areas, can significantly impact landslide occurrence by influencing water flow, soil accumulation, and slope stability. As shown in Figure 6, the curvature classes in Kamonyi District are valleys, flat slopes, and uplands/upslope. Valleys are concave slope segments, that are highly vulnerable to landslides due to their tendency to collect water, deposit sediment, and undercut slopes. Uplands, characterized by convex curvature, can pose moderate to high landslide risks depending on the steepness of the slope and soil conditions. Flat areas, where there is no significant curvature, are the least prone to landslides but can still be impacted by landslide deposits from steeper slopes. These flatlands may become zones for the deposition of debris from surrounding slopes, and poor drainage in these areas can increase the risk of soil liquefaction or subsidence, particularly in alluvial plains.

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Figure 6: Thematic Layer of the Curvature



Topographic Wetness Index (TWI)

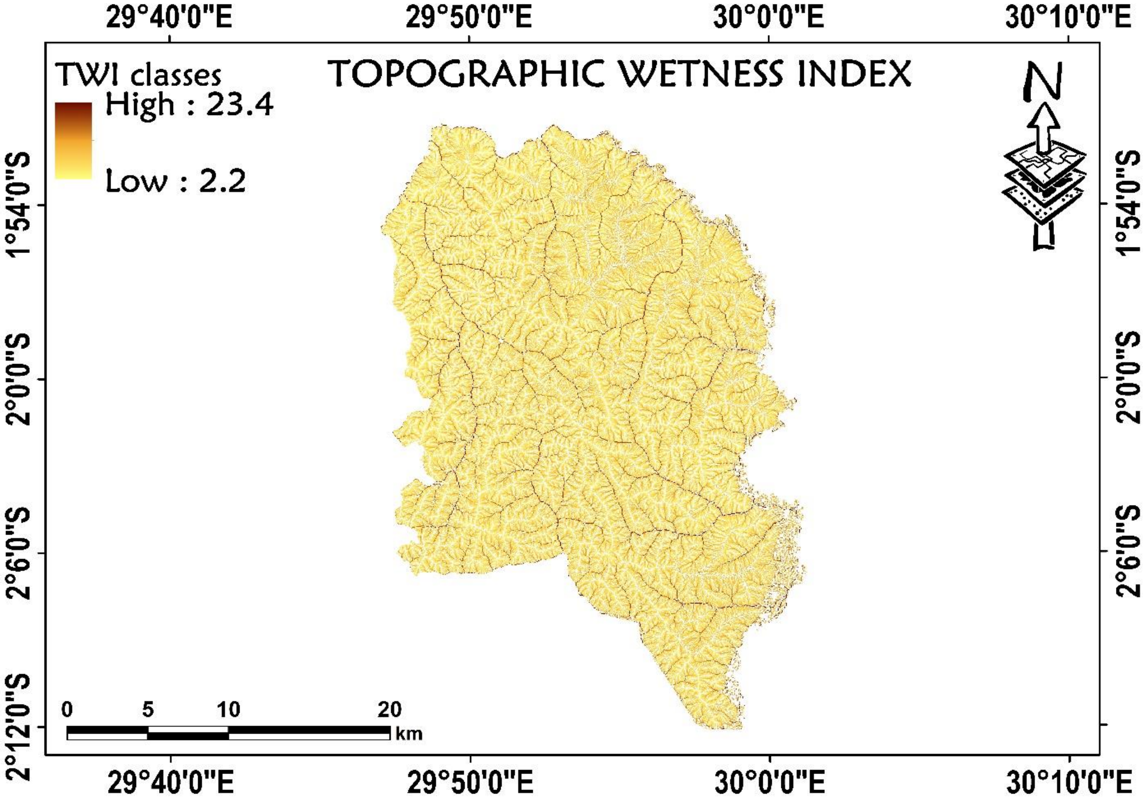
The Topographic Wetness Index (TWI) is an important tool in assessing landslide susceptibility, as it measures the potential wetness of an area based on its topography. TWI considers both slope and upstream contributing areas to identify regions more likely to experience water saturation and accumulation, which are key factors in landslide risk. The TWI model also reflects hydrological processes, particularly water flow accumulation influenced by the slope of the terrain. By understanding TWI's role in landslide susceptibility, researchers can develop more focused strategies for risk management and intervention to reduce landslide impacts.

In this study, the TWI analysis revealed predominantly low TWI values across the Kamonyi District, suggesting a higher likelihood of water stagnation in these areas. Figure 7 illustrates the water flow accumulation, showing that the district is particularly prone to water accumulation, contributing to landslide occurrences. The TWI values ranged from Low (2.2) to High (23.4), with lower values being more widespread. Areas with lower TWI values indicate reduced soil moisture and greater potential for water accumulation, which can increase the risk of water infiltration, reduce soil cohesion, and heighten pore water pressure weakening the slope. In contrast, higher TWI values imply reduced water accumulation, due to better moisture retention and drainage.

The spatial distribution of TWI values in the study area was primarily concentrated in lower ranges, corresponding to higher landslide potential. Although a few pockets with higher TWI values indicated areas with better drainage, most of the terrain exhibited conditions that promote water runoff and soil movement, as shown by the TWI mapping. This pattern highlights the need for targeted landslide mitigation and land-use management efforts in the district, as the landscape’s tendency to retain moisture and promote runoff increases landslide susceptibility.

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Figure 7: Thematic Layer of the Topographic Wetness Index

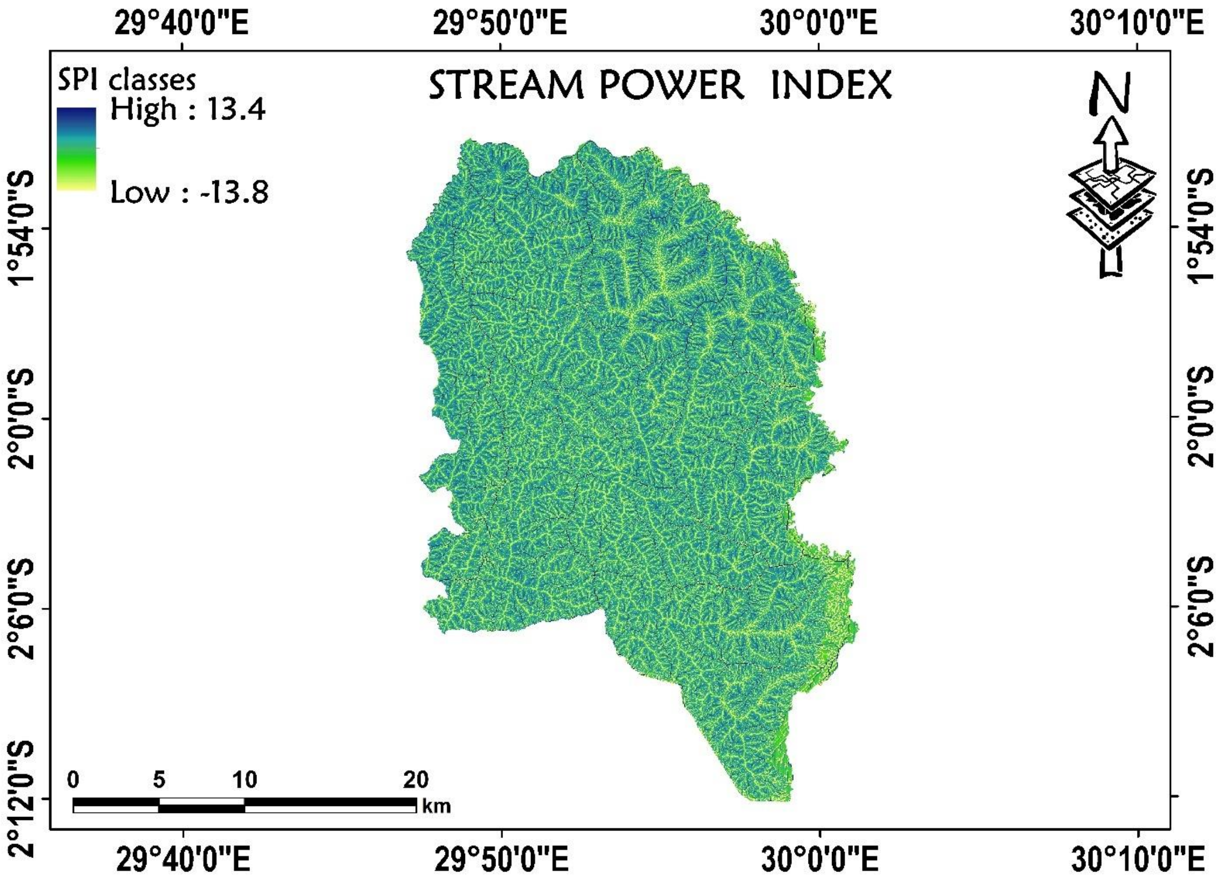


Stream Power Index

The Stream Power Index (SPI) is a hydrological and geomorphological metric that evaluates the potential erosive force of flowing water. It operates on the principle that water's ability to erode and transport sediment is influenced by both the slope and the contributing drainage area. Soil erosion is a significant geomorphological process that directly affects landslide potential in a region. This index was utilized to visualize potential erosion caused by water flow, and it is linked to landscape processes. In this study (Figure 8), the SPI results ranged from Low (-13.8) to High (13.4) classes. In high SPI areas, concentrated water flow increases pore water pressure, saturates the slope material, and reduces soil cohesion, which significantly weakens slope stability and increases the likelihood of landslides. Conversely, in low SPI areas, where water accumulation is minimal and slopes are gentler, conditions remain more stable, and the balance of gravitational and frictional forces helps maintain slope integrity.

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Figure 8: Thematic Layer of the Stream Power Index



Distance to Roads

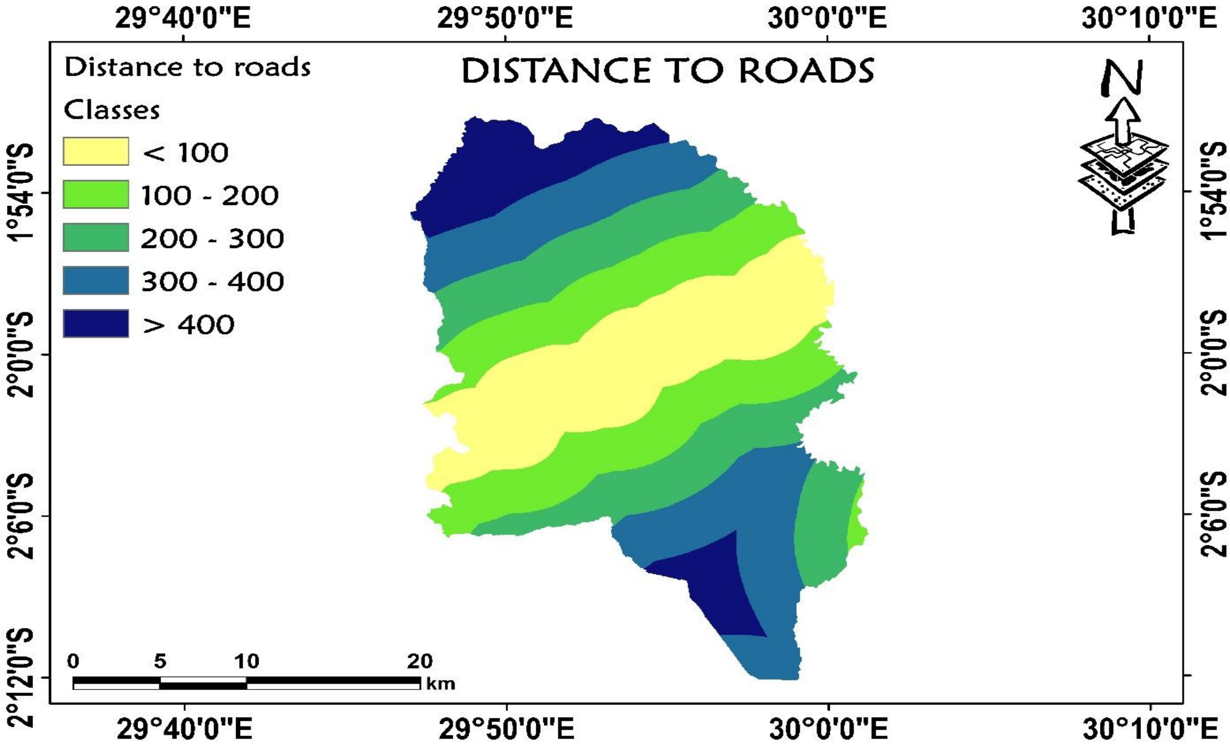
The proximity to roads is an important factor in landslide susceptibility assessment, as it affects the accessibility of areas that may be impacted by landslides. Roads are critical for evacuation, emergency responses, and the transport of goods and services during and after landslides. Understanding the spatial relationship between roads and landslide-prone areas is essential for evaluating landslide risks, planning evacuation routes, and creating effective disaster management strategies. In this study, proximity to roads was found to be a key factor influencing landslide susceptibility across the region. Roads can hinder rainwater infiltration and exacerbate slope instability, increasing landslide risks in surrounding areas. The proximity analysis categorized the study area into five distance classes, ranging from less than 100 meters to over 400 meters from roads. Figure 9 illustrates these five proximity classes. Areas within 100 meters of roads, particularly in the central part of Kamonyi district, were found to be the most vulnerable to landslides. The first class covers distances under 100 meters, the second class spans 100 to 200 meters, the third class covers 200 to 300 meters, the fourth class is between 300 to 400 meters, and the fifth class includes areas more than 400 meters away from roads. The map reveals that Kamonyi district is intersected by a national road.

Research has shown that impervious road surfaces and associated drainage systems can significantly disrupt natural water infiltration during heavy rainfall, leading to rapid runoff accumulation. This runoff, combined with blocked stormwater paths, increases the likelihood of water infiltration in nearby areas, weakening soil stability, particularly in zones near roads represented by the lowest distance class. However, it is important to note that

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

landslide susceptibility is influenced by multiple factors beyond proximity to roads. Terrain characteristics, soil conditions, land use, and other hydrological features can further influence or intensify landslide risks, even in areas further from road networks.

Figure 9: Thematic Layer of the Distance to Roads



Distance to Rivers

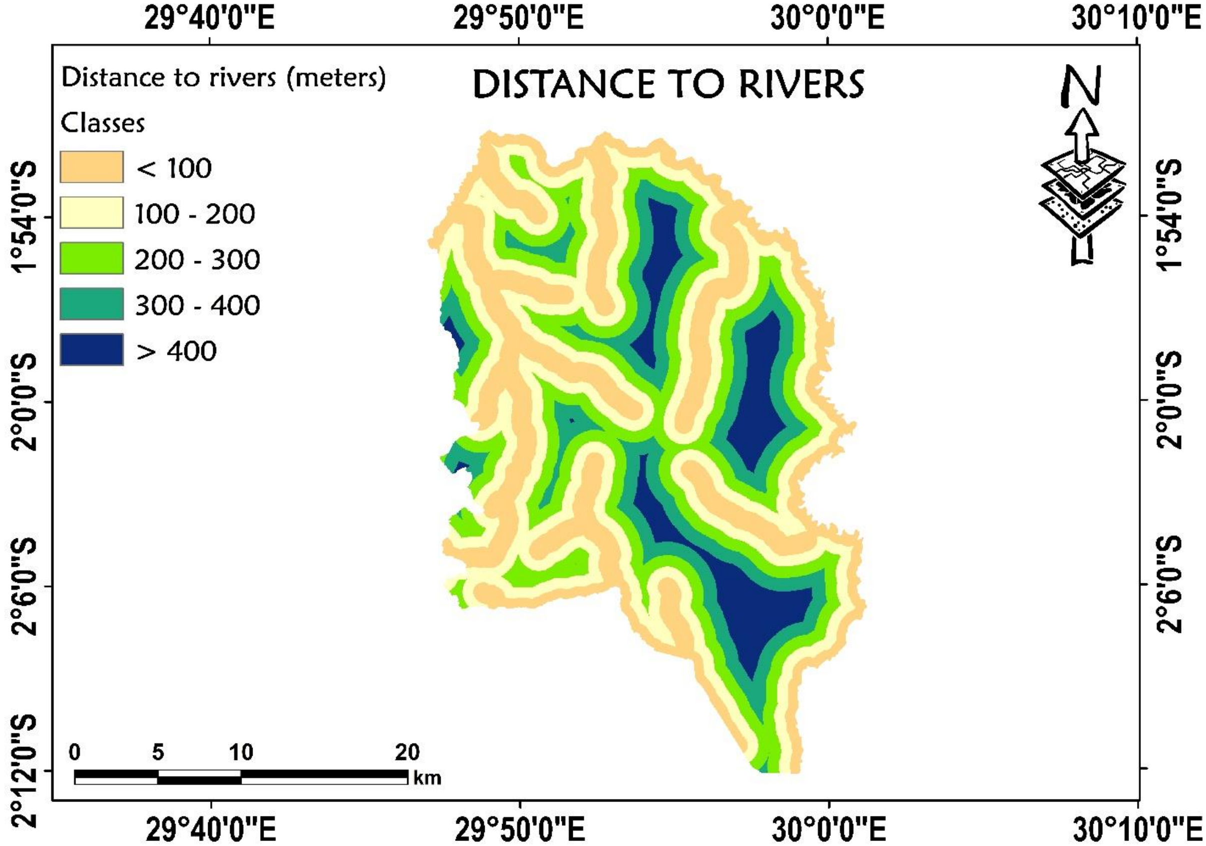
Proximity to rivers is a critical factor in landslide susceptibility assessments as it directly affects areas along riverbeds. Regions close to rivers are generally more vulnerable to landslides due to the potential for river overflow during heavy rainfall, which can saturate the soil and destabilize slopes.

The proximity to rivers was identified as a key conditioning factor influencing landslide susceptibility in the study area. Figure 10 shows five proximity classes to rivers. The analysis revealed that a significant portion of the region lies near river networks, with distances ranging from under 100 meters to more than 400 meters.

The proximity classes are as follows: the first class includes areas within 100 meters of rivers, the second class extends from 100 to 200 meters, the third class ranges from 200 to 300 meters, the fourth class spans 300 to 400 meters, and the fifth class includes areas farther than 400 meters. The map also highlights that Kamonyi district is crossed by a network of streams and rivers. Areas closer to rivers, especially those within 100 meters, are at higher risk for landslides. However, it is important to recognize that severe landslides or additional factors such as inadequate drainage or impervious surfaces may still present risks in more distant areas. The prevalence of proximity zones closer to rivers underscores the need for targeted mitigation strategies, such as establishing buffer zones along riverbanks, planting bamboo along river edges, and implementing land use policies to limit development in these high-risk zones adjacent to rivers.

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Figure 10: Thematic Layer of the Distance to Rivers



Land Use Land Cover

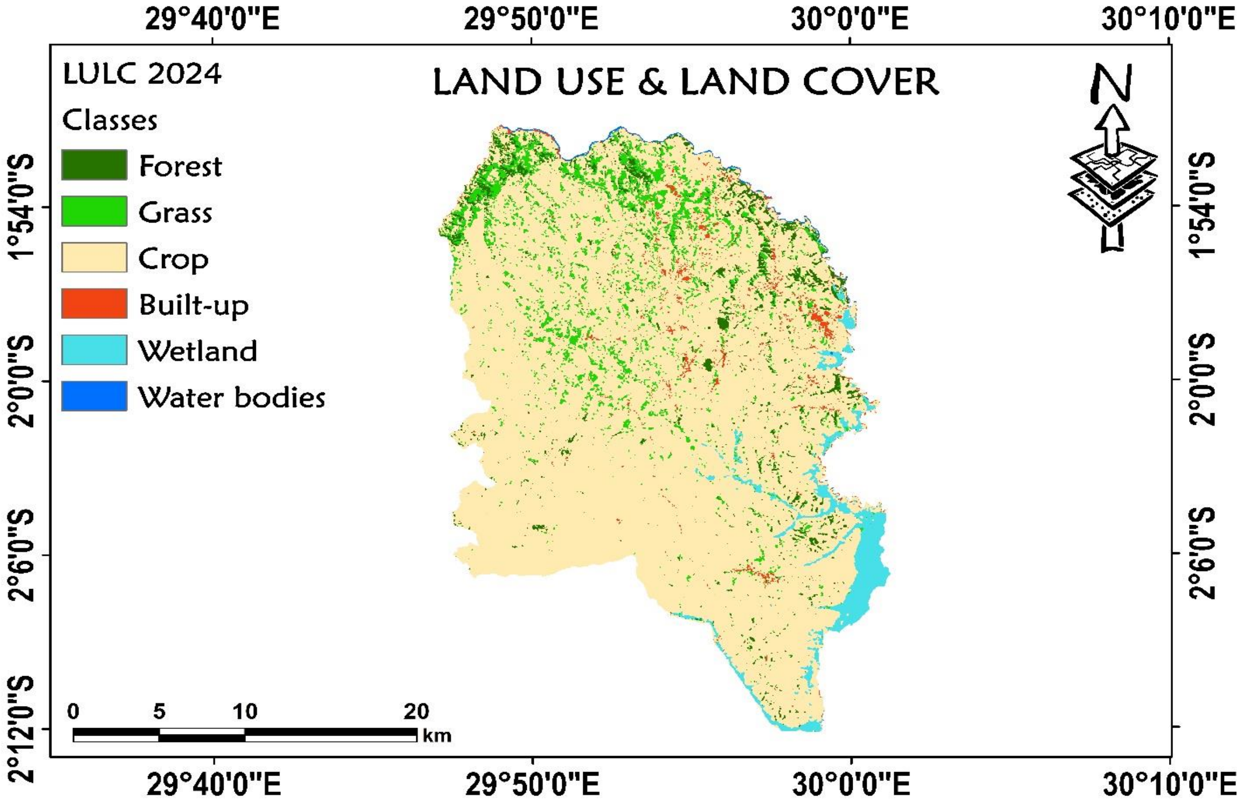
Land Use and Land Cover (LULC) significantly affect the occurrence of landslides. Analyzing LULC is essential in landslide susceptibility assessments as it offers valuable insights into the distribution of different land uses and management strategies, as well as ecosystems that directly impact the likelihood of landslides. Understanding the interaction between human activities and natural features within a landscape is key to evaluating landslide risk, identifying areas prone to landslides, and implementing effective mitigation strategies. LULC analysis helps pinpoint areas that might either increase or reduce landslide risk, guiding land use planning and sustainable practices to improve resilience against potential landslide events. The LULC analysis in this study identified six distinct categories: forest, grass, crop, built-up areas, wetland, and water bodies (Figure 11). Each of these categories has varying degrees of influence on soil stability and landslide susceptibility. The study area was predominantly dominated by croplands, which significantly increases the vulnerability of agricultural areas to landslide-related impacts. Built-up areas, spread evenly across the region, consist of impervious surfaces that hinder natural water infiltration, which can reduce the likelihood of landslides in urbanized regions, as noted by several studies.

Natural vegetation, such as forests and grasslands, generally lowers the risk of landslides by stabilizing slopes through root systems and absorbing water. However, it is important to recognize that in this study, vegetated areas may still experience landslides if rainfall intensity surpasses the soil's ability to stay stable. Unsustainable agricultural practices like overgrazing, slash-and-burn techniques, and poor farming practices contribute to soil erosion and elevate landslide risk. The LULC map indicates that Kamonyi district lacks sufficient

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

forest cover, which underscores the need for integrated land use and management strategies that balance urban growth with sustainable land practices.

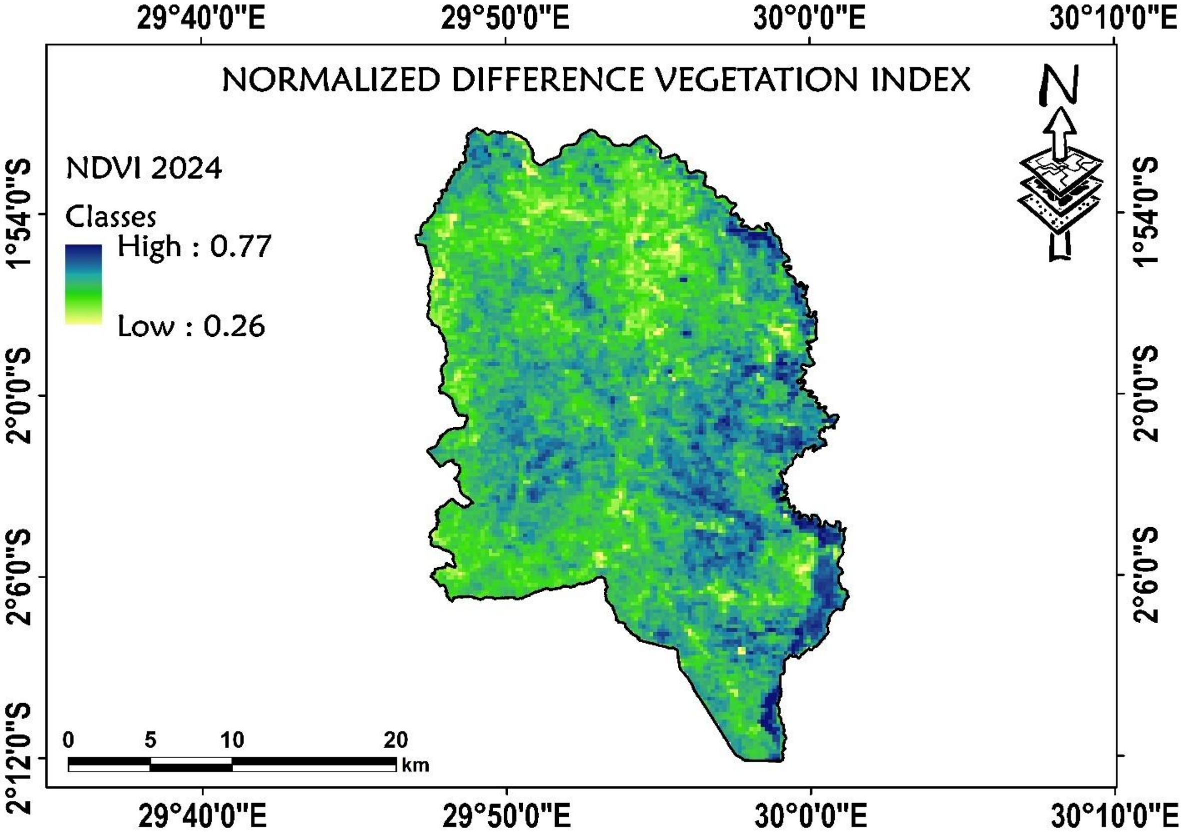
Figure 11: Thematic Layer of the Land Use Land Cover



Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is a key factor in landslide susceptibility analysis as vegetation cover plays a critical role in stabilizing slopes. For this study, NDVI values were used to evaluate landslide-triggering factors. NDVI values range from -1 to 1, with higher values indicating dense vegetation and lower landslide risk. In the study area, high NDVI values (0.77) were found in the central, southern, and eastern parts, where dense vegetation contributes to slope stability. On the other hand, low NDVI values (0.26) correspond to areas with sparse vegetation, bare land, or water bodies, which are more prone to landslides (Figure 12). NDVI is a valuable tool in assessing landslide susceptibility, as a decrease in vegetation cover typically correlates with an increase in landslide risk. Therefore, it serves as an essential parameter in early warning systems and disaster risk management strategies.

Figure 12: Thematic Layer of the Normalized Difference Vegetation Index



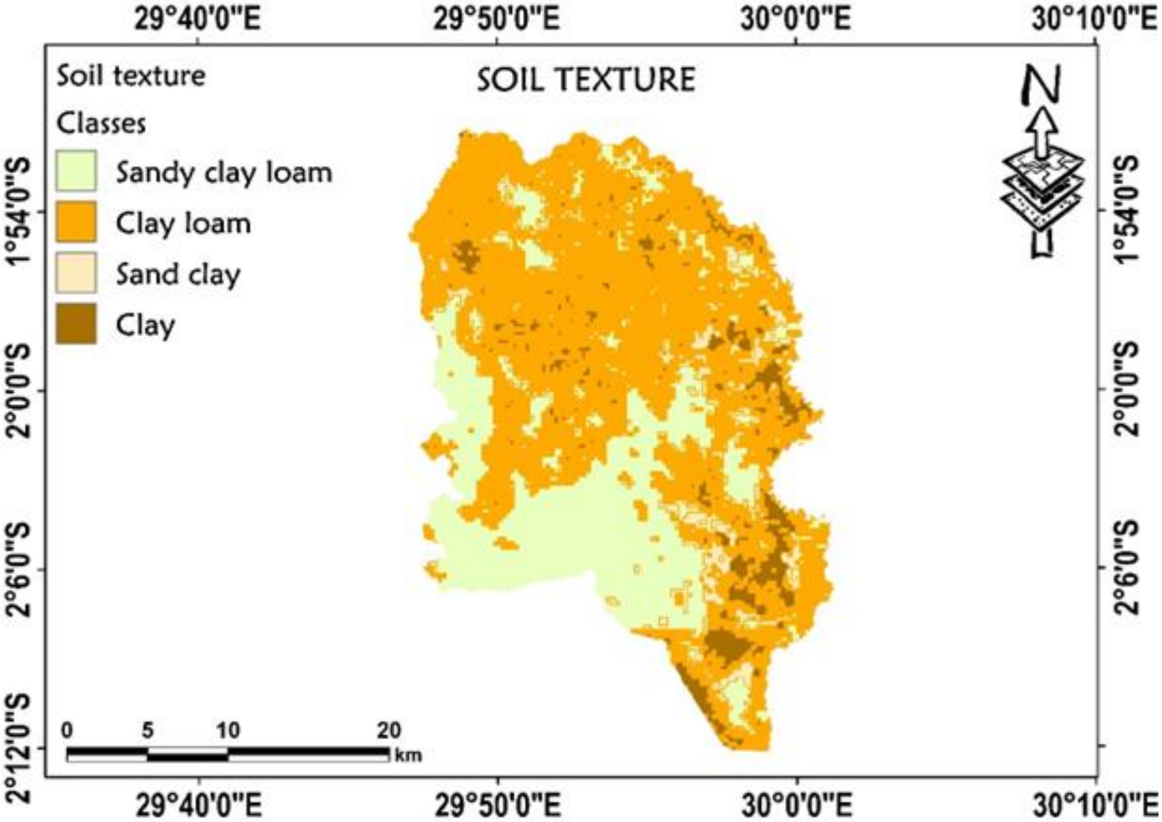
Soil Texture

Soil texture is a key factor in determining landslide susceptibility as it influences drainage, cohesion, shear strength, and water retention within the landscape. Soil is classified based on the proportions of sand, silt, and clay, which affect its ability to resist slope instability. The composition and structure of the soil directly impact the potential for water saturation and groundwater runoff, thereby influencing the likelihood of landslides. Understanding soil texture provides valuable insights into the land's ability to absorb and convey water, aiding in landslide risk assessments, land use planning, and the development of effective mitigation strategies. In this study, soil texture emerged as a crucial factor shaping landslide susceptibility patterns in the study area. Soil characteristics influence water flow, runoff, and moisture retention during landslide events, thereby modulating the risks of landslides in different regions. The soil texture analysis identified four distinct classes: sandy-clay-loam, clay loam, sandy clay, and clay (Figure 13). Among these, clay loam was the most dominant and widespread throughout the study area.

From a landslide susceptibility perspective, this is significant, as clay loam's low permeability and high water-holding capacity can lead to rapid saturation, increasing soil instability and landslide risk in areas dominated by this texture. The clay soil was also found across the study area, though its susceptibility to landslides can be influenced by other factors such as slope, vegetation cover, and precipitation intensity. The spatial distribution of these soil textures underscores the need for targeted landslide mitigation strategies tailored to the specific soil types of each region. The findings illustrated in Figure 13 show that clay loam is the most prevalent soil type, while clay is present in smaller, isolated zones within Kamonyi district.

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Figure 13: Thematic Layer of the Soil Texture



Rainfall

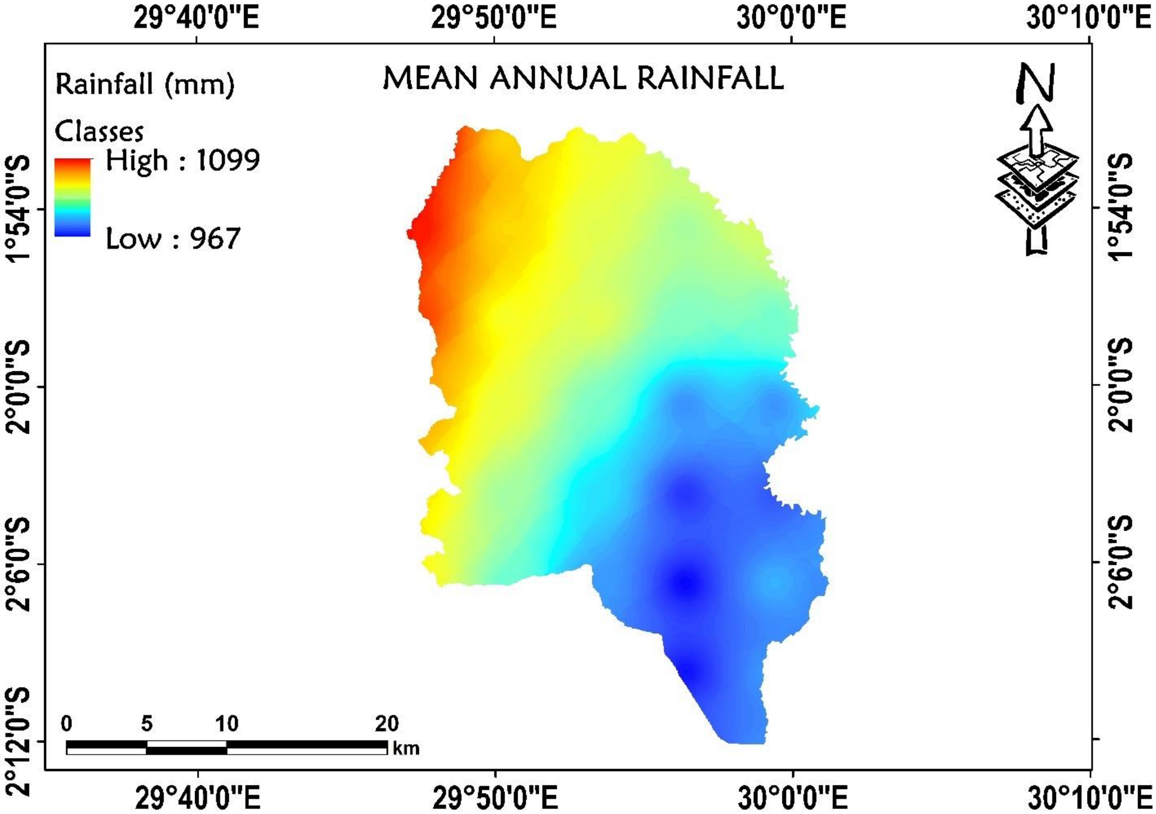
Among the various factors contributing to landslide susceptibility, rainfall stands out as the most significant climatic determinant in the study area. The rainfall analysis classified the region into two distinct categories, with annual precipitation ranging from 967 mm to 1099 mm (Figure 14). A clear spatial gradient was observed, with rainfall progressively increasing in the north-western parts of Kamonyi district. This area contrasted with others in the study region, as it exhibited a higher density of forestland and grassland cover. Despite this increased vegetation, the north-western sections experienced higher mean annual rainfall compared to other areas.

Rainfall has long been recognized as a primary driver of landslides, particularly when intense or prolonged rainfall overwhelms both natural and artificial drainage systems, leading to surface runoff, soil saturation, and slope instability. Although the southeastern parts of the district received relatively lower annual rainfall, it is important to understand that landslide susceptibility results from the complex interaction of multiple factors. Even regions with lower annual rainfall can still be prone to landslides if there are impervious surfaces, poor drainage infrastructure, or intense localized rainfall events.

The findings from this study indicate that the spatial distribution of rainfall plays a critical role in the accumulation of water, which can transport materials, saturate soils, and trigger landslides. Consequently, rainfall data is an essential factor for assessing and prioritizing landslide mitigation strategies in the region.

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Figure 14: Thematic Layer of the Annual Rainfall



Landslide Susceptibility Map Exhibiting Landslide Prone Areas

The key objective in developing a landslide susceptibility map is to accurately identify areas at risk of future landslides. In this study, a landslide susceptibility map was created by incorporating 12 influential layers. The resulting map was classified into five categories: very high, high, moderate, low, and very low susceptibility zones within Kamonyi district. The landslide susceptibility assessment revealed a heterogeneous distribution of susceptibility across the study area (Figure 15), highlighting the complex interaction of multiple factors that contribute to landslide risk. The very high and high susceptibility areas together occupied a significant portion of the district, with a notable concentration in the northeastern and central parts of Kamonyi, particularly in the sectors of Runda, Rukoma, Ngamba, and the parts of sectors Kayenzi, and Kayumbu and Gacurabwenge (Figure 15). High susceptibility zones were also present in smaller parts of the southern region, particularly in the Rugalika and Mugina sectors. These areas exhibited a combination of conditions that intensified landslide risks, such as steep slopes (Figure 4), high rainfall (Figure 14), and land use changes (Figure 11).

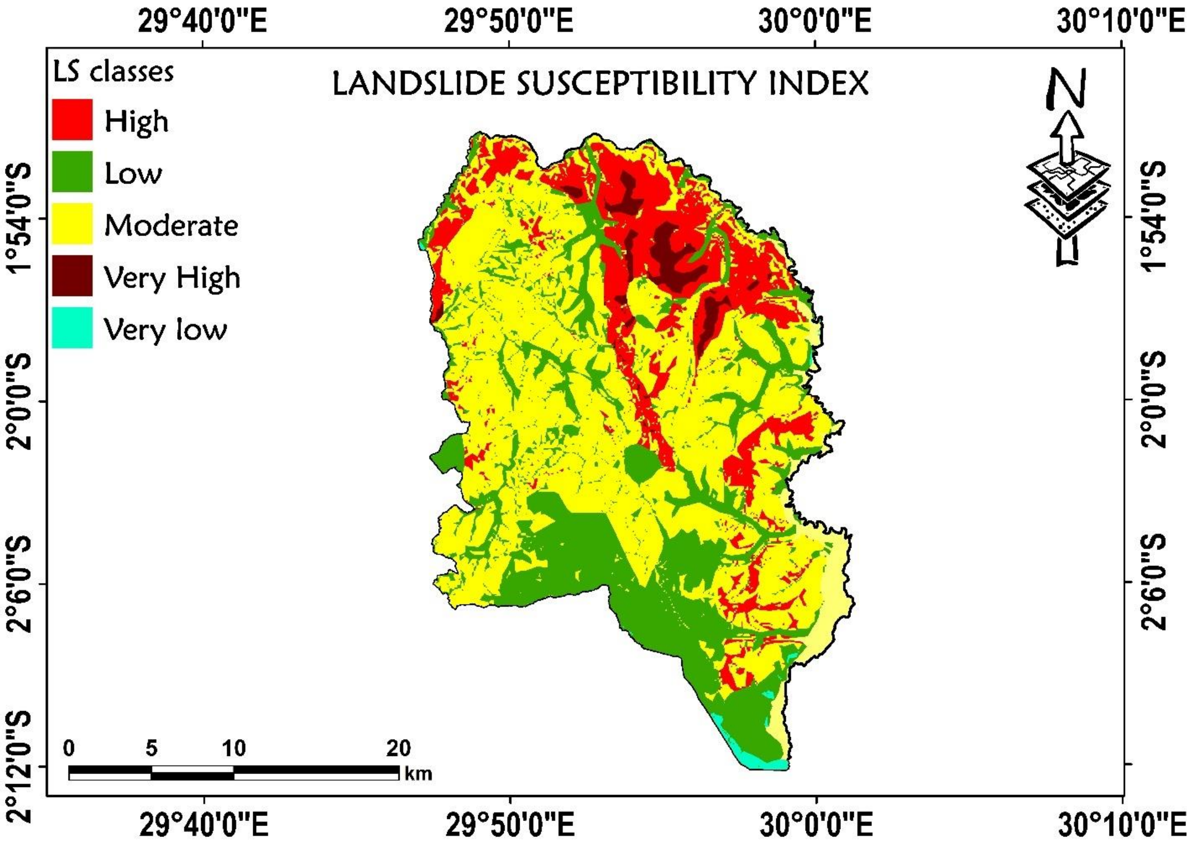
The prevalence of landslide-prone soils, particularly clay loam, further increased susceptibility by influencing water infiltration and runoff generation. Together, the very high and high susceptibility zones covered 19.4% of the total area (Figure 15), indicating a notable but not widespread presence of landslide risk factors across the district. These regions shared common characteristics, although the intensity of contributing factors varied slightly.

Conversely, the moderately vulnerable areas, which covered the largest portion of the district at 52.7%, were scattered throughout the entire study area. These zones were likely protected by a combination of factors that moderately reduced the overall

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

landslide risk, including favourable drainage conditions, moderate rainfall on steep slopes, or more permeable soil types (Figure 13). However, localized factors such as urban development or topographic depressions could still contribute to moderate landslide susceptibility in these areas. Very low susceptibility areas were confined to a small part of the southern zone of Kamonyi district (Figure 15).

Figure 15: Spatial Distribution of Landslide Susceptibility Zones in Kamonyi District



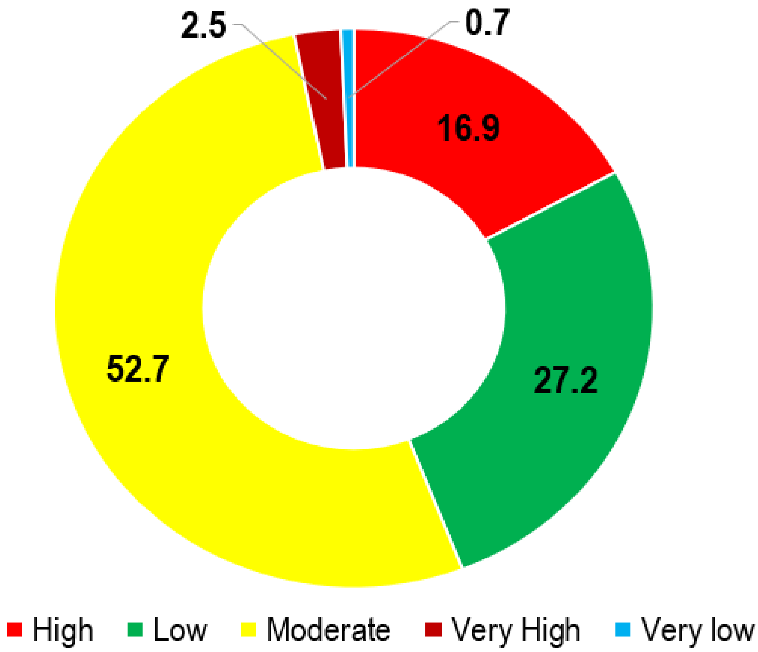
The low susceptibility zones, which account for 27.2% of the total area, were primarily located in the southern part of the study area, extending westward. These regions exhibited characteristics that significantly reduced their landslide susceptibility, such as lower rainfall intensities (Figure 14), well-drained soils (Figure 13), moderate elevations (Figure 3), and greater distances from roads (Figure 9). However, it is important to note that even areas with low susceptibility can experience landslides during extreme rainfall events or when multiple susceptibility factors converge. The very low susceptibility areas represented a small portion of the study area (0.7%) and were concentrated in the southern part. These zones likely benefitted from a favourable combination of factors that minimized landslide risks, including vegetated landscapes (Figures 11 & 12), highly permeable soils, and relatively low rainfall amounts (Figure 14).

Overall, the study indicated that 69.6% of the area falls under moderate to high susceptibility, highlighting the significant landslide risk in Kamonyi district. This emphasizes the need for localized prevention and mitigation measures to address the identified vulnerabilities. It is crucial to understand that landslide susceptibility is a dynamic phenomenon influenced by a complex interaction of both natural and human-induced factors. While susceptibility zoning provides valuable insights for

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

risk assessment and mitigation planning, continuous monitoring of these factors is essential to adapt and update mitigation strategies accordingly.

Figure 16: Percentage per each Classified Susceptibility Class in the Study Area



Relationship between the Driving Factors and Landslide Susceptibility Level in Kamonyi District

The relationship between the driving factors and landslide susceptibility level in Kamonyi District has been measured and revealed based on the influencing factors and their levels of contribution to landslide susceptibility following the weight given by the AHP process as displayed in the below Table 2.

Table 2: Influencing Factors per Level of Contribution to Landslide Susceptibility with Their Calculated Weight Using AHP

No	Influencing factor	Weight (%)	Position	Level of influence
1	Elevation	6.3	6	Moderate influence
2	Slope	22.5	1	High influence
3	Aspect	1.5	12	Low influence
4	Curvature	2.8	11	Low influence
5	TWI	5.2	7	Moderate influence
6	SPI	3.1	10	Low influence
7	Proximity to rivers	4.6	8	Moderate influence
8	Proximity to roads	7.8	5	Moderate influence
9	LULC	13.6	3	High influence
10	NDVI	3.9	9	Low influence
11	Soil texture	10.4	4	High influence
12	Rainfall	18.3	2	High influence

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Each factor was assessed based on its calculated weight percentage and assigned position, along with its corresponding level of influence categorized as high, moderate, or low influence. Firstly, it's important to note that not all influencing factors exert the same degree of impact on landslide susceptibility. Instead, their influence varied, as determined by their respective weight percentages derived from AHP. This method allows for a systematic evaluation of factors to prioritize their importance in landslide susceptibility assessment.

The results of this study on factors contributing to landslide susceptibility in Kamonyi District exhibited that slope, rainfall, LULC and soil texture had a high level of influence. The slope that weighted 22.5% emerged as the most significant factor, underscoring the pivotal role of topography in exacerbating landslide susceptibility within the district. Additionally, changes in rainfall patterns due to climate variability or climate change can significantly impact the frequency and severity of landslide events in the area. Excessive or prolonged rainfall events that weighed 18.3% can overwhelm and weaken the soil and increase slope instability. The study also revealed that LULC with a weight of 13.6% played a crucial role in determining landslide susceptibility.

Landslides are most prevalent in areas where human activity has altered natural land cover, such as deforested slopes, hillside urban developments, terraced agricultural land, and mining zones, as well as in naturally susceptible regions like steep forested slopes and sparsely vegetated hillsides with unfavourable geology. The soil texture with a weight of 10.4% aligned with areas with clay-rich and silty soils, layered soil profiles where permeable materials overlie impermeable layers, poorly consolidated materials lacking cohesion, soils with high shrink-swell capacity, and weathered volcanic soils, all of which become particularly unstable when saturated with water.

Furthermore, the proximity to roads, elevation, TWI and proximity to rivers exhibited a moderate level of influence on landslide susceptibility in Kamonyi District. The proximity to roads that weighted 7.8% often increases landslide susceptibility by creating unstable cut slopes, altering natural drainage patterns, concentrating water runoff, removing vegetation that would otherwise stabilize hillsides, adding weight to already vulnerable slopes through both the infrastructure itself and traffic vibrations, and providing pathways for water infiltration into soil layers.

On the other hand, elevation accounting for 6.3%, influences the susceptibility of an area to landslides, as highly-elevated regions are more likely to be affected by landslides. Integrating elevation data into landslide susceptibility assessments can help identify and prioritize susceptible areas for targeted mitigation efforts. Moreover, the TWI, with 5.2% of weight considers the combined influence of topography and soil moisture conditions, with higher values indicating areas where water naturally accumulates due to topographic conditions, creating zones of increased soil moisture and reduced soil strength that significantly amplify the risk of slope failure, particularly during heavy rainfall events when these already saturated areas can quickly exceed stability thresholds.

Incorporating TWI into landslide susceptibility assessments can provide valuable insights into the spatial distribution of potential landslide-prone areas and inform targeted mitigation strategies. In addition, the proximity to rivers weighing 4.6%, shows a moderate contribution to landslide susceptibility as riverbanks experience continuous erosion at their bases, gradually undermining slope stability, while periodic flooding and fluctuating water levels can saturate adjacent slopes and increase pore water pressure in soil, creating conditions favourable for mass movement especially where rivers have carved steep valley sides through natural erosional processes.

Finally, NDVI, SPI, curvature and aspect exhibited low level of influence to landslide susceptibility in the study area. NDVI weighting 3.9% could indicate

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

that vegetation cover is relatively uniform across the study area, or that other factors override its protective effects.

In some regions, even densely vegetated areas experience landslides due to deep-seated failure planes below the root zone, meaning root stabilization has minimal impact on overall slope stability. Additionally, the study area has predominantly shallow-rooted vegetation, implying that the soil reinforcement capabilities may be insufficient to significantly reduce landslide risk. Moreover, the SPI of the area with 3.1% of weight shows low influence as the area has relatively uniform topography without major variations in channel flow or erosive power. SPI values would be similarly distributed across the landscape, reducing its predictive power for distinguishing landslide-prone areas from stable ones.

The low influence of curvature that weighted 2.8% could suggest that the shape of slopes in the study area (whether concave or convex) is less important than other factors like soil properties or human activities. This occurs in the area because of the underlying geology and soil characteristics highly uniform, and anthropogenic modifications that have altered the natural topographic controls. In some areas, the scale at which curvature is measured might not capture the relevant morphological features that influence slope stability.

Lastly, the aspect (slope orientation) showing minimal influence with a weight of 1.5% indicates that the study area doesn't experience strong directional weather patterns or solar radiation differences that would make certain slope orientations more susceptible than others. In regions near the equator or with minimal seasonal variation, aspect-related differences in moisture, temperature fluctuations, and weathering rates might be negligible.

DISCUSSION

The findings from this study provide essential insights that highlight the complex interplay between environmental and anthropogenic factors contributing to landslide susceptibility in Kamonyi District. The dominant role of slope, rainfall, land use/land cover (LULC), and soil texture confirm existing understandings in the field and aligns with similar research conducted in comparable mountainous areas. For instance, studies in the Himalayas and Andes have consistently demonstrated that steeper slopes correlate with increased landslide occurrences (Irjesh, 2022; Fabrizio *et al.*, 2022). Such collaboration enhances the credibility of the conclusions and emphasizes the significance of geomorphological features that are inherent to the region, where physical characteristics dictate environmental stability. Moreover, the significant impact of rainfall emphasizes the vulnerabilities associated with climatic variability. The finding that rainfall is a key factor influencing landslide susceptibility emphasizes an urgent need for communities to adapt to the increasing unpredictability of weather patterns due to climate change. Previous studies, such as those by Kayastha *et al.* (2013); Haque *et al.* (2016); Mind'je *et al.* (2020) and M.J.Claude *et al.* (2020).

Underscore that intense rainfall events can act as primary triggers for landslides, confirming the need for enhanced early warning systems and community preparedness strategies. As Rwanda's climate is projected to continue experiencing shifts, the advisory role of local meteorological services becomes critical in monitoring weather patterns and potentially dangerous rainfall thresholds that could lead to landslides. The role of LULC changes also highlights how human activities can adversely affect environmental stability. With LULC showing considerable impact, several researchers have emphasized the need for sustainable land management practices that promote ecological balance (Ntawigenera & Yadufashije, 2019; Mugisha *et al.*, 2020). The interaction between inherent slope stability and anthropogenic activities such as urban expansion, agricultural development, and deforestation indicates that community

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

engagement and education on sustainable practices are vital for reducing vulnerability. For instance, promoting agroforestry and responsible land use could enhance soil stability and improve community awareness of risks. This relationship signifies that local governance should not only focus on economic development but also incorporate environmental considerations in land-use policies. The moderate influence of proximity to infrastructure, such as roads, warrants further scrutiny.

Numerous studies have noted the link between infrastructure development and enhanced landslide risks, particularly in regions where drainage patterns are significantly altered, Moradi (2018) and Yalcin (2008). As infrastructure expands, it is crucial to assess its potential impacts on slope stability and hydrological conditions to prevent exacerbating landslide risks. This situation highlights a need for an integrated approach to land-use planning, wherein infrastructure, environment, and community needs are harmoniously balanced. Given that roads are often pathways for both access and the potential spread of landslide debris, civil engineering design must account for local geomorphological data to minimize risks (Skilodimou *et al*., 2018). Identifying areas of susceptibility provides an opportunity for targeted interventions. With more than half of the region classified as having moderate susceptibility, local governments can prioritize these zones for risk management efforts. Implementing zoning regulations to limit high-risk land use, alongside advocating community education initiatives, can form the bedrock of effective disaster preparedness strategies. Evidence from other regions indicates that involving communities in disaster risk assessments significantly enhances resilience (Emily et al, 2018); Claude *et al.*, 2020; Mugisha et al., 2020).

Such proactive measures, coupled with awareness campaigns informing locals about potential hazards, can significantly mitigate risks often neglected in development planning. While this study contributes significantly to understanding landslide susceptibility in Kamonyi District, it also highlights areas for future inquiry. The reliance on historical data limits the understanding of real-time dynamics influencing landslide events. Engagement in longitudinal studies that capture changes over time would facilitate better predictions and adaptive strategies against potential landslide threats. The findings serve as a clarion call for local governments and stakeholders to take decisive action to implement preventative measures to equip communities better against environmental challenges. By integrating scientific insights into local planning, effective risk management strategies can be developed to enhance community resilience, ultimately fostering a sustainable future amid changing climatic conditions.

CONCLUSION

This study provides a comprehensive assessment of landslide susceptibility in Kamonyi District, Rwanda, highlighting the intricate relationships between various driving factors and their contributions to landslide dynamics. It has employed secondary data on causal factors of landslide susceptibility in Kamonyi district. GIS and Remote sensing applications were the main tools for data collection and analysis. The findings demonstrate that Kamonyi district faces a significant risk from landslides, particularly in areas classified as having moderate to high susceptibility. The insights gained from this research not only fill critical gaps in the understanding of landslide behaviour specific to Kamonyi but also reinforce the urgent need for localized risk mitigation strategies. Therefore, as climate change continues to pose challenges through altered rainfall patterns and increased weather variability, ongoing monitoring and adaptive management will be essential in safeguarding communities. By integrating scientific insights into local planning, effective risk management strategies can be developed to enhance community resilience, ultimately fostering a

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

sustainable future amid changing climatic conditions. Local government authorities are recommended to mainstream environmental management practices and inspect their implementation in all development projects and policy formulation at all levels mainly through public consultation and participation before, during and after every development project implementation.

REFERENCES

Ali Yalcin (2008). GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): Comparisons of results and confirmations, *CATENA*, Volume 72, Issue 1,2008, Pages 1-12, ISSN 0341-8162, https://doi.org/10.1016/j.catena.2007.01.003.

Ayalew, L., & Yamagishi, H. (2005). The application of GIS-based logistic regression for landslide susceptibility mapping in the Kakuda-Yahiko Mountains, Central Japan. *Geomorphology*, 65(1-2), 15-31.

Bizimana, H., & Sönmez, O. (2015). Landslide occurrences in the hilly areas of Rwanda, their causes and protection measures. *Disaster Science and Engineering*, *1*(1), 1-7.

Claude, M. J., Martin, N. V., Abias, M., Francoise, M., Johnson, U., Tonny, K., & Martine, U. (2020). Mapping landslide susceptibility and analyzing its impact on community livelihoods in Gakenke District, Northern Rwanda. *Journal of Geoscience and Environment Protection*, *8*(5), 41-55.

Emily Y.Y. Chan, Janice Y. Ho (2018). Urban community disaster and emergency health risk perceptions and preparedness, Editor(s): Rajib Shaw, Koichi Shiwaku, Takako Izumi, Science and Technology in Disaster Risk Reduction in Asia, Academic Press, Pages 95-110, ISBN 9780128127117, https://doi.org/10.1016/B978-0-12-812711-7.00007-9.

Ezzat, A. E., & Hamoud, H. S. (2016). Analytic hierarchy process as module for productivity evaluation and decision-making of the operation theater. *Avicenna journal of medicine*, *6*(01), 3-7.

Fabrizio Delgado, Swann Zerathe, Stéphane Schwartz, Bastien Mathieux, Carlos Benavente, (2022). Inventory of large landslides along the Central Western Andes (ca. 15°–20° S): Landslide distribution patterns and insights on controlling factors, Journal of South American Earth Sciences, Volume 116, 103824, ISSN 0895-9811, https://doi.org/10.1016/j.jsames.2022.103824.

Geertsema, M., Highland, L., & Vaugeouis, L. (2009). Environmental impact of landslides. *Landslides–disaster risk reduction*, 589-607.

Gessesse, A. A., & Melesse, A. M. (2019). Temporal relationships between time series CHIRPS-rainfall estimation and eMODIS-NDVI satellite images in Amhara Region, Ethiopia. In *Extreme hydrology and climate variability* (pp. 81-92). Elsevier.

Gessesse, A. A., & Melesse, A. M. (2019). Temporal relationships between time series CHIRPS-rainfall estimation and eMODIS-NDVI satellite images in Amhara Region, Ethiopia. In *Extreme hydrology and climate variability* (pp. 81-92). Elsevier.

Guzzetti, F., Reichenbach, P., Cardinali, M., Galli, M., & Ardizzone, F. (2005). Landslide hazard assessment in the Collazzone area, Umbria, Central Italy. *Natural Hazards and Earth System Sciences*, 5(6), 691-704.

Haque, U., Blum, P., Da Silva, P. F., Andersen, P., Pilz, J., Chalov, S. R., ... & Keellings, D. (2016). Fatal landslides in Europe. *Landslides*, *13*, 1545-1554.

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Hyndavi, A., James, L., Anjaneyulu, R. V. G., Suresh, S., Rao, C. V., & Bothale, V. M. (2019, October). Evolution of value addition process for generation of Normalised Difference Vegetation Index (NDVI) product–A case study. In *2019 IEEE Recent Advances in Geoscience and Remote Sensing: Technologies, Standards and Applications (TENGARSS)* (pp. 86-91). IEEE.

Irjesh Sonker, Jayant Nath Tripathi, Swarnim (2022). Remote sensing and GIS-based landslide susceptibility mapping using frequency ratio method in Sikkim Himalaya, Quaternary Science Advances, Volume 8, 100067, ISSN 2666-0334, https://doi.org/10.1016/j.qsa.2022.100067.

Karamage, F., Zhang, C., Kayiranga, A., Shao, H., Fang, X., Ndayisaba, F., ... & Tian, G. (2016). USLE-based assessment of soil erosion by water in the Nyabarongo River Catchment, Rwanda. *International journal of environmental research and public health*, *13*(8), 835.

Kayastha, P., Dhital, M. R., & De Smedt, F. (2013). Application of the analytical hierarchy process (AHP) for landslide susceptibility mapping: A case study from the Tinau watershed, west Nepal. *Computers & Geosciences*, *52*, 398-408.

Khasanov, S., Juliev, M., Uzbekov, U., Aslanov, I., Agzamova, I., Normatova, N., ... & Holov, N. (2021). Landslides in Central Asia: a review of papers published in 2000–2020 with a particular focus on the importance of GIS and remote sensing techniques. *GeoScape*, *15*(2).

Kumar, R., & Anbalagan, R. (2016). Landslide susceptibility mapping using analytical hierarchy process (AHP) in Tehri reservoir rim region, Uttarakhand. *Journal of the Geological Society of India*, *87*, 271-286.

Lamek Nahayo, Chi Zhang, Fidele Karamage, Felix Ndayisaba, Hua Shao, Alphonse Kayiranga, Xia Fang, Christophe Mupenzi and Guangjin Tian (2016). USLE-Based Assessment of Soil Erosion by Water in the Nyabarongo River Catchment, Rwanda. *International Journal of Environmental Research and Public Health 13: 835; doi:10.3390/ijerph1308083.*

Long Nguyen Thanh, L. N. T., & Smedt, F. D. (2012). Application of an analytical hierarchical process approach for landslide susceptibility mapping in A Luoi district, Thua Thien Hue Province, Vietnam.

Mind'je, R., Li, L., Nsengiyumva, J. B., Mupenzi, C., Nyesheja, E. M., Kayumba, P. M., ... & Hakorimana, E. (2020). Landslide susceptibility and influencing factors analysis in Rwanda. *Environment, Development and Sustainability*, *22*, 7985-8012.

Ministry in Charge of Emergency Management; MINEMA (2012). Identification of Disaster Higher Risk Zones on Flood and Landslides in Rwanda. By Jean Baptiste Nsengiyumva.

Mugisha, P., Ngoga, A., Rutagengwa, J., Maniragaba, A., & Nahayo, L. (2020). Analysis of Landslide Vulnerability and Community Risk Awareness in Rwanda.

Nakamura, F., Swanson, E.J., & Wondzell, S.M. (2000). Disturbance regimes of stream and riparian systems – a disturbance-cascade perspective. Hydrological process 14, 2849-2860.

New Times.(2024). Rwanda: Govt Closely Monitoring Mysterious Landslides in Three Districts[Online]. Available on World Wide Web: https://www.newtimes.co.rw/news. Retrieved on October 28, 2024.

NISR. (2023). "The Fith Rwanda Population and Housing Census (RPHC5)", National Institute of Statistic of Rwanda (NISR), Kigali, Rwanda.

Ntawigenera, Narcisse & Yadufashije, Callixte. (2019). Environmental Protection as Disasters'

Article DOI: https://doi.org/10.37284/eajenr.8.2.3074

Risk Reduction Strategy in Rwanda: Knowledge, Attitudes and Practices of Community Members in Kamonyi District. International Journal of Research in Environmental Science. 2454-9444. 10.20431/2454-9444.0503001.

Petley, D. N., Hearn, G. J., Hart, A., Rosser, N. J., Dunning, S. A., Oven, K., & Mitchell, W. A. (2007). Trends in landslide occurrence in Nepal. *Natural hazards*, *43*, 23-44.

Rwanda Environment Management Authority; REMA (2021). Floods and Landslides Impact Assessment and Description of at-Risk Areas in Four Urban Sub-catchments in Rwanda. Global Green Growth Institute (GGGI), 19F Jeongdong Building, 21-15, Jeongdong-gil, Jung-gu, Seoul, Republic of Korea 04518.

Saaty, T.L. and Vargas, L.G. (2001) Models, Methods, Concepts and Applications of the Analytic Hierarchy Process. Kluwer Academic Publishers, Norwell. http://dx.doi.org/10.1007/978-1-4615-1665-1

Skilodimou, H. D., Bathrellos, G. D., Koskeridou, E., Soukis, K., & Rozos, D. (2018). Physical and Anthropogenic Factors Related to Landslide Activity in the Northern Peloponnese, Greece. *Land*, *7*(3), 85. https://doi.org/10.3390/land7030085

Teradignews (2024). Rain Damage: Kigali-Southern Province Road Closed for Repairs [Online]. Available on World Wide Web: https://www.teradignews.rw, retrieved on October 28, 2024.

United States Geological Survey Earth Explorer; USGS, (2025). Landsat missions: Landsat Normalized Difference Vegetation Index. [Online]. Available on World Wide Web: https://www.usgs.gov/landsat-missions/landsat-normalized-difference-vegetation-index. Retrieved on January 28, 2025

