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Analysis impacts and influence of Landslides on Local Infrastructure and the Environment by Using Reclassification Method of Spatial analysis tools of GIS, Case study Muhanga District

Obed NYANDWI

Department of Geography and Urban planning, Specialization of Geoinformation for Environmentally Sustainable Development, University of Rwanda

Email: obednyandwi@gmail.com

Aboubakar DUKUNDIMANA

Department of Chemistry, Specialization of Environmental Chemistry Masters, University of Rwanda

Email: abudukunde@gmail.com

Theogene NTWARI

Department of Humanities and Languages specialization Kiswahili Masters, University of Rwanda.

Email: ntwatheo@gmail.com

ABSTRACT

Landslide are key disasters that frequently affect localized areas of the country and cause damaged in farmlands, non-cultivated lands, properties, and loss of life. The heavy rainfall, high slope, land caver and land use change, and anthropogenic activities are the most trigged factors of landslides in Muhanga District. The environmental impact of landslides in Muhanga district poses a significant challenge that requires attention and action. The District's hilly terrain and heavy rainfall make it prone to landslides, leading to detrimental consequences for the environment and its ecosystems. One of the key problems is the destruction of vegetation and loss of biodiversity caused by landslides. The uprooting of trees, destruction of crops, and disruption of natural habitats result in the loss of plant and animal species, leading to a decline in biodiversity and ecological imbalance. Another issue is the erosion of soil caused by landslides. The movement of soil and rock downslope strips away fertile topsoil, degrading agricultural land and reducing its productivity. This poses a threat to food security and agricultural sustainability in the affected areas. Landslides also contribute to water pollution as sediment and debris carried by landslides contaminate water bodies. This not only affects aquatic ecosystems but also poses risks to human health like waterborne diseases and other health hazards. Furthermore, landslides pose risks to human settlements and infrastructure. The damage or destruction of homes, roads, and bridges disrupts communities and hinders economic development. The displacement of people due to landslides has social and economic consequences. Addressing the environmental impact of landslides in Muhanga District requires comprehensive measures for risk assessment, prevention, and mitigation. GIS classification methods play a crucial role in analyzing landslides due to their ability to process and interpret spatial data effectively. Here are some of the importance of GIS classification methods like mapping factors triggered by Landslide and also enable quantitative analysis of landslide-related factors. These maps provide a quantitative assessment of the likelihood and severity of landslides, aiding in decision-making processes. Moreover, GIS classification methods enhance our understanding of landslide dynamics, assist in risk assessment, and support informed decision-making processes related to landslide management and mitigation. This includes implementing effective land-use planning strategies, adopting slope stabilization techniques, establishing early warning systems, and promoting community education and awareness to enhance resilience and minimize the environmental damage caused by landslides.

Key words: Landslides, impacts, factors, environment and GIS

I. GENERAL INTRODUCTION

Landslide, also known as landslip which is a geological hazard that occurs when soil, rock, or vegetation moves downward or outward under the influence of gravity (Lee, 2005). This movement can occur in various ways, such as falling, toppling, sliding, spreading, or flowing, and can range from slow to rapid (Jiang et al., 2010). Landslides are the second most destructive natural hazard after earthquakes in mountainous areas, and they can occur anywhere in the world. The economic and life losses due to landslides have increased considerably in the last century, and most of the landslides are resultant from global climate change, and human activities (Yagodin & Amirov, 2020), (Bizamana & Sönmez, 2015). Landslide hazards may be single, sequential, or combined in their origin and effects and can be characterized by location, intensity or magnitude, frequency, and probability (MIDIMAR, 2012)

Landslides can be caused by natural phenomena or human activities. Natural causes include heavy rains, droughts, earthquakes, and volcanic eruptions. Areas of steep terrain, land previously burned by wildfires, land that has been modified due to human activities, and channels along a stream or river are most vulnerable to landslides(World Health Organization, 2020). Climate change and rising temperatures are expected to trigger more landslides, especially in mountainous areas with snow and ice(Highland & Bobrowsky, 2008). Human activities that involve undercutting, such as road or railroad excavations, can also cause landslides. Overexploitation of resources, unplanned land use such as deforestation, poor agriculture mechanization, and mining activities are also considered factors that cause landslides. Slope curvature and steepness are the main topographic factors that create susceptibility to landslides(USGS, 1999)

Landslides have significant global impacts on both human life and the environment. According to the World Health Organization, over 18,000 people died and an estimated 4.8 million people were affected by landslides between 1998 and 2017(Ur Rehman et al., 2020). Landslides contribute directly or indirectly to about 17% of all disaster-related fatalities worldwide and rank as the 7th most killing natural hazard(Mertens et al., 2018). Landslides not only result in casualties to both humans and animals but disrupt the water quality of streams and rivers as well as the destruction of structural and infrastructural developments(Sim et al., 2022) . The economic impact of landslides is likely the greatest on transportation infrastructures, especially in rural regions where the transportation network is scattered, and the availability of alternate routes is few to none. As a result, a minor landslide will bring a great impact on the economic sector over an extensive region. Landslides also have negative impacts on infrastructure, environment, agriculture, and livestock farming(Winter et al., 2019).

Muhanga District, located in central plateau in Rwanda, is known for its hilly terrain and high rainfall, which make it prone to landslides (GoR, 2004). The District's topography, characterized by steep slopes and unstable soils, increases the vulnerability to landslides and their associated environmental impacts (Bizamana & Sönmez, 2015).

The destruction of vegetation and loss of biodiversity are significant consequences of landslides in Muhanga where, uprooted trees, destroyed crops, and disrupted natural habitats result in the loss of plant and animal species. This loss of biodiversity can disrupt the ecological balance and have long-term effects on the overall health of ecosystems in the affected areas (Bizuru et al., 2011).

Landslides also contribute to soil erosion in Rwanda (RWB & IUCN, 2022). The movement of soil and rock downslope during a landslide can strip away fertile topsoil, leading to the degradation of agricultural land. This reduction in soil fertility can have adverse effects on food production and agricultural livelihoods, impacting the country's food security (REMA, 2010) .

Moreover, landslides in Muhanga District can result in the transportation of sediment and debris into water bodies, leading to water pollution. The contamination of rivers, lakes, and other water sources can have detrimental effects on aquatic ecosystems, affecting the health of aquatic organisms and compromising water quality for human use (REMA, 2020). GIS classification methods play a crucial role in analyzing landslides due to their ability to process and interpret spatial data effectively. Some of the importance of GIS classification methods for analyzing landslides about are identifying and mapping factors triggered by Landslide and this classification methods enable quantitative analysis of landslide-related factors (Sestras et al., 2019). By assigning numerical values to different variables and applying classification method, GIS can generate landslide susceptibility or hazard maps. These maps provide a quantitative assessment of the likelihood and severity of landslides, aiding in decision-making processes (Vakhshoori et al., 2019). Moreover, GIS classification methods enhance our understanding of landslide dynamics, assist in risk assessment, and support informed decision-making processes related to landslide management and mitigation. To address these environmental impacts, Muhanga and Government of Rwanda has been implementing various measures to mitigate landslide risks and promote sustainable land management practices. These include land-use planning, reforestation efforts, terracing techniques to control erosion, and the establishment of early warning systems to alert communities about potential landslide hazards.

By understanding the environmental consequences of landslides in Muhanga District and implementing appropriate measures, the country aims to minimize the negative impacts on ecosystems, protect biodiversity, and ensure the sustainable use of its natural resources.

II. STUDY AREA DISCRITION

The study was conducted in the Muhanga district, which is the one of districts in Rwanda's southern province. It is one of the eight districts in Southern Province which separated into three hundred and thirty-one (331) villages (Imidugudu), sixty-three (63) cells, and twelve (12) sectors. The District is surrounded by the Districts of Gakenke in the North, Kamonyi in the East, Ruhango in the South, Karongi District lies to the southwest and Ngororero in the West. Its total area is six hundred forty-seven-point seven square kilometers (647.7 km2), and has 358,433 Population (de Bruyn & Wets, 2006); (NISR, 2022).

The "central plateau" of the nation, which has a hilly topography, is one area of Muhanga District. This region, with its high and low peaks, is among the best parts of the nation's central "plateau". The District's other portion is situated a top the Nil-Congo Mountains, which have peaks rising to elevations of more than 2000 meters. Therefore, the District is situated between 1100 and 1200 mm above sea level in a well-watered area (Muhanga, 2013).

***Figure 1**: Location of Muhanga District*

III. METHODOLOGY AND DATA COLLECTION METHOD

Quantitative and qualitative approach are used to produce high quality of data (Daniel, 2016). Quantitative approach for classification method also produces high accuracy information for analysis of landside. The Classification method is Quantile Each class will contain an equal number of features. This method is well suited to linearly distributed data. In this method, data values are arranged in order. The class breaks are determined statistically by finding adjacent feature pairs between which is a relatively large difference in data value. This is the default classification method in ArcGIS 10.8 (Psomiadis et al., 2020).

Classification method of GIS analysis tool are used to provide the quantitative data which played role of analysis and provide maps of factors triggered landslides such as slope, soil type and soil depth, Rainfall, land use and land cover change, distance from the roads and distance from the river. Moreover, GIS provides significant tools to identifying landslide-prone areas, assessing the impact of landslides on infrastructure and the environment, or predicting future landslide occurrences.

III.1. DATA REQUIREMENTS AND DATA SOURCES

Different data were collected on the seven factors such as distance to river, soil type, soil depth, rainfall, slope, land cover, distance from the river and distance to roads.

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Figure 2: *Seven factors influence analysis model of landslides*

SOURCES OF DATA

Types of data	Source
DEM	USGS/UR, 2021
Land caver	Landsat image from USGS, 2021
Soil	CGIS/UR, 2016
Distance from roads	CGIS/UR, 2016
Slope	DEM from USGS, 2021
Rain fall	METEO Rwanda, 2021
Lithology	CGIS/UR, 2016

III.2. DATA COLLECTION

For Gathering relevant data about landslides used for analysis, including digital elevation models (DEMs), satellite imagery, geological maps, land cover data, rainfall data, and any other data sources that can provide information about landslides and their contributing factors. Field investigation, landslide inventory mapping, Google Earth Imagery analysis, landslide factor evaluation, and mapping, information value, and certainty factor landslide susceptibility modeling and validation were applied. Furthermore, relevant data, including Digital Elevation Model (DEM) with 30m resolution provide topographic map for slope analysis which collected from USGS website. Although, ArcGIS 10.8 also used to provide the different maps such as slope, soil types, lithology, land cover, distance to road and rain fall. The slope map delivered from DEM of 30m resolution with spatial analysis tools with slope tools to slope map. After reclassify also used raster analysis to classify into five class, very low risk of landslide, lower risk of landslide, Moderate risk of landslide, High risk landslide and very high risk of landslide. Steepness area from 0^0 to 20^0 are not affected with landslide, the degree from 20^0 to 50^0 are affected with moderate landslide, area above 50^0 are mostly phone to landslide (GoR, 2004). Moreover, conversional provided to convert from raster to polygons in order to get non-spatial data or quantitative (statistical) which supported to analyze the result. To produce the land cover map were used Landsat image with unsupervised reclassification into ArcMap.

Slope analysis

Area affected with risk of landslide = area of class * 100/ Total area

Land use/cover analysis

Area affected with risk of landslide= Area of class*100/Total area

IV. RESULTS AND DISCUSSION

Landslide is a major geological hazard, which poses serious threat to human population and various infrastructures, the idea that it could occur is frightening people in every area prone to such phenomena. This is because the effects of landslides can be devastating, leaving thousands of people without home and threatening their lives. In this paper we were discussed about the landslide impacts on the landscape of the earth’s surface, quality of rivers and streams and groundwater flow, landslide damage households and other infrastructures.

IV.1. PHYSICAL AND HUMAN FACTORS TRIGGERING LANDSLIDES IN MUHANGA DISTRICT

Muhanga District is one of district of Rwanda which mostly affected risk flooding and landslides in high level. Both natural and anthropogenic activities which contribute of triggering factors disposed to landslides. These consist of Slope steepness, Geology and soil composition, Precipitation, Vegetation cover and Human activities for instance, Construction, excavation, deforestation, and improper land use practices can alter the natural stability of slopes, increasing the risk of landslides.

IV.1.1. PHYSICAL OR NATURAL FACTORS INFLUENCING LANDSLIDES IN MUHANGA DISTRICT

Nature of Slope Influence on Landslides

Slope is a principal factor in the determination of the intensity and character of landslides (Bizamana & Sönmez, 2015), it has direct as well as indirect influences. Direct influences encompass slope steepness, river valley morphology. The most important slope characteristic is the steepness, which affects the mechanism as well as the intensity of the landslides (Campforts et al., 2022). The greater the height, steepness and convexity of slopes, the greater the volumes of the landslides (Placide, Dibanga B et al., 2016). The areas of high slope are more vulnerable to landslide than areas of gentle slopes. In Rwanda three parts of relief exist which are High land area, center Plateau and low land areas. The high land areas are more affected with landslide compared to center plateau and lower land areas. An important factor in the distribution of landslides is the slope gradient, mass movements occur only when a critical angle is exceeded (Bizamana & Sönmez, 2015). The slope gradient plays a significant role in the distribution of landslides, and mass movements only happen when a critical angle is exceeded. Landslides mostly happen in Rwanda on slopes as high as 14°, the lowest reported in all the research. Bizimana (2015) stated that, the majority of Rwanda's north province is above a 45-degree slope gradient, the west is above 35 degrees, and the south is above 25 degrees. The nature of steepness and heavy rain occurring between middle March to middle May and September to December prayed great role of landslides. For instance, 31.94% are very low risk landslide, 24.30 are low risk landslide, 25.72 are moderate risk landslide, 13.50% are high risk landside and 4.54% of total area was very risk high. Despite of appearing the landslides whole part of the district, the southern parts are mostly prone to landslide (See figure 3).

Figure 3: *graph that shown the rate of landslide caused by Nature slope*

Figure 4: *Natural Slope map analysis*

INFLUENCE OF SOIL DEPTH AND SOIL TYPES ON LANDSLIDES

The depth of soil plays a significant role in landslide susceptibility. Shallow soils, especially those sitting on top of bedrock or hard layers, may have limited stability and can easily slide or erode during heavy rainfall or seismic activity (Nseka et al., 2022). Deeper soils, on the other hand, can provide more stability and resistance to landslides. Different soil types have varying properties that can affect landslide occurrence. Some soil types, such as clay and silt, have a higher water-holding capacity and can become easily saturated during periods of heavy rainfall. This increased water content reduces the soil's shear strength, making it more prone to landslides. Other soil types, like sandy or gravelly soils, may have better drainage and lower water-holding capacity, reducing the likelihood of landslides (Poesen & Deckers, 2009); (Batumalai et al., 2023).

Soil properties play a significant role in influencing landslides in Muhanga District. Several soil characteristics can contribute to the occurrence and susceptibility of landslides. Soil Composition of Muhanga influence landslide dues to composition of soil, including its mineral content, organic matter, and particle size distribution, can affect its stability. Soils with high clay content tend to have lower shear strength and are more prone to landslides compared to soils with higher sand or gravel content.

Soil Moisture Content in Muhanga influence of landslides due to the moisture content of soil is a critical factor in landslide occurrence whereas saturated or waterlogged soils have reduced shear strength, making them more susceptible to failure and movement. Heavy rainfall or improper drainage can increase soil moisture, leading to increased landslide risk. During the rainy season occur in between September to December and March to May causing high infiltration due prone landslide in hills and mountains region (Kuradusenge et al., 2021).

Moreover, Soil Porosity and Permeability also influence its ability to absorb and drain water. For this, soils with low porosity and permeability, such as clayey soils, can retain water and become saturated more easily, increasing the likelihood of landslides. For instance, soil found in Cyeza sector are rich to carbonate and sand which provide high level of penetration which prone to landslides.

According to the figure 5 and figure 6 for analysis soil depth. Are ranked from 0 to 3 which mean 0 from very low affected to 3 very highest affected areas. According to figure 4, graph above shows that percentage of soil depth and soil class that affected with landslide. With spatial analysis 19.13% are affected with low landslide or no landslide triggered by soil depth. 36.61% are affected with medium landslides triggered by soil depth. In this region largest part with 44.30% are affected by high landslides which triggered by soil depth and Humic Acrisols (Sombric) soil because of this soil accumulate high infiltration capacity which cause soil shaking each other.

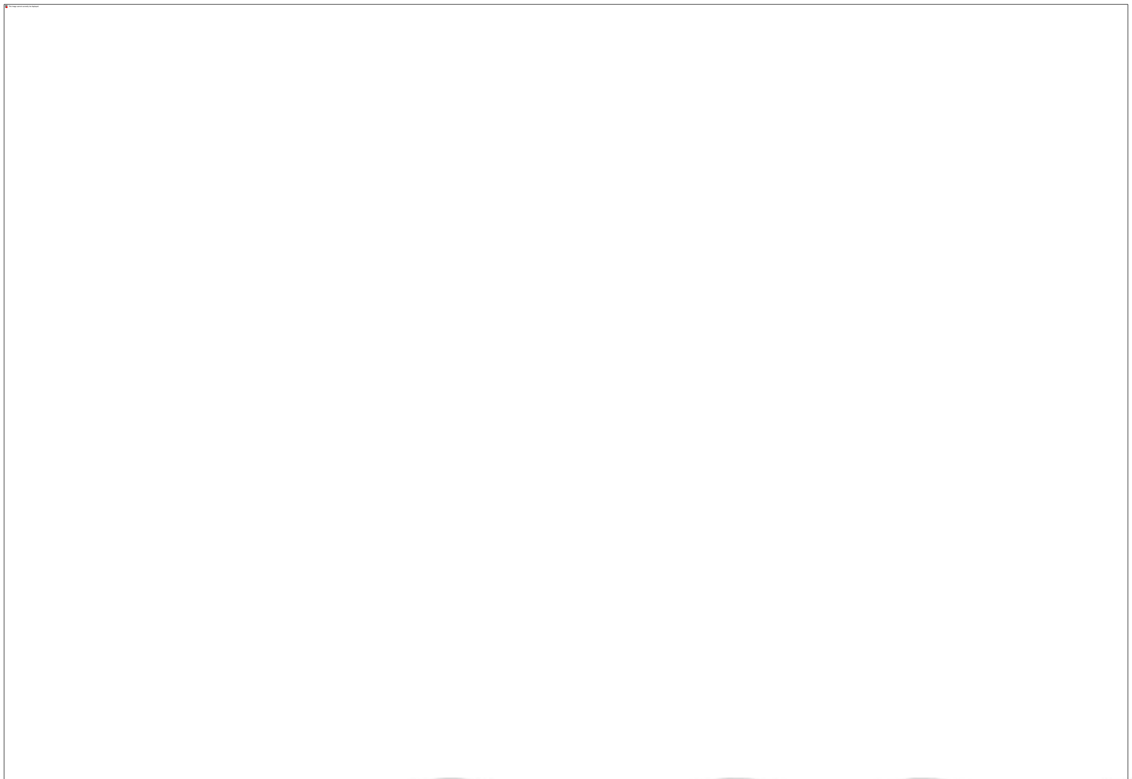

Figure 5: graph of soil analysis

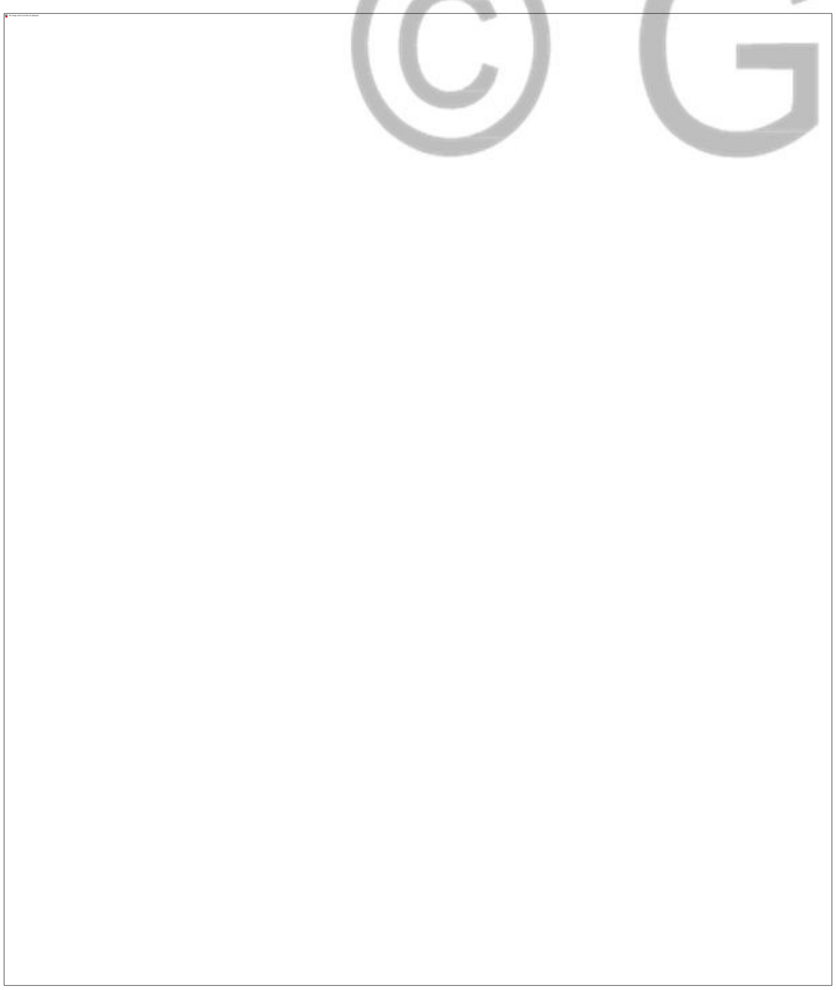

Figure 6: *Soil analysis map*

INFLUENCE OF RAINFALL ON LANDSLIDES

Heavy rainfall contributes to soil erosion. The month getting more rainfall are getting heavy landslide triggered by rain. Rainfall plays a significant role in influencing landslides in Rwanda. The amount, intensity, and duration of rainfall can directly impact the stability of slopes and trigger landslides. During rainy season the Saturation of soil with Heavy or prolonged rainfall can saturate the soil, reducing its shear strength and cohesion. This makes the slopes more susceptible to failure and increases the likelihood of landslides occurring (Kuradusenge et al., 2020). Absence of vegetation cover with Intense rainfall can lead to rapid infiltration of water into the ground. If the soil has a low permeability or is already saturated, the excess water cannot be absorbed quickly, resulting in increased pore water pressure. This buildup of water pressure can weaken the slope and trigger landslides in different parts of country.

Muhanga's climate is tropical. Winter rainfall is significantly higher than summer rainfall. In Muhanga, the yearly average temperature is 18.7 °C. Every year, about 1207 mm of precipitation fall. (Muhanga, 2019). Landslides occurring after periods of intense, heavy rain rainfall are likely result from one or more of the following waters loading of the slope (MeteoRwanda, 2020). According to figure 7 rainy seasons between from mid- March to mid- June and from September to December this region received heavy rain and soil absorb more water which led to high infiltration capacity and high soil Percolation. As the soil started to deteriorate, mud began to flow. As a neighborhood expands, hills and mountains eventually collapse due to gravity. This area experienced landslides twice a year caused by heavy rainfall. The figure displays the pattern of rainfall and temperature variation over time. The majority of people who reside in high-risk zones are more vulnerable to landslides and experienced the greatest amounts of precipitation during March, April, October, November, and December. For example, prolonged rainfall has triggered more phone landslides in the Ndiza region since 2016 and many people in the Rugendabari, Nyabinoni, Rongi, Kiyumba, and Kibangu sectors lost their lives and possessions, suffered injuries, and numerous infrastructures sustained damage.

Figure 7: *graph of annual precipitation and annual temperature in Muhanga District*

INFLUENCE OF LAND USE AND LAND COVER ON LANDSLIDES

Studies have suggested that changes in land use and cover (LULC) might render landslides more susceptible to rainfall-triggered landslides, making LULC an important conditioning factor. Because plants' and trees' roots hold the soil in place deforestation increases the risk of landslides (Pacheco et al., 2023). When vegetation is removed from a mountain slope, the protective layer is gone. As a result, rainwater runs off the slopes at a very high speed, resulting in landslides (Broadhead, 2011).

Land use and land cover (LULC) have a significant influence on landslides in Muhanga. For instance, Deforestation such as Clearing forests for agriculture, logging, or urbanization reduces the natural stability provided by tree roots. Deforested slopes are more susceptible to landslides as the soil becomes less bound together and more prone to erosion. Improper land management practices, such as overgrazing, improper irrigation, or excessive tilling, can lead to soil degradation and erosion. This weakens the soil structure and increases the likelihood of landslides. infrastructure development includes Construction activities associated with urbanization, road building, or infrastructure development can alter the natural drainage patterns and slope stability. Excavation, improper grading, and changes in surface water runoff can contribute to increased landslide risks. Furthermore, Inadequate land use zoning and planning can result in inappropriate development in landslide-prone areas. If settlements, infrastructure, or critical facilities are located in high-risk zones without proper mitigation measures, the potential for landslides and associated damages increases (UNDP, 2021).

According to figure 8, the protected areas in Muhanga District are those covered by forest which represent 13,85% and sparse forest represent 13. 30%. Largest place in Muhanga district are rural areas which practiced with agriculture activities. The largest part in Muhanga District engaged in agriculture. 58.10% are represented seasonal agriculture and 1.70% are perennial agriculture. The agriculture practiced in this area were causality more risk of prone landsides. In addition, 1.13% are represented of building, when this anthropogenic activity still increased without master plan the cause extremely disaster in future event. Largest part of Muhanga District practicing both season and permanent agriculture which contribute to risk of landslide in greatest region.

Figure 8: *Map of land use and cover change*

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INFLUENCE OF RIVERS ON LANDSLIDES

Muhanga district is a district which doesn't have a lake or large water bodies like ocean or the sea, as is the case of Rwanda. The district has a rich distribution of rivers of different categories led by Nyabarongo river. This Nyabarongo forms the hydrographic belt of district crosses six sectors and collects more than 90% of the runoff/small river alone (UWAMARIYA Beatrice, 2018). The river influence landslides two way, when the river debris flow eroded in the riverbed and when the river moving the debris and obstacle in middle of river which formed oxbow and river take new channel. According to relief of Muhanga district many moves from mountain toward down valley. In the top of river moved by debris material with eroded on side of rivers which threated by landslide. When the debris material landslide exposed before reaching the valley it formed meander and oxbow lakes. for analysis landslide new the river I could use the distance of 10 m are high vulnerability of landslide. Figure 9 show that Muhanga district had more river density network than other district in Rwanda. The mostly river are found in mountainous region and other it's the tributaries of Nyabarongo river. In rainy season those rivers eroded material from the top toward valley. The river eroded in the side of river the 10 m in both sides are more prone to landslide.

Figure 9: *Map of river density network analysis*

INFLUENCE OF ROADS ON LANDSLIDES

More people experience rockslides caused by human activity than by natural causes, such as when roads are excavated or transportation is undercut. Undercutting by humans scatters compacted soil particles into loose particles, decreasing the stability of the soil. Undercutting by humans has a significant effect on the region's stability and is thought to be a major contributing factor to slope failures in this district. Concentrated flows are triggered by slope undercutting caused by footpaths and house construction (Geertsema et al., 2009). For example, Rongi, Nyabinoni, Rugendabari, and Kibangu are the sectors most likely to experience landslides undercutting the slope. Figures 10 depict the density of the road network and the locations most vulnerable to landslides. The vicinity 10 meters from the roads is more vulnerable to landslides.

Figure 10: *Map of roads density network analysis*

IV.1.2. HUMAN FACTORS TRIGGERING LANDSLIDES IN MUHANGA DISTRICT

Influence of Mining Activities on Landslides

Mining activities can potentially contribute to landslides in the Muhanga District due to several factors; Excavation and destabilization of slopes, mining operations often involve the removal of large amounts of soil, rock, or minerals from the ground. This excavation can weaken the stability of slopes, making them more susceptible to landslides. For instance, Rongi, Nyabibinobi and Rugendabari sector are mostly vulnerable to risk of mining activities due to Excavation.

Mining activities can disrupt natural drainage patterns by altering the flow of water. Improper management of water runoff can lead to increased water infiltration into the soil, reducing its stability and increasing the likelihood of landslides. In this case Nyabarongo rivers and its tributaries are mostly prone to risk of landside due mining actives appeared in this region. In addition, mining operations may require the clearing of vegetation in the area. Vegetation plays a crucial role in stabilizing slopes by absorbing water, reinforcing the soil with its roots, and reducing erosion. The removal of vegetation can leave slopes more vulnerable to landslides. It occurring all sectors of Muhanga sector accepted urban region.

Influence of Deforestation on Landslides

Deforestation have a significant influence on landslides in Muhanga District. Deforestation contribute to the Soil erosion, trees and vegetation play a crucial role in holding soil together with their roots. When forests are cleared due to timber products, fire woods and charcoals. the protective cover of vegetation is lost, leading to increased soil erosion. Without the roots to anchor the soil, heavy rainfall can wash away the topsoil, making slopes more susceptible to landslides. The Reduced water absorption the Forests act as natural sponges, absorbing and retaining rainfall. When trees are removed, the water absorption capacity of the land decreases. This can result in increased surface runoff and the accumulation of water on slopes, further weakening the stability of the soil and increasing the likelihood of landslides. Increased surface flow the deforestation lead to the removal of natural barriers that slow down the flow of water across the land. This can result in higher surface flow velocities, which can erode the soil more rapidly and increase the potential for landslides (de Bruyn & Wets, 2006). Furthermore, Loss of slope stability, trees help stabilize slopes by their root systems, which bind the soil together. When forests are cleared, the loss of this natural reinforcement can lead to decreased slope stability, making the area more prone to landslides.

Influence of Agricultures on Landslides

The influence of agriculture on landslides in Rwanda can be significant due to various factors. Agriculture donate the deforestation, clearing forests for agricultural purposes, such as expanding farmland or obtaining timber, can remove the natural vegetation cover that helps stabilize slopes. The loss of trees and their root systems can increase the susceptibility of the soil to erosion and landslides. Unsustainable agricultural practices, such as improper land management, overgrazing, or inadequate soil conservation measures, can lead to soil erosion. When topsoil is eroded, it reduces the stability of slopes and increases the likelihood of landslides(Bikorimana & Mupenzi, 2023). In addition, poor construction of terracing i. e in some cases, terracing techniques used in agriculture can help reduce the risk of landslides by creating level platforms on slopes. However, if terraces are poorly constructed or maintained, they can contribute to erosion and landslides. Land use changes for instance converting steep slopes or areas prone to landslides into agricultural fields without proper engineering measures can increase the vulnerability to landslides. The alteration of natural landforms and soil characteristics can disrupt the balance and stability of the landscape.

IV.2. IMPACTS OF LANDSLIDES ON ENVIRONMENT AND SOCIOL ECONOMIC IMPACTS

In this research we were discussed about landslides impact on landscape of the earth surface, Landslide impacts on Quality of rivers, streams and ground water flow, Landslide Impacts on Drinking Water Quality and Environmental Health, Landslide Impacts on Forests and vegetation, Landslide Impacts on Forests and vegetation and Social and economic impacts of Landslide in Muhanga District.

V.2.1. IMPACTS OF LANDSLIDES ON ENVIRONMENT

Landslides Impacts on Deformation of Landscape of The Earth’s Surface in Muhanga

Slope gradient and slope curvature are the main topographic factors that create susceptibility to landslide. Steeper gradients are generally more prone to landslide although other geological climatic factors may also make gentler slope susceptible to failure (Nakileza & Nedala, 2020). For example, slope facing a particular direction may be subjected to more intense storms. Deeply-incised landforms and topographic depressions are also susceptible during rain storms. Slope with blower gradients that have been altered by road construction are also more susceptible to sliding. Landslides can have significant impacts on the landscape of the Earth's surface in Muhanga District. When a landslide occurs, it can result in the rapid movement of soil, rocks, and debris down slopes, leading to the reshaping of the land. The magnitude and extent of these impacts depend on various factors such as the size and velocity of the landslide, the type of material involved, and the topography of the area.

One of the primary impacts of landslides on the landscape is the alteration of landforms. Landslides can create new landforms such as scarps, terraces, and debris fans. These landforms are often characterized by steep slopes, irregular shapes, and accumulation of landslide material. The original contours of the land can be significantly modified, resulting in changes to the overall appearance and structure of the landscape.
Landslides can also lead to the destruction of vegetation and the removal of topsoil. The movement of soil and

debris during a landslide can strip away the fertile top layer of soil, which is essential for supporting plant growth. This can result in the loss of vegetation cover and the exposure of bare slopes, further contributing to erosion and instability in the affected areas (Highland & Bobrowsky, 2008).

Moreover, landslides can impact the drainage patterns and water flow in the landscape. They can block or divert water channels, leading to changes in the course of rivers and streams. This can result in the formation of new water bodies or the alteration of existing ones. The deposition of landslide material can also affect the natural flow of water, leading to the creation of new drainage paths and the disruption of existing ones.

Landslides Impacts on Quality of Rivers, Streams, And Ground Water Flow

Due to different agents some amounts of earth and organic materials should slide and enter streams as sediments, thus will contribute in reducing the portability of the water and quality of habitat for fish and wildlife. The main types of landslides that impact streams are debris flows, which may fill and/or erode the stream channel for great distances. Debris flows provide important sediment transport links between hill-slopes and alluvial channels (Highland, 2015) and thus are an important factor in drainage-basin sediment budgets. In addition, debris flows influence the spatial and temporal distributions of sediment in stream channels, either because they deposit sediment in the channels or because the deposits provide a source for accelerated transport of sediment farther downstream (Benda, 1990).

Landslides can have significant impacts on the quality of rivers, streams, and groundwater flow in Muhanga Districts. Landslides can result in the deposition of large amounts of sediment into rivers, streams, and groundwater sources. This sediment can reduce water quality by increasing turbidity, reducing oxygen levels, and affecting aquatic habitats. The introduce pollutants into water bodies of Nyabarongo River and it tributes. For example, agriculture activities occurring on hills slope such Kibangu, Nyabibononi, Rongi, Kiyumba and Mushishiro sector contribute to land landslides, it can carry pesticides, fertilizers, and other chemicals into rivers and streams, leading to water contamination. Landslides alter the natural flow patterns of rivers, streams, and groundwater. They can block or divert watercourses, leading to changes in water availability and distribution. This can impact ecosystems, agriculture, and water supply system. In this region landslides accelerate erosion processes, especially in areas with steep slopes. Increased erosion can lead to the loss of topsoil, nutrients, and organic matter, affecting the overall health and productivity of rivers, streams, and groundwater sources.

Figure 11: *Water pollution*

Landslides Impacts on Forests and Vegetation

Landslides can have significant impacts on forests and vegetation in Rwanda. When a landslide occurs, it can result in the destruction or damage of trees, plants, and other vegetation in its path. The force and movement of the landslide can uproot or break trees, strip away vegetation, and bury plants under debris and sediment.

The loss of forests and vegetation due to landslides can have several consequences. it disrupts the ecosystem and biodiversity of the affected area. Forests play a crucial role in providing habitat for various plant and animal species, and their destruction can lead to a loss of biodiversity and disrupt the delicate balance of the ecosystem. landslides can result in soil erosion. The removal of vegetation exposes the soil to erosion by wind and water, leading to further degradation of the land. This erosion can have long-term impacts on the fertility of the soil, making it more difficult for vegetation to regenerate and grow in the affected area. Furthermore, landslides can contribute to increased sedimentation in rivers and streams. The eroded soil and debris from landslides can be carried by water into nearby water bodies, leading to sediment buildup. This sedimentation can negatively impact aquatic ecosystems, affecting fish populations, water quality, and overall ecosystem health

IV.2.2. SOCIAL ECONOMIC IMPACTS OF LANDSLIDES IN MUHANGA DISTRICT

The social and Human impacts on landslide are focused on the following includes landslides causes death of people, injury, damage and destroyed the houses, loss of crops and it's destroyed the different infrastructures include roads and bridge, church, school, hospital and water supply which help human being for survival.

Figure 12: *Graph of social and economic impacts of landslide in Muhanga district*

Figure 13: *Nyabarongo Bridge network connected Muhanga and Gakenke District damaged by landslides*

Landslides can have significant negative impacts on both the social and economic aspects of Muhanga District. Socially, landslides can result in the loss of lives, displacement of communities, and destruction of infrastructure such as homes, schools, and hospitals. This can lead to a disruption of social networks, increased vulnerability, and psychological distress among affected individuals and communities. Economically, landslides can cause severe damage to agricultural lands, leading to crop loss and reduced food production. This can result in food scarcity, increased prices, and food insecurity. Additionally, landslides can damage transportation networks, making it difficult for people to access markets, healthcare facilities, and other essential services.

Landslides can cause injuries and deaths due to the following factors. the steep topography and hilly terrain of the Muhanga District, which makes it susceptible to slope failures and landslides. Heavy rainfall, especially during the rainy seasons, can saturate the soil, increasing its weight and reducing its stability. This, combined with the steep slopes, can trigger landslides. When landslides occur, they can bury or trap people under debris, leading to injuries or fatalities. The force and speed of moving soil and rocks can cause significant physical harm. Moreover, 76 people died, 56 people injured due to landslides from 2016 to 2022.

Building in steepest slope and agriculture practiced on steep slope of Muhanga District contribute to land degradation. Unprotected areas and informal building that found on mountains and hills as high-risk zone are treated by landslide due to high surface runoff risk to erosion. According to Figure13, 1048 houses and bridges are damaged.

The steep terrain and heavy rainfall in this region susceptible to slope failures and landslides, which can directly impact infrastructure. The infrastructure damage is by destabilizing slopes and hillsides, leading to the collapse or displacement of roads, bridges, and other transportation networks, see figure 12. The force and movement of soil and rocks during a landslide can undermine the stability of these structures, resulting in their destruction or rendering them impassable. Furthermore, landslides can block or divert watercourses, leading to the flooding of nearby areas. This can damage water-related infrastructure, impacting agricultural activities and water supply. As figure show that 53 classrooms are destroyed and 52 roads and bridge are damaged.

More than 80% Rwandan depends on agriculture and livestock farming. Landslides can destroy agricultural fields, leading to the loss of crops. The force of the landslide can bury or wash away plants, making them unsalvageable. This can result in reduced food production, scarcity of crops, and increased prices, affecting both farmers and consumers. The Soil Erosion remove of topsoil, which is crucial for crop growth. The movement of soil and rocks can strip away fertile layers, leaving behind infertile or rocky terrain. This erosion can make it challenging to cultivate crops and negatively impact their productivity. Disruption of Livestock Farming, Displaced soil and rocks can block access to grazing lands, limiting the availability of food for livestock. Additionally, landslides can cause injuries or fatalities to animals, further impacting the livelihoods of farmers. MINEMA and MIDIMAR reported from 2016 to 2018, and 491.6 ha crops and 46 livestock are lost due landslides in Muhanga District.

V. CONCLUSION AND RECOMMENDATION

Worldwide, every year, landslides damage houses and cause millions of dollars' damage to buildings, roads, pipelines, agricultural land and crops with some causing injuries and loss of life. According to MINEMA reported from 2016 to 2022, the flooding and landslide are mostly disaster that affected more population in Muhanga District more 76 people died, 56 and 1048 households were damaged triggered by landslides. 25.72%, 13.50% and 4.5% of surface area are located in medium risk landslides, high risk landslides and very high risk of landslide. This means that natural factors and Human factors are the main threated of risk of landslides. When compared time ago landslide is extremely increasing due to anthropogenic activities growth led to climate change. When they meet with natural factor like steepest slope and natural relief their causes extremely prone to landslide. In Muhanga District, Landslide are key disasters that frequently affect localized areas of the country. Most of the affected people do not have efficient mechanisms to cope with natural hazards. In addition, the hilly topography and high annual precipitation rates with over exploitation of the natural environment such as deforestation, illegal mining, inappropriate farming and poor housing techniques accelerate the disaster risks and hence results into losses of lives and damage the properties.

Moreover 58. 10% are seasonal agriculture and 1.70 % are perennial agriculture, when those factors continue without mitigation measure the landslide were continuing to damage infrastructures and people loss their life. Local governments can accomplish this through land use policies and regulations. Individuals can reduce their exposure to hazards by educating themselves on the past hazard history of a desired site and by making inquiries to planning and engineering departments of local governments. They could also hire the professional services of a geotechnical engineer, a civil engineer, or an engineering geologist who can properly evaluate the hazard potential of a site, built or unbuilt. In some cases, monitoring and warning systems allow residents to evacuate temporarily during times when the probability of landslide activity is high. Planting or encouraging natural growth of vegetation can also be an effective means of slope stabilization. I recommend the government of Rwanda to increasing terracing technical with steepest slope. To mobilizing people to use the home tank in residential areas in order to reduces high surfaces runoff. To make policies of all mining site to build water filtration plant that used to filter water before send tributes this policy will reduces the water pollution. To implement the polices that defines boundaries of rivers and wetlands such as buffer zone. The more people in Muhanga District are still living in high risk zone. For this, governmental of Rwanda and local government should enforces to relocate people from high risk zone to planned settlement in order to prevent the risk of landslides in sustainable way.

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