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Suitability Analysis of Slope Protection Measures in Road Construction against Landslide Occurrence in Western Province, Rwanda

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Abstract: Human infrastructure development like road, markets and buildings are among drivers to natural landscape modification. The North-western Rwanda is the largely affected by landslide occurrence either due to human activities and/or natural causes. This study analyzed the suitability of slope protection measures against landside occurrence during road construction in Rutsiro District, Western Rwanda. Shapefiles and other secondary data on road network (types, location and slope protection are collected from the Rwanda Transport Development Agency (RTDA) and National Institute of Statistics of Rwanda (NISR). Geographic Positioning System (GPS) localized the slope protection measures. It is observed that the major slope protection measures in place are Gabions, Retaining walls and Bench terraces. Elevation, slope, soil texture, lithology, land use and land cover, rainfall are employed as major landslide conditioning factors. The extraction by masking technique in Spatial Analyst Tools of Geographic Information System (GIS) produced maps of landslide conditioning factors and its hazard. Murunda, Nyabirasi, Manihira, Musebeya and Mukura sectors record high landslide hazard. For the effectiveness of slope protection measures applied against landslide, bench terraces and Gabions and Retaining walls at some extent, reveal stable condition compared to their counterparts applied. However, within roads under very high landslide hazard zones, there are no slope protection measures identified. This recommends building similar measures mainly those which are cost effective to

minimize the damages. Further national similar study is greatly recommended and the current findings can facilitate policy makers to understand the types of slope protection measures used in road construction and their effectiveness in landslide hazard mitigation.

Keywords: Landslide Hazard, Road Construction, Slope Protection Measures, Rutsiro District, Western Rwanda

1. Introduction

The occurrence of generates immense damage and losses amongst the vulnerable communities mainly due to reason that the risk reduction polices are top-bottom while its involvement can help to empower their mitigation and adaptation capabilities (Anderson and Holcombe, 2013). The highly elevated areas are the mostly affected by the occurrence of landslide and its occurrence ranks it among the major hazardous phenomenon which sometimes causes loss of human lives and properties (Kühnl et al., 2022; Ogila, 2021).

Slope protection measures are applied in most of case to minimize the likelihood of landslide occurrence in areas under road construction and/or on mountainous with the aim of decreasing the runoff risk (Petley, 2012). However, some slope protection measures are not appropriately allocated and under influence of human activities, climate change and nature of the soil, it is becoming more evident that slope protection measures are not suitable to one or another area (Kerle and De Vries, 2001).

The impact of landslide on people's livelihood, environment and development is considered by the Rwandan government. For this case, the national disaster risk management plan (NDRMP) was developed in Rwanda to reduce disaster risk and lessen the vulnerability among the citizens. This is associated with the national contingency for flood and landslides in order to empower disaster copying, recovery and response capabilities among the vulnerable (Iribagiza et al., 2015; MIDIMAR, 2015). Despite current measures in place, the North-western part of Rwanda is the most impacted by the occurrence of landslides being due to its soil types which easily allows runoff, its high rainfall intensity and frequency along with unprotected land under traditional farming techniques (Nwazelibe et al., 2023).

Similarly, in Rwanda, large areas under threat of landslide are those that are modified either due to building houses, road construction, and poor farming (Nahayo et al., 2019; Nsengiyumva et al., 2019). With aim of minimizing landslide risks, it is recommended that local government

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must arrange list of requirements for land using and safety building codes in land with landslide hazard to minimize negative impact when land sliding occurs (Marin and Mattos, 2020). The location of Rutsiro District (in the Western Rwanda) is located is reported among areas impacted by landslide and several studies on landslide hazard mapping, vulnerability assessment have been conducted with focus on this area (Nwazelibe et al., 2023).

Nevertheless, there no studies on the suitability of slope protection measures applied against landslide occurrence. Such studies would advise policy makers to recognize each area's landslide hazard exposure mainly roads and then chose relevant slope protection measure to allocate, respectively. Therefore, this study aims to assess the suitability of slope protection measures being utilized during road construction with reference to landslide occurrence in Rutsiro District of the Western Rwanda. The uniqueness and contribution of this study is that it considers a small unity of research and that its findings can be easily applied at other similar areas.

2. Methods and Materials

2.1 Description of study area

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This study considered Rutsiro District one of seven Districts (Rusizi, Nyamasheke, Karongi, Rutsiro, Nyabihu, Ngororero and Rubavu) in Western Province of Rwanda. The District of Rutsiro shares border with rivers Bihongora and Nyanzo from North to South side. The western-eastern part is shared by the border between the Republic of Rwanda and the Democratic Republic of Congo (DRC) toward river Nyamwenda flowing into Lake Kivu. The South-northern part of Rutsiro District is the border of Rwanda and DRC. The District elevation ranges between 1,400 and 2,600 meters (Macháček, 2020).

The District is made up of 13 administrative Sectors (Boneza, Gihango, Kigeyo, Kivumu, Manihira,Mukura, Murunda, Musasa, Mushonyi, Mushubati, Nyabirasi, Ruhango, Rusebeya), 62 Cells and 483 villages covering a surface area of 1157.3 km². Rutsiro district has a population density accounting for 281 inhab/sq.km ranks the District fifth from bottom countrywide. The District is prevalently rural with an urban population of 2.2%. The population is unevenly distributed over the District area the most densely populated area is Kivumu Sector while the least densely populated sector is Mukura (Macháček, 2020).

The land in Rutsiro is mainly used for agriculture under mountainous landscape characterized by steeper slopes with an acidic soil. Rutsiro soil is basaltic, generally permeable and rich in iron but very susceptible to erosion and therefore less fertile. Its tropical climate records an average temperature of 20° - 24° C with gradually increasing rainfall (Macháček, 2020).

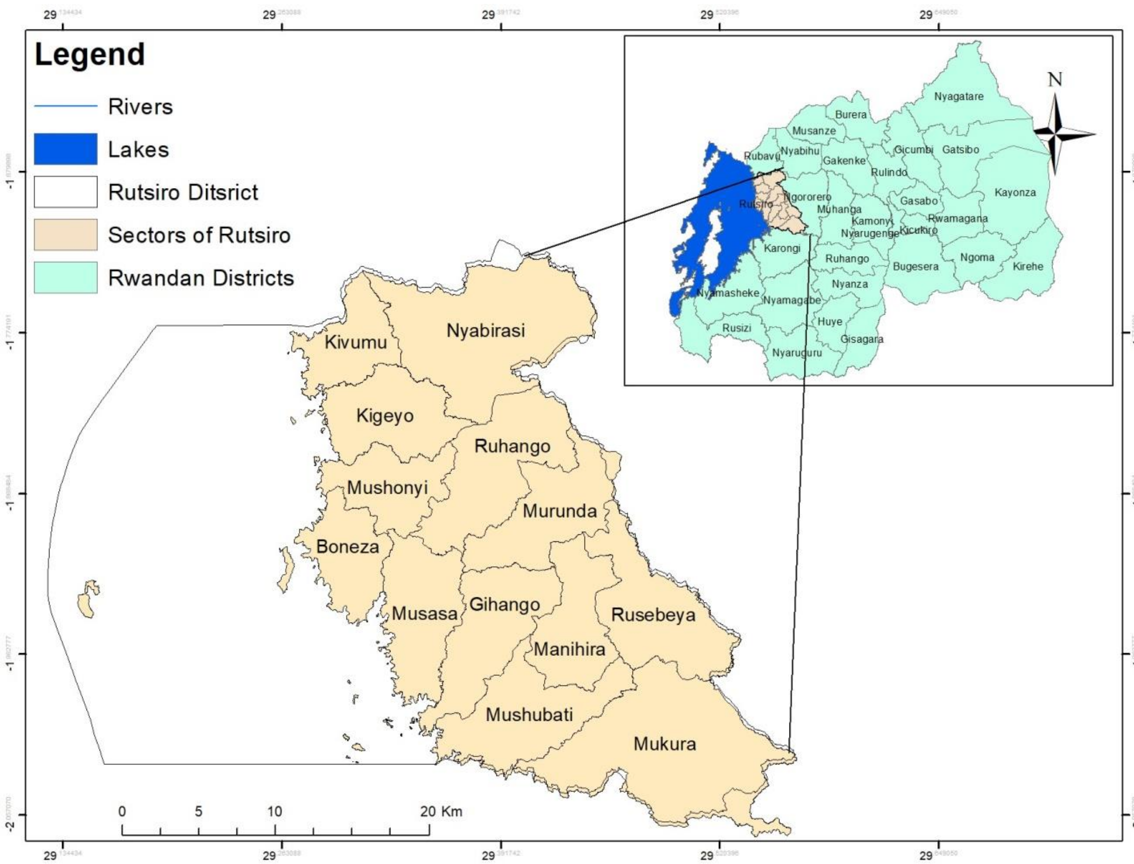

Figure 1: Map showing the location of Rutsiro district and its Sectors
Source: Authors' compilation, 2024

2.2. Data Collection and Analysis

2.2.1 Slope protection measures in road construction

This study utilized the 2023 road network of Rwanda collected from the road shapefile available at the Rwanda Transport Development Agency (RTDA) and National Institute of Statistics of Rwanda (NISR). The authors utilized RTDA slope protection measures put in place against landslide occurrence. GPS helped to localize each slope protection toward deciding on each slope protection measure suitability (stable versus failed).

2.2.2 Landslide causal factors

The authors spatially distributed landslide conditioning factors such as land use and land cover (LULC), rainfall, slope, elevation, soil texture and lithology. These factors are collected from the United States Geological Survey (Clark et al., 2003). The elevation measured in meters and slope calculated in angles are derived from Digital Elevation Model (DEM) of 30 m resolution and acquired from the United States Geological Survey Earth Explorer (Clark et al., 2003). For the rainfall, the 4 Km resolution average annual rainfall interpolated by using the 2021-year rainfall data, is used from the Tropical Applications of Meteorology using Satellite (TAMSAT) data and ground-based observations (Maidment et al., 2015).

The 2020 land use and land cover map is produced from multispectral Landsat-8 Operational Land Imager (OLI) images from the United States Geological Survey Earth Explorer (Clark et al., 2003). The produced LULC map classified into five LULC classes with reference to the East African Classification of Regional Center for Mapping and Resources Development (Tramberend et al., 2021). Finally, both soil texture and lithology were derived from Rwandan Geological, Mining and Soil Databases (Rushemuka et al., 2014). The above landslide causal factors are selected with reference to literature review, researcher' knowledge of the study area.

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2.2.3 Data analysis

Slope protection measures

To analyse current slope protection measure in place, the authors used Clipping option in Data Management Option or Extract by Mask technic of the Spatial Analysts Tools of GIS. The tool enabled to localize each slope protection measure per constructed road in Rutsiro District.

Landslide hazard mapping

The Math Algebra also found in the Spatial Analyst Tools of GIS merges conditioning factors and distributes landslide hazard within the study area. To estimate the spatial distribution of landslide hazard in the District of Rutsiro, the authors applied the following equation.

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

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

Slope protection measures suitability analysis

The last phase of data analysis was to overlay slope protection and constructed road within the landslide hazard map over Rutsiro District. This process helped to determine whether each area's exposure to landslide is within the appropriate slope protection measure (s). This exercise was also completed by using GIS and by the end, facilitated to indicate slope protection measures which are found irrelevant with reference to area's experience on landslide and those that stand as appropriate are indicated as well.

3. Results

3.1 Slope protection measures applied during road construction

As illustrated in Fig.2, the considered roads in Rutsiro District are National and District Roads. These roads are under bench terraces, Gabions, retaining walls, and stone pitching with gabions slope protection measure. These measures applied by RTDA are localized within Mushubati and Gihango sectors

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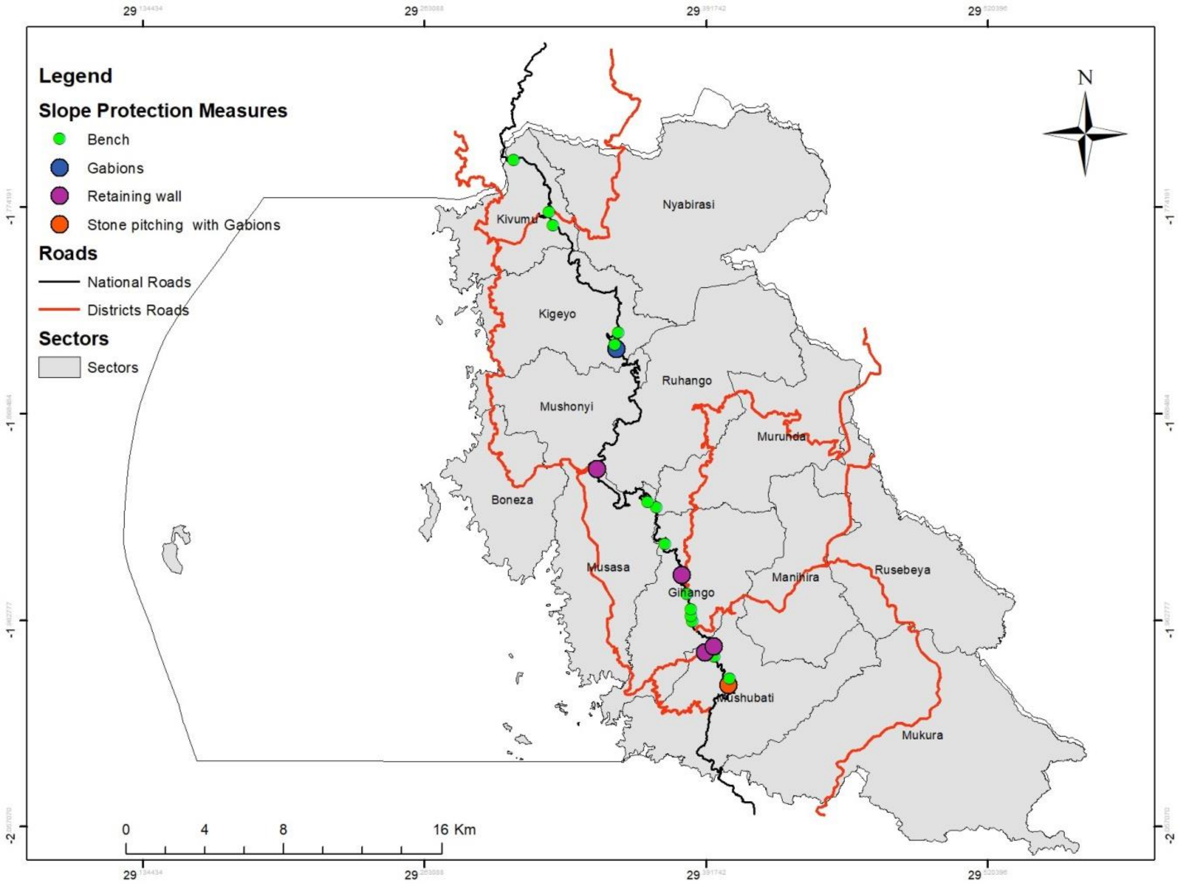

Figure 2: Road types and Slope protection measures applied in Rutsiro District
Source: Authors' compilation, 2024

3.2 Landslide causal factors and its hazard distribution

3.2.1 Landslide occurrence causes

The results in Figure 3 on elevation across Rutsiro District show that all thirteen (13) sectors of Rutsiro District are localized within a high topography since their elevation is above 1,500 m. The same Figure 3 shows that some sectors like Mushabati, Nyabirasi, Musebeya and others record high slope degrees compared to their counterparts. The above elevation and slope record express that in case roads are not well constructed with strong slope protection policies under such elevation, runoff can be easily recorded in the District.

For LULC, Figure 3 shows that Kivumu sector is the largely inhabited that others in Rutsiro District while large part of forest is occupied by Mukura and Nyabirasa sectors. This expresses that these areas are covered and that in case of poor slope protection, runoff cannot easily take off land during rainfall due to vegetation cover. For the soil texture in the study area, the Clay loam is the dominant soil texture class in Rutsiro district followed by Clay.

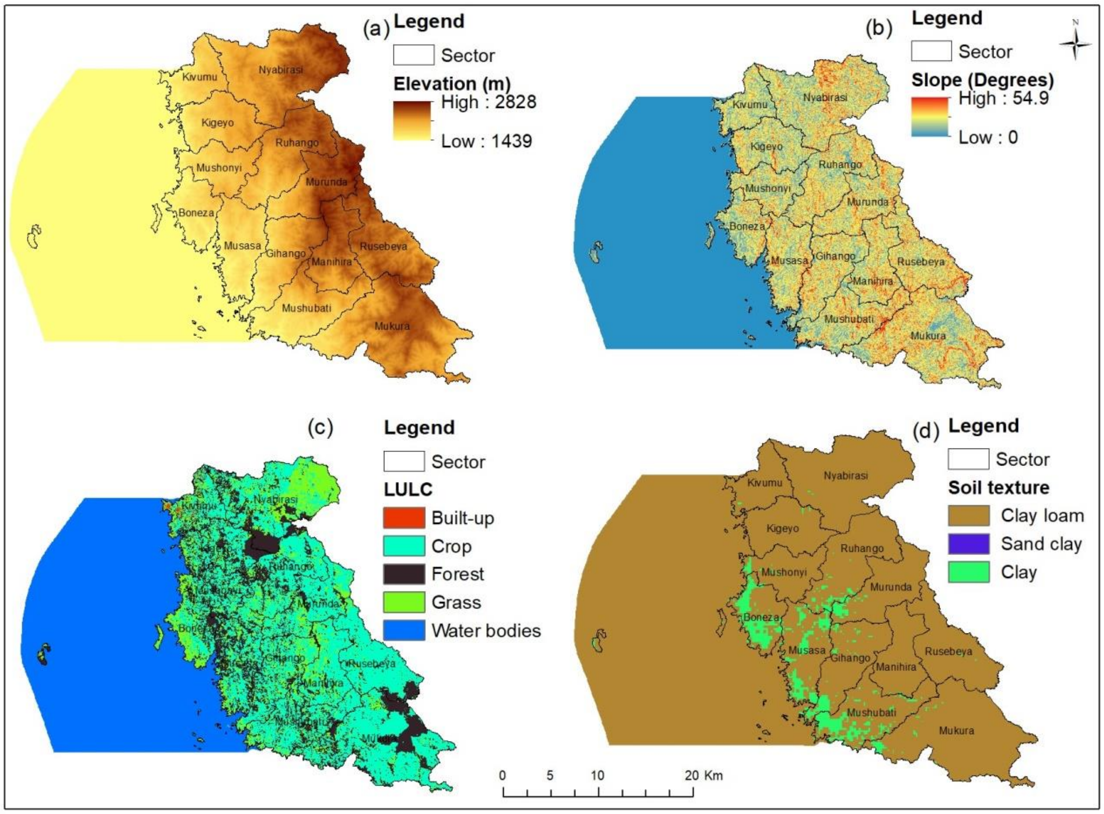

Figure 3: Spatial distribution of elevation, slope, LULC and soil texture in Rutsiro District
Source: Authors' compilation, 2024

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For the rainfall, Figure 4 displays the mean annual rainfall distribution in Rutsiro District which shows that low annual mean rainfall (68 mm) is registered in the sectors of Mushubati, Mukura, Gihango and part of Musasa as well. The highest annual mean rainfall (90 mm) is mainly recorded within Nyabirasi, Kigeyo, Mushonyi, Tuhango and Runda sectors, respecetively.

Finally, the lithology type of Rutsiro District is illustrate din Figure 4 and Schist lithology class is the most dominant in the study area along with water. The Granite, Volcanic ash and Quartzite do not occupy large area of Rutsiro District.

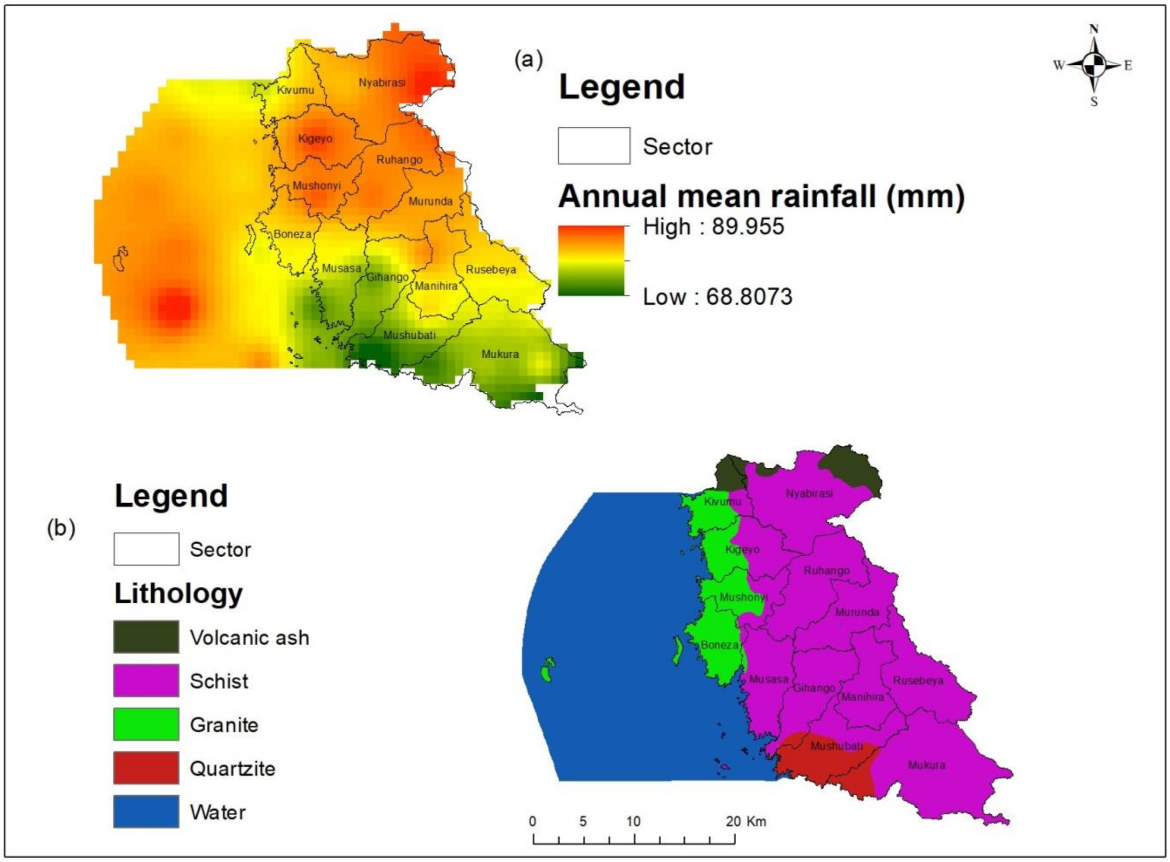

Figure 4: Annual mean rainfall and lithology distribution
Source: Authors' compilation, 2024

3.3 Landslide hazard distribution

The results in Figure 5 indicate that some areas of Murunda, Nyabirasi, Manihira, Musebeya and Mukura sectors record high landslide hazard. The Lowest part of landslide hazard is observed within the part under water bodies while very low areas are registered by some zones of Baneza, Mushonyi, Musasa, Mushubati, Kigeyo and Kivumu sectors.

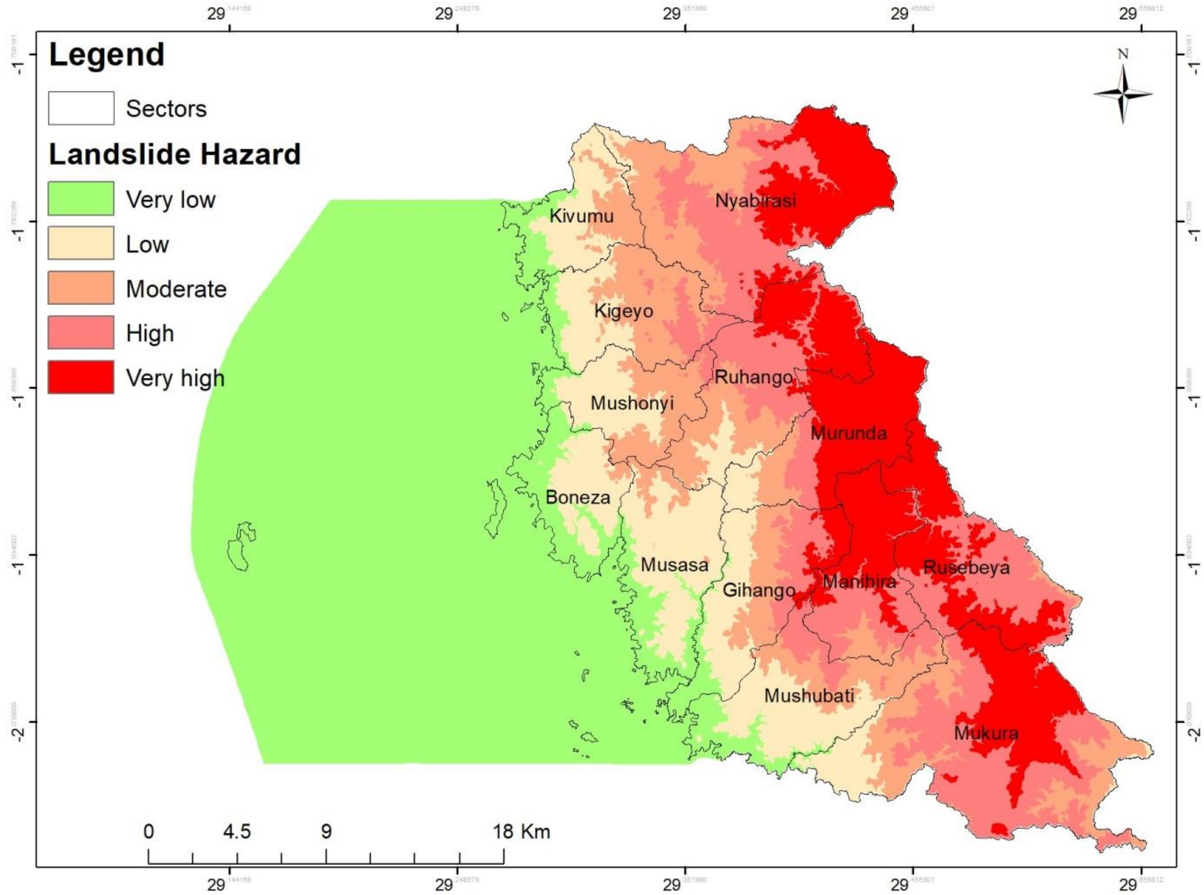

Figure 5: Landslide hazard distribution within Rutsiro District
Source: Authors' compilation, 2024

3.4 Suitability of slope protection measures against landslide under road construction

From the analysis on current slope protection measures applied in Rutsiro District, it is notice that bench terraces occupy most of them (see Fig.6). These slope protection measures are localized within very low, low and moderate landslide hazard classes over the study area. This can be expresses as that in case of landslide occurrence; the current slope protection measures in place would serve well in terms of protection from further damages. This results from the reason that their location (very low, low and moderate sides) can't be affected. However, it is good to mention that since both high and very high landslide hazard zones are not protected by the existing slope protection measures being used by the RTDA, immense losses would be recorded in case of landslide hazard within both hazard areas and this calls for policy maker to add relevant slope protection measures.

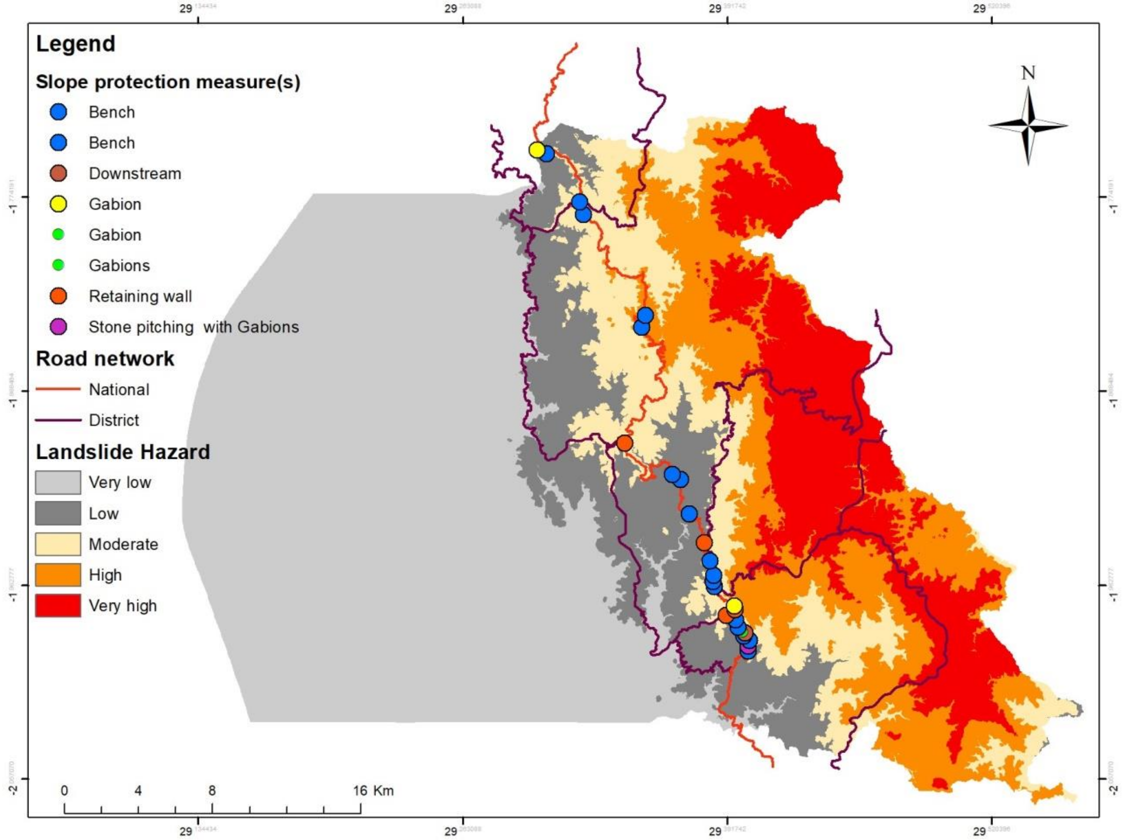

Figure 6: Comparison of slope protection measures and landslide hazard zonation in Rutsiro District
Source: Authors' compilation, 2024

5 Discussion of results

In Rwanda, it is reported (Nema et al., 2023) that both north and western parts are largely susceptible to landslide mainly due to its high topography, frequent rainfall and poor land management practices. For example, in May 2023, huge losses of landslide and flooding were reported and human deaths, injuries, livestock loss, cropland damage and infrastructures (roads, classrooms, hospitals, etc.) were among the reported damages (Nema et al., 2023).

Specifically, for roads in the north-western Rwanda, during landslide occurrence, these parts are in most of cases affected due to how their surrounding slopes are protected during road construction even some protection measures are placed in the right position which would facilitate in ensuring slope stabilization (Nema et al., 2023; Nwazelibe et al., 2023).

However, under human development activities including road construction, roads are exposed to slope failure and some of the protection measures are either localized in wrong places and /or not well established which leads to continuous losses. For example, as shown in Figure 7, some slope protection measures mainly gabions applied by RTDA on both national and district roads in Rutsiro District already failed.

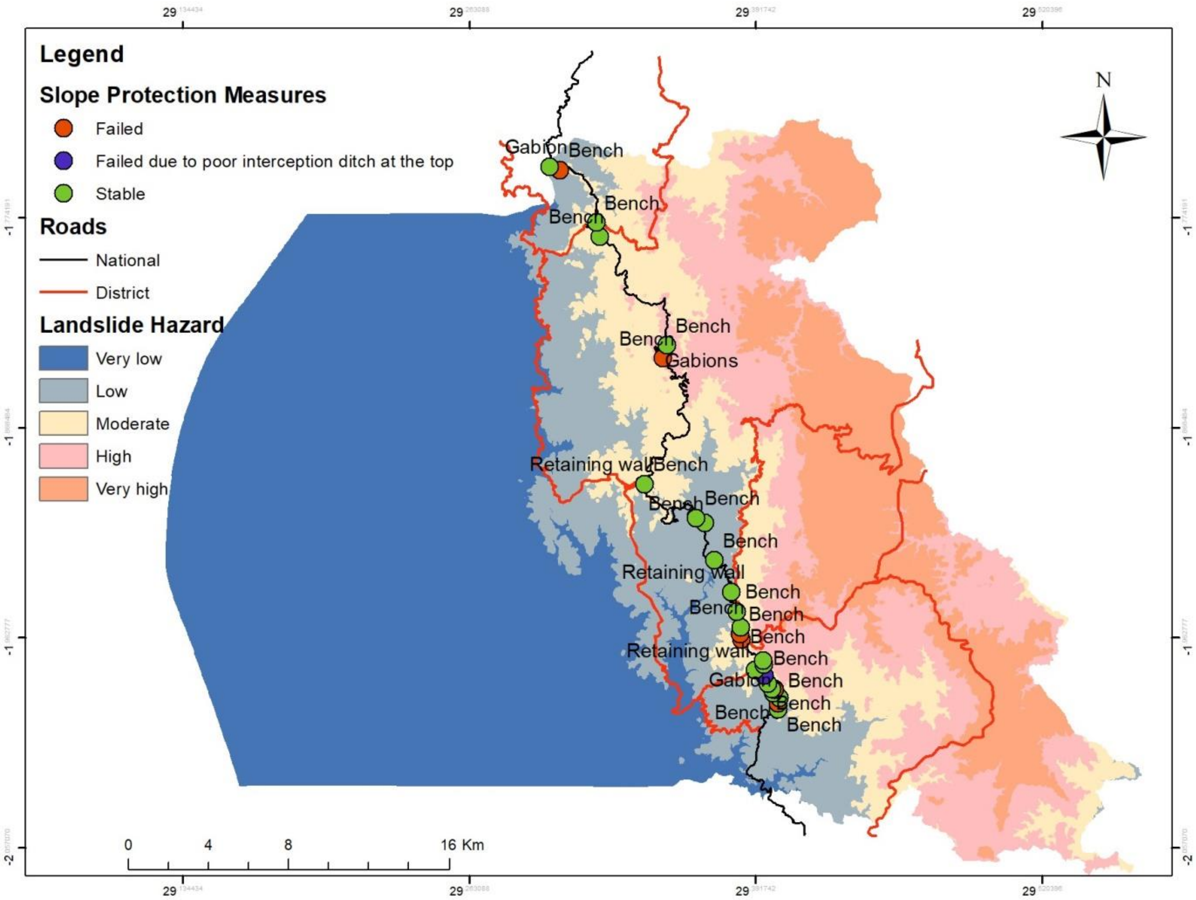

Figure 7: Status of slope protection measures under landslide
Source: Authors' compilation, 2024

Table 1: Slope protection measures suitability analysis

No	**Landslide hazard class**	**Slope protection measure (s) applied**	**Suitability**
1	Very high hazard	None	N/A
2	High hazard	Bench	Stable
3	Moderate hazard	Bench	Stable
		Gabion	Failed
		Retaining wall	Stable
		Stone pitching with gabions	Failed
4	Low hazard	Bench	Stable
		Gabion	Failed
		Retaining wall	Stable
		Stone pitching with gabions	Failed
5	Very low hazard	None	N/A

N/A: Non-applicable
Source: Authors' compilation, 2024

Nevertheless, bench terraces which are not expensive as gabions reveal successful trend across their location (see Figure 7) which expresses that in case bench terraces are utilized in this area, the cost would be low with impact assurance. In Rutsiro District, as shown in Figure 7, slope protection measures are widely spread over the national roads. However, since the community in most cases, use district roads in their neighbourhoods under which high and very high landslide hazard is classified, it is good to consider this case.

This is previously reported (Ayetor et al., 2021; Ntakiyimana et al., 2021; Ogila, 2021) that in many cases, government put more efforts on national roads which connect to different place and leave in-country roads similar Rutsiro District (see Figure7) where national roads are protected than district roads. Furthermore, regardless of existing slope protection measures in place, some of them already reveal failing trend despite their location in very low, low, moderate hazard zones. This can result from the fact that before localizing these slope protection measures, there was no study on the measures and their location relevance.

The above can lead to suggesting that slope protection measures mainly bench terraces which are not expensive and nature-based practices should be introduced within areas under high and very landslide hazard classes. Also, trying the existing but failing slope protection measures in another location would help in understanding the likely reason behind and/or right location.

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5. Conclusion

This study assessed the suitability of slope protection measures being applied during road construction against landslide occurrence in the District of Rutsiro of the Western Rwanda. The study utilizes secondary data on road network from the Shapefiles and slope protection measures applied by the Rwanda Development Authority. The secondary data on causes of landslide occurrence in Rutsiro District are collected from several sources. Microsoft Excel, Geographic Information System and Geographic Positioning System (GPS) are used for field data collection and analysis. The results reveals that both national and district roads are considered for construction. The slope protection measures applied on both roads include the bench terraces, Gabions, Stone pitching with gabions, and retaining wall. The selected major causes of landslide are elevation, slope, soil texture, lithology; land use and land cover along with rainfall. Mapping of landslide hazard depicts Murunda, Nyabirasi, Manihira, Musebeya and Mukura sectors under high landslide hazard. Slope protection measures under usage are mainly located within low and moderate landslide hazard. However, bench terraces and Gabions and Retaining walls at some extent, which reveal stable condition compared to their counterparts applied. It is recommended to effective measures across high landslide zones. Extending slope protection measures within local roads could reach roads that likely are high and very high landslide hazard zones. This study can be a reference to further studies on road construction, their location and slope protection measures which can be even applied at national level.

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References

Anderson, M. G., and Holcombe, E. (2013). "Community-based landslide risk reduction: managing disasters in small steps," World Bank Publications.

Ayetor, G., Mbonigaba, I., Ampofo, J., and Sunnu, A. (2021). Investigating the state of road vehicle emissions in Africa: A case study of Ghana and Rwanda. *Transportation Research Interdisciplinary Perspectives* **11**, 100409.

Clark, R. N., Swayze, G. A., Wise, R., Livo, K. E., Hoefen, T. M., Kokaly, R. F., and Sutley, S. J. (2003). USGS digital spectral library splib06a. *US Geological Survey, Open File Report* **3395**.

Iribagiza, J., Ndabaga, E., Iravo, M., and Oduor, J. (2015). Stakeholders' participation in planning and designing of locally based UNDP projects: a case of Ministry of Disasters and Refugees Affairs (MIDIMAR). *European Journal of Business and Social Sciences* **4**, 141-153.

Kerle, N., and De Vries, B. V. W. (2001). The 1998 debris avalanche at Casita volcano, Nicaragua—investigation of structural deformation as the cause of slope instability using remote sensing. *Journal of Volcanology and Geothermal Research* **105**, 49-63.

Kühnl, M., Sapena, M., Wurm, M., Geiß, C., and Taubenböck, H. (2022). Multitemporal Landslide Exposure And Vulnerability Assessment In Medellín, Colombia.

Macháček, J. (2020). Alluvial Artisanal and Small-Scale Mining in a River Stream—Rutsiro Case Study (Rwanda). *Forests* **11**, 762.

Maidment, R. I., Allan, R. P., and Black, E. (2015). Recent observed and simulated changes in precipitation over Africa. *Geophysical Research Letters* **42**, 8155-8164.

Marin, R. J., and Mattos, Á. J. (2020). Physically-based landslide susceptibility analysis using Monte Carlo simulation in a tropical mountain basin. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards* **14**, 192-205.

MIDIMAR (2015). The National Risk Atlas of Rwanda. Nairobi Ministry of Disaster Management and Refugee Affairs.

Nahayo, L., Mupenzi, C., Habiyaremye, G., Kalisa, E., Udahogora, M., Nzabarinda, V., and Li, L. (2019). Landslides hazard mapping in Rwanda using bivariate statistical index method. *Environmental Engineering Science* **36**, 892-902.

Nema, M.-L., Saley Mahaman, B., Diedhiou, A., and Mugabe, A. (2023). Local perception and adaptation strategies to landslide occurrence in the Kivu catchment of Rwanda. *Natural Hazards and Earth System Sciences Discussions* **2023**, 1-14.

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Nsengiyumva, J. B., Luo, G., Hakorimana, E., Mind'je, R., Gasirabo, A., and Mukanyandwi, V. (2019). Comparative analysis of deterministic and semiquantitative approaches for shallow landslide risk modeling in Rwanda. *Risk analysis* **39**, 2576-2595.

Ntakiyimana, C., Zhang, Y., and Twagirayezu, G. (2021). Road Flooding in Kigali City, Rwanda: Causes, Effects on Road Transportation and Mitigation Measures. *Polish Journal of Environmental Studies* **31**, 3735-3744.

Nwazelibe, V. E., Egbueri, J. C., Unigwe, C. O., Agbasi, J. C., Ayejoto, D. A., and Abba, S. I. (2023). GIS-based landslide susceptibility mapping of Western Rwanda: an integrated artificial neural network, frequency ratio, and Shannon entropy approach. *Environmental Earth Sciences* **82**, 439.

Ogila, W. A. M. (2021). Analysis and assessment of slope instability along international mountainous road in North Africa. *Natural Hazards* **106**, 2479-2517.

Petley, D. (2012). Global patterns of loss of life from landslides. *Geology* **40**, 927-930.

Rushemuka, P. N., Bock, L., and Mowo, J. G. (2014). Soil science and agricultural development in Rwanda: state of the art. A review. *BASE*.

Tramberend, S., Burtscher, R., Burek, P., Kahil, T., Fischer, G., Mochizuki, J., Greve, P., Kimwaga, R., Nyenje, P., and Ondiek, R. (2021). Co-development of East African regional water scenarios for 2050. *One Earth* **4**, 434-447.

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