Landslides Occurrence and Related Causal Factors in the Gishwati and Mukura Landscape of Rwanda

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Abstract

The Gishwati and Mukura Landscape of Rwanda was affected by and is still susceptible to landslides events. This research aimed to establish the relationship between landslides occurrence and some major related causal factors including precipitation, slope gradient, lithology, soil type and depth, and land use/ cover type. In total, 45 landslide locations with visible features were identified through field observation and survey. With the aim of contributing to the landslide hazard evaluation, a detailed analysis of the rainfall events from 1981 to 2017 was carried out on monthly basis. Other secondary data were also collected. The data recorded were analyzed and compared with the occurrence of landslides. The results revealed that heavy rainfall clustered during two rainy seasons were the principal triggering factor of landslides in the landscape. It has been revealed that 56.5% of the observed landslides falls into the slope category of 8.7 –27.5% followed by the category of 27.5 –39.0% with 41.3% of the total case identified. The areas occupied by the crop land was found to be the most affected with 50.0% of the total identified sites, followed by forest (34.8%) and built-up areas (15.2%). The soils with high percentage of clay content (>35%), originated from granite and quartzite, dominate the identified zones that were affected by landslides. Based on these findings, the outcomes of this study will help to build short and long-term flexibility into landslide risk management planning processes and decisions at the Gishwati and Mukura landscape level.

Key words: *landslide occurrence, landslide related causal factors, landscape*

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Introduction

Natural hazards are increasing day by day due to high degradation of natural land covers, especially forests, for searching alternative livelihoods (Mukashema, 2007), which also reflect the rapid human population growth in Rwanda. According to Forbes & Broadhead (2011), landslide was classified as the third most dangerous disaster, since they cause various detrimental effects not only on human beings but also on their surrounding environment, especially in hilly topographic zones (Wangari, 2011). Therefore, strong and adequate strategies should be adopted and developed for preventing landslides and mass movements, which will contribute to minimize the associated destructive impacts.

In fact, landslide disasters have serious and diverse destructive impacts. Globally, the figures were much more serious in the last decade, with 32,322 fatalities recorded; monitoring, mapping and forecasting of these landslide hazards are less than adequate as required within different countries worldwide (Highland, 2008). Different types of landslides such as the rockslides, debris flows, rock falls, avalanches and others generated huge number of loss of lives and other related consequences, and they continue to intensify, particularly in hill and mountainous regions (Capitani *et al.*, 2013). Apart from natural factors influencing landslides, the anthropogenic factors have been also identified to increase landslides with highly recurrent rainfalls (Wangari, 2011).

Like many other countries in Africa, landslides in Rwanda, are among the very deadly natural disasters that are taking lives and inducing numerous negative impacts in the community (Nsengiyumva *et al.*, 2018). 15,000,000 tons of more fertile soils are lost on average every year in Rwanda to foreign countries through flowing water from the Nile and Congo River catchments (De Taeye, 2016). Different types of soils are negatively affected by high annual intense rainfalls, by providing high saturation of soil profiles, resulting in frequent occurrences of mass movements (Paper, 2012). In addition, high population pressure to land also results in the Environmental disasters and encroachment on the fragile ecosystems. Hence, the topographic nature of the Gishwati and Mukura Landscape is characterized by mountainous and hilly relief, and steep slopes areas, which make it more susceptible to landslides hazards (Nsengiyumva *et al.*, 2018).

Obviously, it was observed that landslides induce various damages in different parts of the Landscape (Nahayo *et al.*, 2018). The integration of different causal factors that really influence them are still not well recognized, understood, and their susceptibility and critical high prone zones are still unidentified. This explains the reason why some hilly areas are not much affected as others. This gap leaves more critical research questions to be answered by scientific approaches. However, there exists significant data gaps related to landslide hazards in Rwanda till date (MIDIMAR, 2015). Former MIDIMAR started a systematic recording of disasters data since 2010. Prior to this period, the only sources of disaster data were international centers of data collection such as CRED (EM-DAT) and the Royal Museum for Central Africa (RMCA). Consequently, the recorded events are not well geo-referenced and the inventory is challenging. In this perspective, different landslide related topics should be conducted to deliver valuable and useful information for landslides hazards mitigation through appropriate planning.

This study aimed to establish the relationship between landslides occurrence and some major related causal factors including precipitation, slope gradient, lithology, soil type and depth, and land use/ cover type.

Materials and methods

Description of the study area

The study area is composed of a landscape associated to Gishwati and Mukura forests reserves, situated in the Northwestern part of Rwanda. The Landscape was defined according to the Rwandan administrative units, namely districts and then sectors (Figure 1). This was done to ease the delineation of the Landscape. It touches four districts, Rutsiro and Rubavu in their West towards Lake Kivu and Ngororero and Nyabihu in their East. Gishwati touches all the four districts, while Mukura is located within Rutsiro and Ngororero. The Landscape is characterized by hilly relief which gives a wonderful lateral and top view. Its geographic coordinates is 1°49’ S and 29°22’E, with an average altitude of 2000 – 3000 m and annual rainfall of 1200 – 1500 mm (RDB, 2017). The total population of the landscape is 396,872.00 inhabitants.

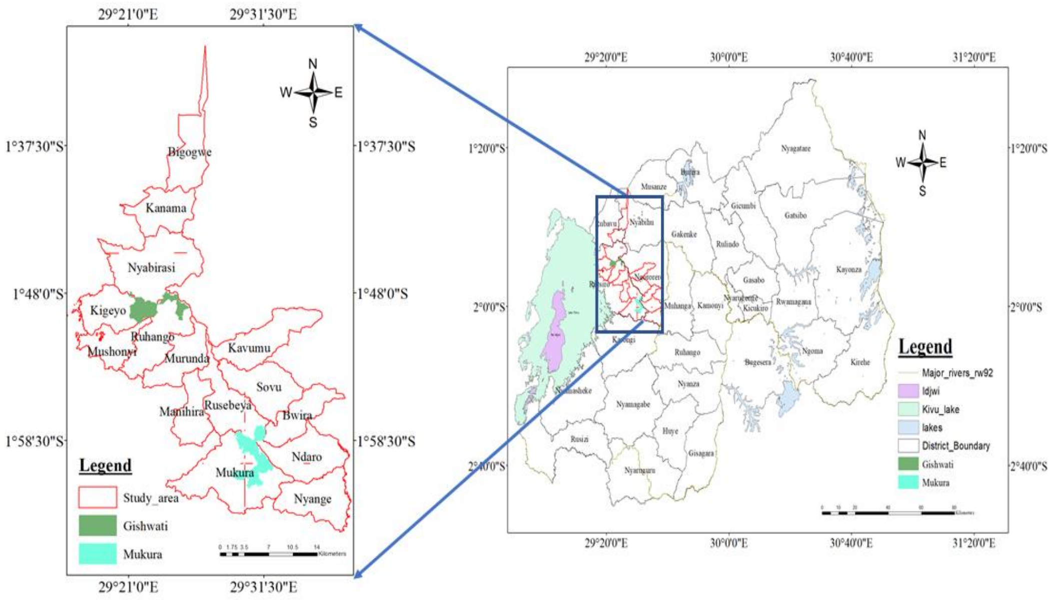

Figure 1. Map of the study area

It was confirmed that the precipitation aspects of the Landscape vary largely in space and in time (Figure 2) and this is due to many different factors including its geo-spatial localization. The Landscape has two main rain seasons: one in the beginning (March–May) of the year and another one towards the end of the year (October–December). Due to these continuous changes in rainfall patterns, an increase of serious weather-related hazards including landslides that impact the landscape at different scale were registered.

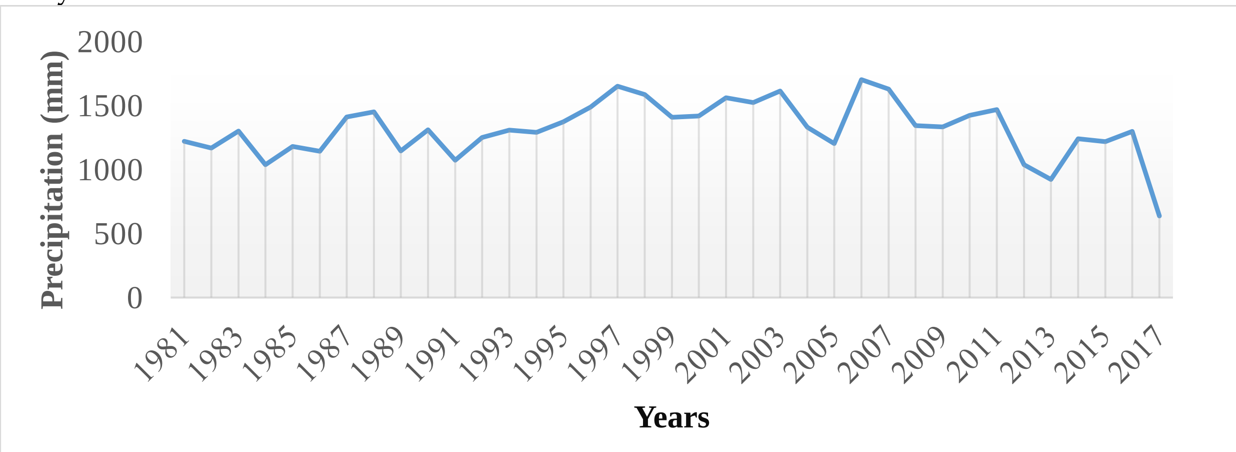

Figure 2. Annual precipitation dynamics of the Gishwati and Mukura Landscape from 1981 to 2017

Methodology

Identification of zones affected by landslides

For the necessities of the current study, landslides were identified through field observation and survey conducted by the researcher (October, 2018 – September, 2019). Some major landslide events and associated impacts in different parts of the landscape within different periods of time were highlighted to confirm the severity of landslide hazards and disasters in the study area.

Identification of Landslide-Related Causal Factors and mapping

For the purpose of this study, we consulted the Rwanda national disaster risk management plan (National Disaster Risk Management Plan, 2016), the national disaster management policy, and the national contingency plan for landslides to deduce the following five landslides related causal factors: (1) Rainfall patterns, (2) land slope gradients, (3) lithology, (4) soil parameters (texture and depth), and (5) land use types. For the rainfall patterns, data were collected from ten meteorological stations located in or near the study area: (1) Crete congo-Nile, (2) Rutsiro, (3) Tamira, (4) Kanama, (5) Sovu, (6) Murunda, (7) Mushubati, (8) Kora, (9) Bigogwe, and (10) Nyange. The lithological features of the study area were derived from available mining map of Rwanda in good scale (1:100,000).

To develop the maps of the study area, we first used the digital elevation model (DEM) of Rwanda and thus, the slope map was derived. Second, to consider land use factor on the landslide occurrence, the Rwanda updated land use cover map of 2019 was classified with data obtained from Landsat images delivered by the USGS using appropriate remote sensing and GIS software. Lastly, the geological, lithological, soil type and depth data of the study area were derived from available geological maps of Rwanda and soil map database from the national soil surveys. The source of the data collected are mentioned in Table 1. Data were analyzed using Spatial Multi criteria Model and graphs was produced with the help of excel program.

Table 1. *Data collected and their source*

Data collected	Sources
DEM	Rwanda Environmental Management Authority (REMA)
Rwanda Land cover/use	Landsat-8 images delivered by the United States Geological Survey (USGS)
Lithological features	REMA
Soil datasets	Soil geodatabase/ MINAGRI
Precipitation datasets monthly and annual mean/mm	Rwanda Meteorological Agency
Country, Province and District's Boundaries/Rwanda	Center of Excellent in Biodiversity and Natural Resource Management / University of Rwanda

Results and discussions

Rainfall and la ndslide distribution

Rainfall was found to be the principal landslide triggering factor in the landscape. The percentage of landslides observed was higher in the April (42.2%) with an average rainfall amount of 174.19 mm followed by December (24.4%), May (20.0%), and November (13.3%) with 119.86 mm, 131.55mm, and 148.61 mm respectively (Figure 3).

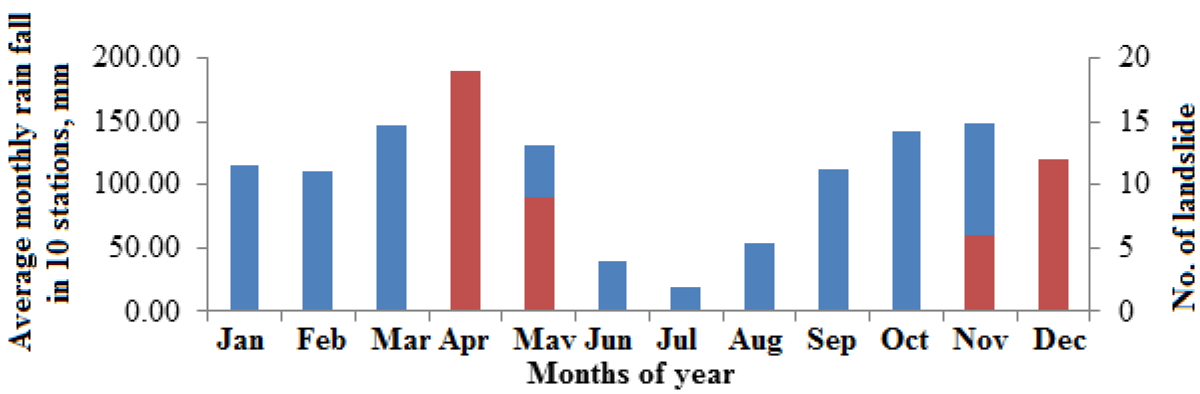

Figure 3. Monthly precipitation pattern and landslide distribution

These results are in agreement with findings of Polemio (2000) who reported that rainfall has both direct and indirect effect on the landside occurrence. Direct effect includes saturation of soil and rock mass, generation of excess pore pressure and erosion of surface soi1. Indirect effect includes gradual removal of fine particles by subsurface flow and facilitating both physical and chemical weathering of soil parent materials.

Land slope gradient and landslide distribution

The slope gradient and angle have an effect on slope stability, increasing the landslide hazard. A digital elevation model (DEM) was derived from the digitized elevation data using the 3D Analyst extension of Arc-GIS, and the slope layer was extracted from DEM. The slopes were classified into five classes: (a) <8.7%, (b) 8.7 –27.5%, (c) 27.5 –39.0%, and (d) 39.0 – 88.9% (Figure 4).

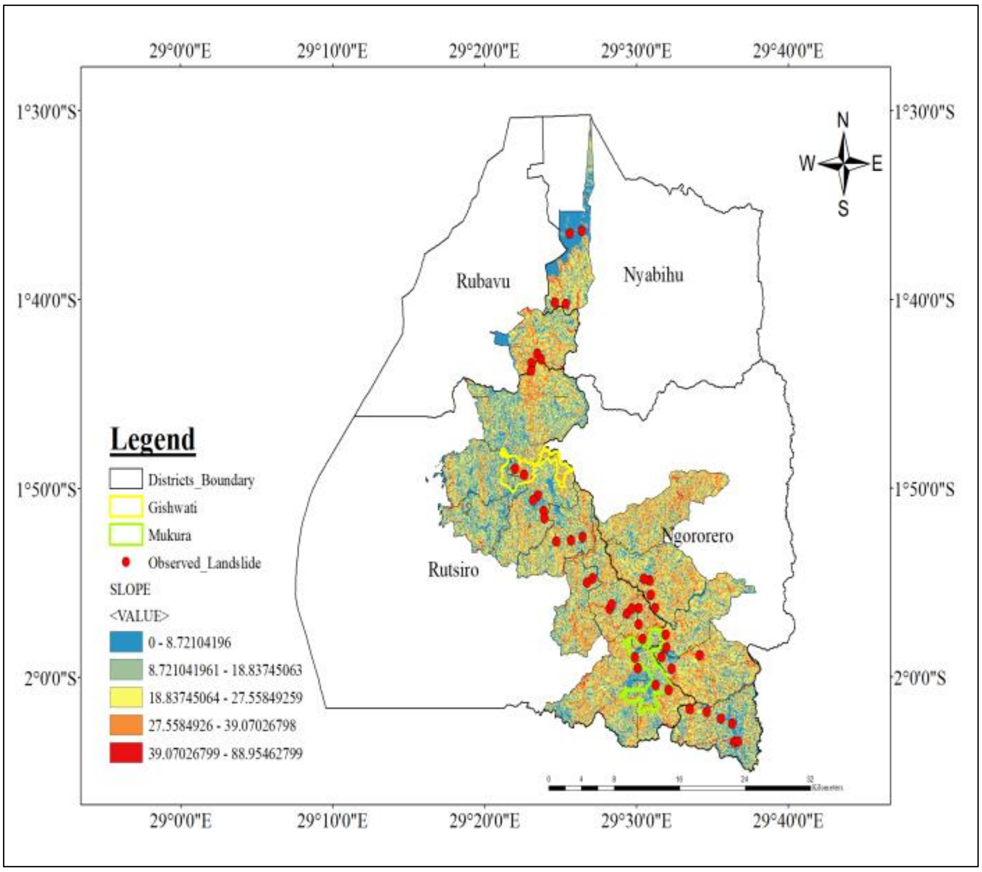

Figure 4. Slope gradient and landslide distribution in the Gishwati and Mukura Landscape

According to the Figure 4, the results reveal that landslides dominates the geomorphic units with slope gradients from 8.72%-27.5%. The results are in accordance with findings of Ngecu & Ichang'i (1999) who reported that the slope steepness is the most important relief characteristic which affects the mechanism as well as the intensity of the landslides. The Gishwati and Mukura landscape is dominated by hilly relief, which make it susceptible to landslide risks. It was revealed that steep slopes and plane concave slopes are more susceptible to landslide risks. In certain parts of the soil mantle during rainstorms, the slope shape influences the distribution of soil water content particularly in the rapid recharge of water. Area of concavity in slip-planes form a concentrated recharge of water into small areas of the slope, which develop perched water tables and pore pressures rise more rapidly which result into the slope failure.

Lithology and landslide distribution

The Landscape is dominated by five parent materials: (1) volcanic ash, (2) granite, (3) Schist, (4) quartzite, and (5) Basic Igneous rock (Figure 5).

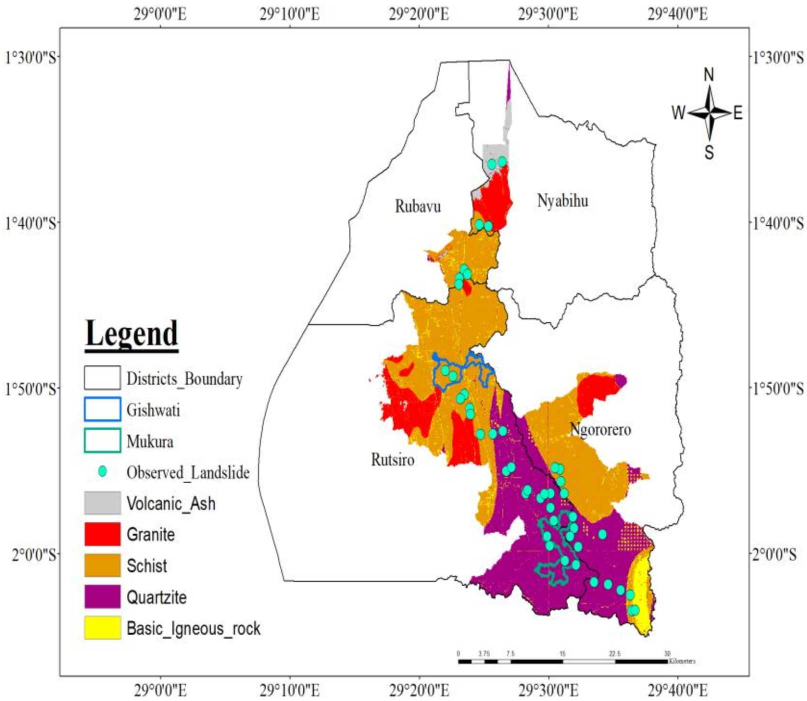

Figure 5. Dominant parental materials in Gishwati and Mukura Landscape

The figure shows that quartzite and schist were the most important formations of land sliding as compared to the other litho-types. Rogério *et al.* (2014) similarly reported that lithology plays a significant role in the occurrence of landslide together with the type, physical and chemical characteristics and mineralogy. The delivery processes and grain size distributions of the sediments are controlled by the lithology and rock-mass strength. Capitani *et al.* (2013) similarly reported that lithology influences the degree of coarsening, thus the sediment volumes and grain sizes supplied to the fluvial system exported from the upland areas are governed by the litho-types.

Soil parameters and landslide distribution

Landslides are influenced by various factors including soil texture and depth. The comparison showed that about 85% of the known landslides lie within the soil depth category ranging from 0.5 – 1m, 11% in the soil depth category of >1m, approximately 4% of known landslides fell into the category <0.5m (Figure 7). Whereas Figure 6 shows that most of landslides were identified in areas with more clay content (>35%) compared to those ranging from 20 – 35%.

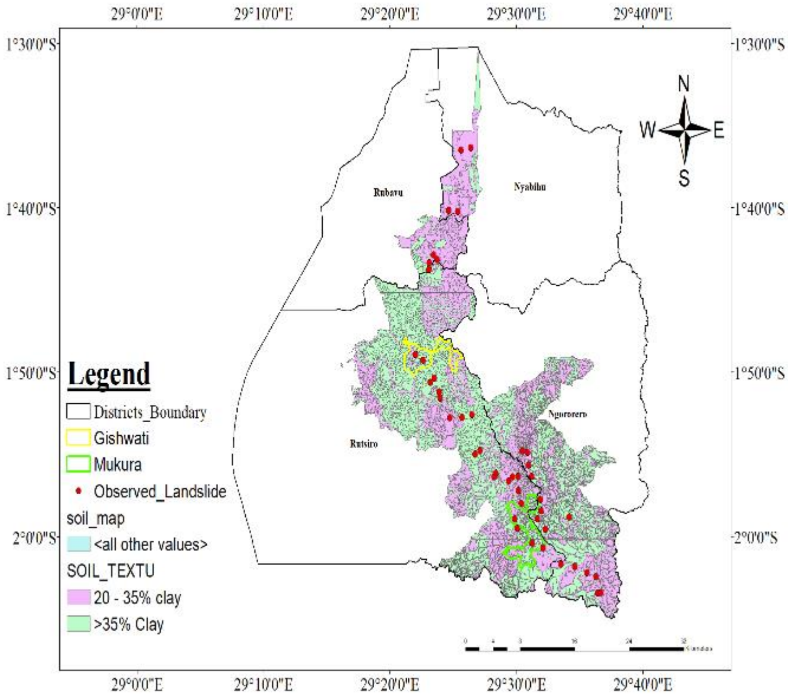

Figure 6. Clay content and landslide distribution in the Gishwati and Mukura Landscape

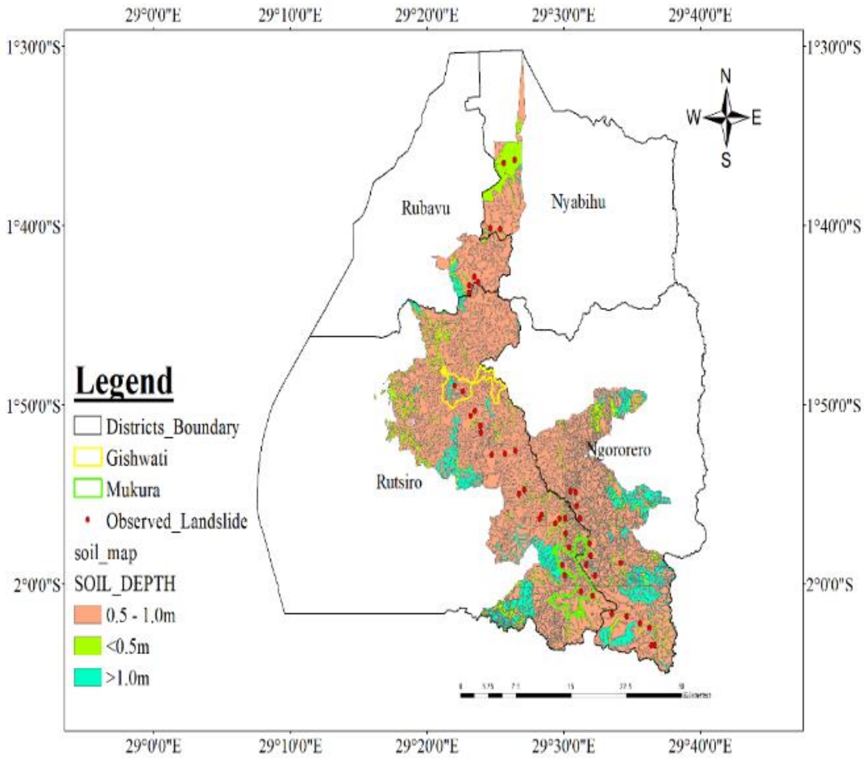

Figure 7. Soil depth and landslide distribution in the Gishwati and Mukura Landscape

Soil variability across the landscape results from the combination of geomorphologic and pedogenetic processes. Despite its importance, little quantitative information exists on vertical variation of soil profile within the landscape. K.M.G (2010) similarly reported that shallow landslides mainly occur during rainfall events in thicker soils where the elevated pore pressure develop in patches of lower root strength.

The high clay as well as with low sand content lead to destitute soil hydraulic properties such as poor aeration as well as low infiltration rate, permeability and other impaired soil physical properties. It was also revealed that the high clay content soils are prone to landslide occurrence because of having low shear strength and high swelling and shrinking ability. K.M.G (2010) similarly reported that clayey soils have been classified as less permeable soils due to low hydraulic conductivity, hence, these kinds of soils are susceptible to landslides because of having high water storage capacity.

Land use/ cover types and landslide distribution

To consider land cover/use types in the landscape, the updated land cover map of 2019 was classified with data obtained from Landsat-8 images delivered by the USGS. The Landscape was hence classified into three main land cover/use types: (a) forest land, (b) agricultural land, and (c) built-up (Figure 8).

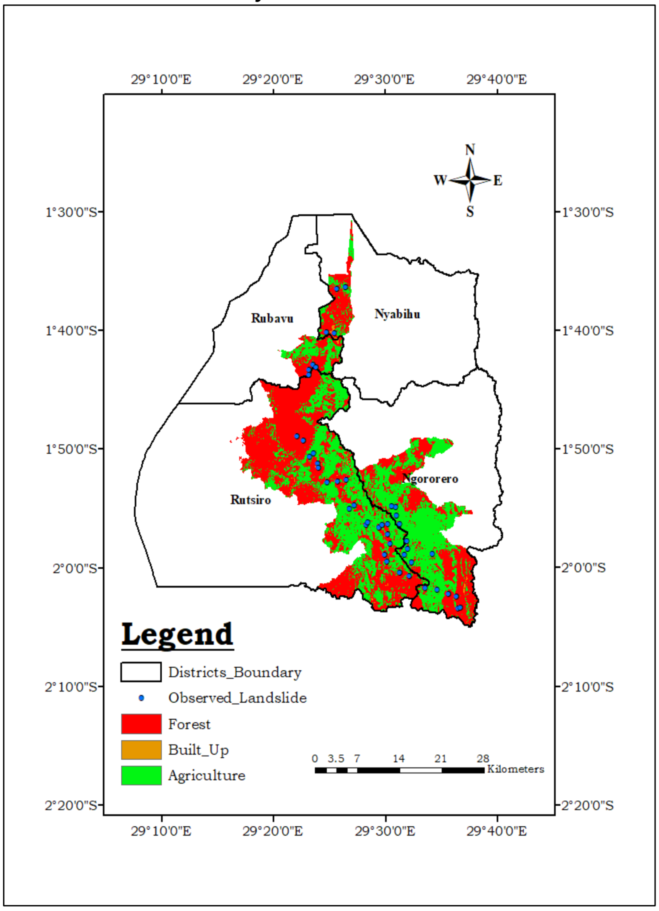

Figure 8. Land use type and landslide distribution in the Gishwati and Mukura

Landscape

The identified landslide in the Gishwati and Mukura landscape was found to occur in the agriculture land, forestry and built-up areas with 56.52%, 34.78% and 8.7% respectively. Mostly, landslide occurs in the agriculture land which has low vegetation density with shallow root system. This result agrees with findings of Wangari (2011) who explained that roots have a low ability to withstand the occurrence of landslide. Additionally, Kavzoglu *et al.* (2019) reported that poor maintenance of the agricultural practices increased the surface water runoff and consequently intensified erosion processes and instability phenomena that led to the slope failure. Thus, the obtained results are particularly useful to understand the best land conservation strategies to be adopted to mitigate the slope failure and the consequence of the economic losses, which are strongly linked with the best agricultural practices in the study areas.

Conclusion

This study aimed to establish the relationship between landslides occurrence and some major related causal factors including precipitation, slope gradient, lithology, soil type and depth, and land use/ cover type. The results indicate that heavy rainfall clustered during two main rainy seasons were the principal triggering factor of landslides in the landscape. It has been revealed that 56.5% of the total observed landslides falls into the slope category of 8.7 –27.5%, followed by the category of 27.5 –39.0% with 41.3%. The areas occupied by the crop land was found to be the most affected with 50.0% of the total identified sites, followed by forest (34.8%) and built-up areas (15.2%). The soils with high percentage of clay content (>35%), originated from granite, dominate the identified zones affected by landslides. Based on those findings, the landslides risk is likely to increase in the landscape as long as there is an increase of inappropriate use of agricultural practices, which reveals that the land is not well covered and thus subjected to easy runoff facilitated by the geographical and climatic features of the Landscape, which in turn generate mudslides and landslides. Therefore, it can be suggested to (i) strengthen the local community risk awareness and preparedness through education, trainings and meetings, (ii) ensure strong population growth control measures, and wise use and management of the available land, (iii) encourage non-agragarian businesses, and (iv) initiate/empower the practice of agroforestry and rainfall harvest to minimize the runoff in the Landscape.

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