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ASSESSING THE EFFECTS OF LULC CHANGE ON LANDSLIDE HAZARDS IN RWANDA: A CASE STUDY IN NYABIHU DISTRICT

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Abstract

Landslides have become important environmental hazard in hilly regions of Rwanda such as Nyabihu district. They are characterized by the downslope movement of debris or other earth materials which damage or destroy everything found in their way such as infrastructure, croplands, and even cause a number of human deaths. The main triggering factors of landslides in Rwanda are intense rainfall and land use/land cover (LULC) change. Therefore, the objective of this study was to assess the LULC change effects on landslide occurrences. LULC maps of 2005 and 2015 were generated and overlaid with mapped landslides. Maximum likelihood classification was used to classify the Landsat satellite images. The results revealed a remarkable decrease of agricultural land, while all other LULC types have increased in the studied period. It was noted that most of the landslides occurred in agricultural land. The study results are expected to be useful for landslide hazard management decisions, land use planning and management regulations, so as to minimize the likelihood of landslide occurrences and their resultant impacts.

Keywords: geospatial techniques, GIS, landslide hazard, land use, land cover, Landsat imagery

INTRODUCTION

Landslides are among the globally recognized environmental hazards that cause numerous fatalities and property damages, particularly in mountainous or hilly regions of the world (Huabin et al., 2005; Bennett et al., 2016). Worldwide, the severity and frequency of landslides differ from one region to another, depending on triggering factors or drivers either physical (e.g. rainfall, slope, and soil properties, etc.) or anthropogenic (e.g. loading the slopes with buildings and infrastructure, changing vegetation cover, etc.) present in the area (Anderson and Holcombe, 2013). Various studies have grouped causative factors of landslides into internal and external causes (Prasad, 1995; Popescu, 1996; Huabin et al., 2005). Internal causes include factors such as faults, freezing and thawing of rocks and soils, material properties such as compressive strength and shearing strength, etc. Whereas external causes include factors such as undercutting the foot of the hill slope when extracting minerals, excavating for creation of canals or roads, land cover change, exerting unbearable loads on slope such as buildings and water tanks, and also vibration induced by earthquakes, etc. Thus, human activities like deforestation, vegetation clearance, improper agricultural practices, housing developments on steep slopes, road and railway construction, illegal mining, hill cutting, and dam constructions, etc., all have direct or indirect effects on slope failure which results in landslide occurrence (Anderson and Holcombe, 2013; Dewitte et al., 2017; Froude and Petley, 2018).

Heavy rainfall, continuous land cover change mostly due to human activities, and other factors such as steep slope, soil depth and structure (clayey-sandy soils), and lithology (lateritic and volcanic) have been noted to induce landslides in hilly regions of Rwanda (Bizimana and Sönmez, 2015; Nsengiyumva et al, 2018). The landslide hazards have serious negative impact on socio-economic livelihoods, devastating croplands and settlements as well as causing deaths. Besides, landslides in Rwanda often result in a lot of damages and people losing their lives, destruction of croplands, and also leaving injuries as well as homeless families. Despite all this, few researches about landslide hazards have been done in the past (MIDIMAR, 2015; MININFRA, 2015).

Rainfall patterns have been changing as a result of climate change which implies the severity of rainfall-induced landslides occurring in different parts of the country (Muhire and Ahmed, 2015; Haggag et al., 2016). Yet, the gravity of rainfall to cause landslide is also aggravated by human activities that destroy the natural land cover when growing crops or constructing houses in steep slope areas as result of population growth, and hence heightening the intensity, severity and frequency of landslides (REMA, 2015). Therefore, it is essential to analyze the relationship between LULC change and landslide occurrences. Since rainfall and LULC change on steep slopes have been identified as the main triggering factors of landslides, assessing LULC change could assist in landslide hazard management. Furthermore, the application of geospatial techniques in providing consistent landslide vulnerability maps in Nyabihu district has received limited attention so far. The application of these techniques could assist in assessing the extent and effects of landslide hazards in vulnerable areas such as Nyabihu district, in western Rwanda. Therefore, the aims of this study were to assess (1) how LULC change affects landslide occurrences; (2) the extent to which LULC change affects landslide occurrences in Nyabihu district of Rwanda.

Study Area

Nyabihu district (area: 537.7 km^2) hosts nearly 294740 inhabitants with population density of 555 capita/km^2. Nyabihu district is located in western province of Rwanda between latitude 1°40.443’ and 1°40.554’ South of the equator, and between longitude 29°38.295’ and 29°21.955’ East (Fig.1). The district is characterized by a continental relief that consists of high, rocky and steep mountain slopes with an altitude ranging between 1460 m and 4507 m (MINAGRI, 2018). In general, the study area presents a mild climate with an annual average temperature of 15℃, and it receives 1400 mm annual precipitation.

The hydrological network of the district is comprised of several streams and springs, that are in deep, lowland valleys between steep mountains. In terms of vegetation, some parts of the study area are covered by exotic species such as eucalyptus on the hillsides and along the roadsides. Other areas comprise agricultural fields with a variety of crops, and also grazing lands. The recently established Gishwati National Park in 2015 (which is dominated by indigenous species, and situated in the southwestern part of Nyabihu district) has experienced deforestation (e.g. due to settlements, conversion of forest into agriculture and livestock farmlands) to the extent that the remaining intact natural forest is less than 7% of the original forest (MINAGRI, 2018).

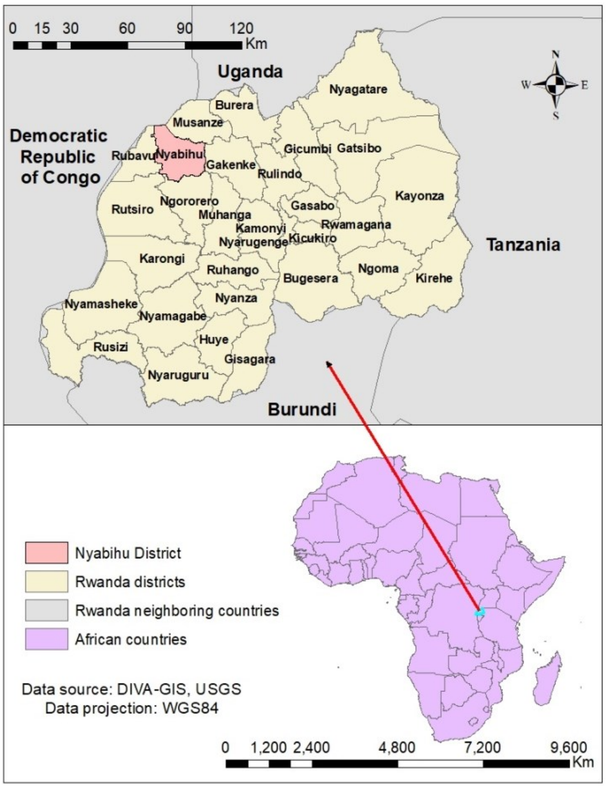

Fig. 1 The research was performed in Nyabihu district of Rwanda

MATERIALS AND METHODS

This study used quantitative research methods to analyze the rate of LULC changes, and the relationship between landslides and LULC change. The study applied remote sensing and GIS techniques, and statistical analysis of the data. To achieve the objective of the study, mostly secondary data (satellite images, and shapefiles) were used. The main characteristics of the applied satellite images are in Table 1. Besides, high resolution Google Earth imagery of 2005 and 2015 were used to extract the geographical coordinates of visible landslides.

The selection of the Landsat images is explained by their long history and free availability compared to other satellites such as SPOT images. However, it was a challenge to find a good satellite image of the study area, as at this geographical location usually thick and continuous cloud coverage is typical for almost all months of the year. The Landsat satellite images of 2005 and 2015 were the sources of data from which geospatial techniques were applied to analyze the land cover change and produce land cover maps of the study area. These satellite images were downloaded from USGS (https://earthexplorer.usgs.gov/). As they were covering other areas that are not part of the study area, images were subsetted in order to have images covering only the study area.

Satellite image processing

After downloading the required satellites images, layer stack and subset processes were done to prepare the images for further processing and analysis. ERDAS IMAGINE 2018 software was used for carrying out the required preprocessing. The images of the study area were subset with the boundary shapefile of Nyabihu district in ERDAS IMAGINE 2018 software. Different pre-processing techniques were used to prepare images for further processing and analysis. These include: radiometric correction, atmospheric correction and topographic correction. In the frame of radiometric correction the distortions in the degree of electromagnetic energy registered by each detector were removed or diminished (Eastman, 2003).

Table 1 Main characteristics of the satellite images used in the study

Image	Acquisition date	Path/Row	Spatial resolution	Cloud cover
Landsat 7 ETM+	21. Febr. 2005	173/61	30 m	free of cloud cover (0%)
Landsat 8 OLI	21. Sept. 2015	173/61	30 m	cloud cover of 10%, but free of clouds in the study area

Radiometric correction was carried out in order to calibrate the radiance of reflectance values in the images, and to allow more assessment of ground surface properties and then facilitate the analysis of the mentioned satellite images. With this, strips in Landsat 7 ETM+ were removed through the use of ERDAS IMAGINE function which allowed overcoming the limitation of lacking information in strips, and hence increasing the certainty in analyzing the image. On the other hand, atmospheric correction was not much of concern in this study since post-classification comparison method that was applied for detecting LULC also compensates for variations in atmospheric conditions (Mausel et al., 2004).

Using ERDAS IMAGINE software, Supervised Classification was used to classify different LULCs in Nyabihu district for the period of 2005 and 2015. Specifically, supervised maximum likelihood classification technique was used in this study, because its relative simplicity and robustness, but also due to its ability to define means, variances and co-variances of training samples (Gao and Zhang, 2009).

For the classification of images of the study area, more than 30 training samples for each LULC class were taken to ensure the representativeness of pixels. Thereafter, *Recode* tool in ERDAS IMAGINE was used to correct the misclassified pixels during the classification process. This was done by using the Google earth images for 2005 and 2015, which were linked to the classified images of the corresponding mentioned years in order to check the correctness of the classification results. After classifying the LULC classes for each image, the post-classification comparison method was utilized to detect LULC changes that have occurred between 2005 and 2015. Post-classification comparison separately classifies multi-temporal images into thematic maps and then compares the classified images, pixel by pixel (Mausel et al., 2004). Accuracy assessment of the classified images was carried out. The Overall Kappa (K) statistics (Table 2) of classified images are 0.82 and 0.88 for 2005 and 2015 respectively.

Identification of landslides in the study area

Since landslides spectral reflectance may be quite similar to bare land (such as exposed rocks, gravel roads, etc.) or ploughed fields, which could affect the accuracy of image classification results, Google Earth images were utilized to identify landslides in the study area by using computer screen-based visual image interpretation technique (Xu, 2015). Google Earth imagery has high spatial resolution which helps accurately discern landslides from other ground features. Visual image interpretation was chosen over supervised classification technique, because it helped to precisely locate landslides based on their rough texture and shape which differ from the one of surrounding ground features (e.g. vegetation, and rectangular shape of croplands). From Google Earth images of 2005 and 2015, the locations of landslides were determined and the coordinates were compiled in Excel. Then, landslides points were imported into ArcGIS to be processed and overlaid with classified images for further analysis. Using these techniques, altogether 8 landslides were identified in Google Earth image of 2005 and 34 landslides were identified on the image made in 2015.

RESULTS AND DISCUSSION

Land use/land cover in 2005

The results of image classification of 2005 indicated that the study area was dominated (76.5%) by agricultural land (Fig. 2, Table 2). The study area is a rural district, where most of the inhabitants rely on growing crops or livestock keeping for their livelihood. The agricultural land occupying 411.67 km^2 comprises the rain fed arable lands, cropland with non-permanent plants (e.g., potatoes, wheat, and vegetables) and permanent crops such as banana and tea plantations, and fallow fields as well. Tea plantations (2.1%) were classified separately from the agricultural land as they appeared as a kind of vegetated area in the satellite image. Tea plantations are located on hills and valleys in the south-west and central parts of the area.

Grasslands (5.3%) include the pasture lands and other uncultivable lands reserved for a specific purpose. They are typical in the SW corner of the study area, where they vary with forests. Forests (13.7%) are mostly located on hills in the north-west and south-west of the study area. Built-up areas (2.2%) comprise single residential houses spread throughout the study area, factories, roads, and other basic infrastructures such as schools, churches, health centers, etc. Bare land (0.01%) occupying less space comprises the unused spaces, rocky areas and cleared areas.

Table 2 Image classification accuracy assessment results of the applied 2005 and 2015 satellite images

Land use/cover type	Landsat 7 ETM+ image (2005)		Landsat 8 OLI&TIRS image (2015)	
	Producer's accuracy [%]	User's accuracy [%]	Producer's accuracy [%]	User's accuracy [%]
Agricultural land	64.52	100	73.08	95
Bare land	50	100	100	100
Built-up	92.86	65	93.33	75.00
Forest	89.47	85	86.96	100
Grassland	90.91	100	100	85
Tea plantation	93.75	75	94.74	90
Water	100	84.21	100	100
Overall accuracy	85%		90%	
Overall Kappa Statistics	0.82		0.88	

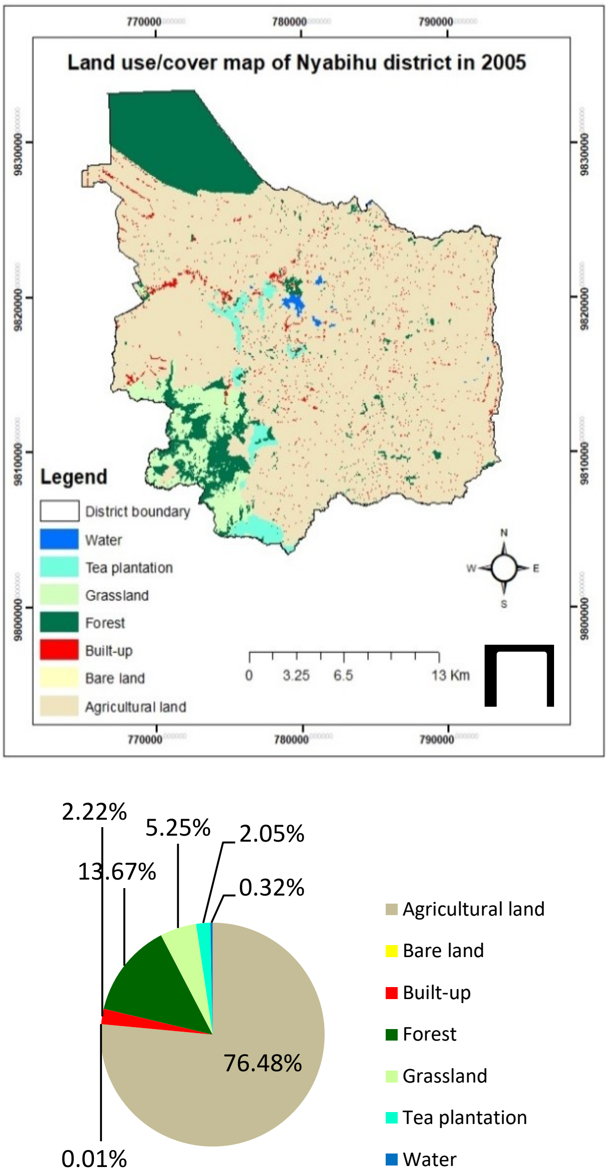

Fig. 2 Land use/land cover in 2005 in Nyabihu district and the areal distribution of these classes based on Landsat-7 satellite image classification

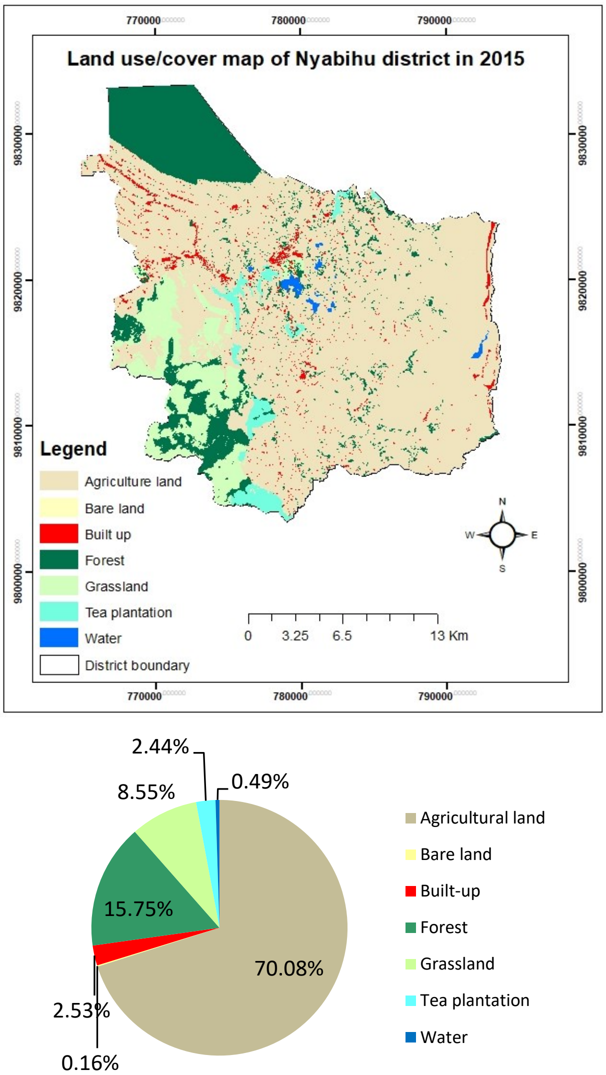

Fig. 3 Land use/land cover in 2015 in Nyabihu district and the areal distribution of these classes based on Landsat-7 satellite image classification

Land use/land cover in 2015

Despite changes that occurred in LULC since 2005, agricultural land in 2015 was still dominant (70.1%), followed by forest (15.8%) (Fig 3). All together, they occupied 85.8% of the area (Table 3).

Land use/land cover change from 2005 to 2015

The study area has undergone various changes in LULC between 2005 and 2015. Approximately one tenth of the agricultural lands were replaced by other land uses, such as forest, grassland and built-up areas (Table 3). The agricultural land decreased 34.46 km^2 in this period, while forest, bare land, built-up, grassland, water, and tea plantation increased by 11.21 km^2 0.8 km^2, 1.66 km^2, 17.77 km^2, 0.92 km^2 and 2.11 km^2 respectively in the period (Fig 4). The matrix of LULC change (Table 4) shows more precisely, that which LULC category was replaced by which category between the years 2005 and 2015.

The diagonal in orange color on Table 4 shows the size of the area (km^2) that has not changed between the two years. For example, the area of agricultural land decreased from 411.69 km^2 (76.47%) in 2005 to 377.23 km^2 (70.07%) in 2015, but only 362.12 km^2 of agricultural land remained unchanged between 2005 and 2015, and 17.86 km^2 of the agricultural lands was converted to grassland, further 16.60 km^2 became forest, and 10.93 km^2 was built in. On the other hand, the total area of forests increased from 73.595 km^2 to 84.80 km^2 until 2015; whereas 64.45 km^2 of forest remained unchanged in this period. The remarkable increase in forest and grassland areas (which are mostly pasture lands) was due to the measures that were taken by the government to reforest Gishwati Reserved Forest. Here, the reforestation efforts increased the area of forest from about 600 hectares in 2002 to 886 hectares between 2005 and 2008, which further increased up to 1,484 hectares between 2009 and 2010 (Kisioh, 2015). The Gishwati Reserved

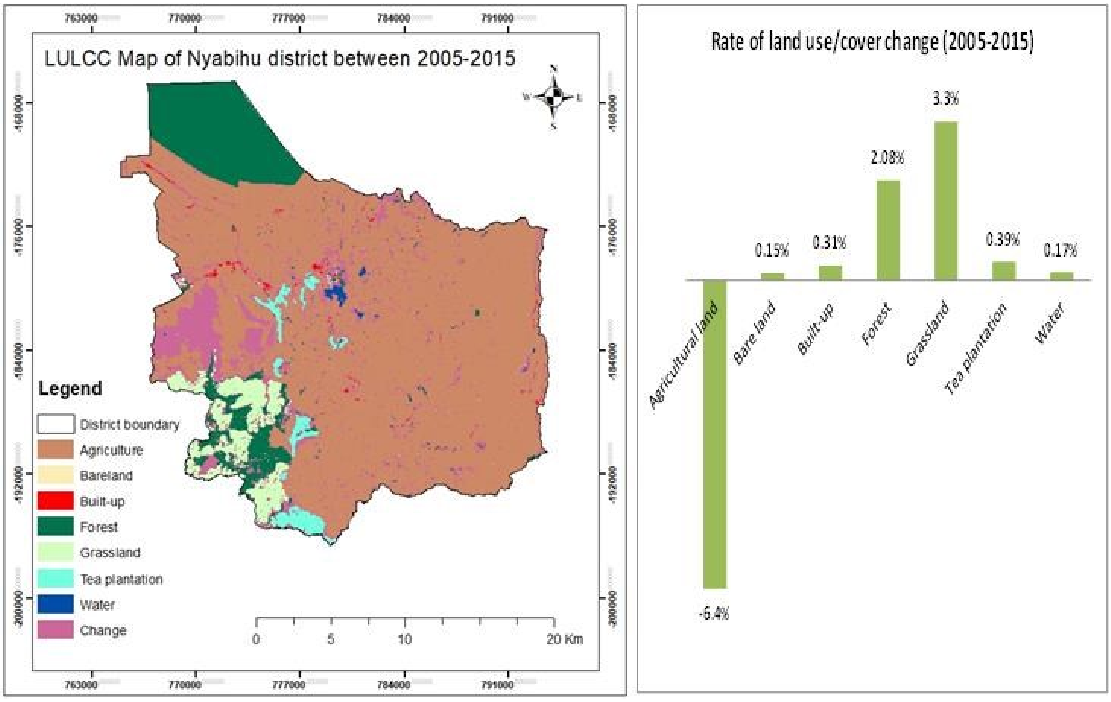

Fig. 4 Land use/land cover change and annual rate of change from 2005 to 2015

Forest was previously deforested by human encroachment through clearing of the forest for small-scale farming, large-scale cattle ranching projects and cattle grazing within the forest as well, as the resettlement of returnees and internally displaced people in the aftermath of the genocide in 1994 (Kisioh, 2015).

Table 3 Area and proportion of Land use/land cover categories in 2005 and 2015 in Nyabihu district, Rwanda

LULC	2005		2015		area change [km^2]
	area [km^2]	proportion [%]	area [km^2]	proportion [%]	
Agricultural land	411.69	76.48	377.23	70.08	-34.46
Bare land	0.08	0.01	0.88	0.16	0.8
Built-up	11.95	2.22	13.61	2.53	1.66
Forest	73.59	13.67	84.80	15.75	11.21
Grassland	28.26	5.25	46.03	8.55	17.77
Tea plantation	11.04	2.05	13.15	2.44	2.11
Water	1.71	0.32	2.63	0.49	0.92
TOTAL	538.32	100.00	538.31	100.00	

Table 4 Land use/land cover change matrix, representing the areal changes between 2005 and 2015

	LULC classes	LULC in 2015 [km^2]							
		Agriculture	Bare land	Built-up	Forest	Grassland	Tea plantation	Water	**Total area**
LULC in 2005 [km^2]	Agriculture	362.1195	0.1980	10.9300	16.8089	17.8649	2.5734	1.1915	411.69
	Bareland	0.0092	0.0028	0.0004	0.0273	0.0202	0.0172	0.0001	0.0772
	Built-up	9.0412	0.0105	2.2301	0.4304	0.1534	0.0647	0.0170	11.947
	Forest	4.4268	0.1424	0.2808	64.4483	3.7750	0.4862	0.0354	73.595
	Grassland	0.4381	0.4709	0.0945	2.8881	24.1967	0.1724	0.0004	28.261
	Tea plantation	0.9120	0.0506	0.0724	0.1575	0.0180	9.8312		11.042
	Water	0.2835		0.0008	0.0352	0.0012		1.3857	1.7064
	Total area	377.2303	0.8752	13.6089	84.7957	46.0296	13.1450	2.6302	538.31

Likewise, the territory of built-up areas increased from 11.95 km^2 in 2005 to 13.60 km^2 in 2015. The increase of built-up areas was undoubtedly due to the population growth which definitely implies the construction of new infrastructures including shelters, etc.

Connection between land use/land cover change and landslides in Nyabihu district

The produced landslide shapefiles were overlaid with the LULC of Nyabihu district in 2005 and 2015 (Fig. 5). The results indicated more landslides (34) in 2015 compared to those occurred in 2005 (8). Most of the landslides occurred in agricultural lands. For instance, in 2005, almost all landslides (7 out of 8, representing 87.5% of the total number of landslides) were located in agricultural land, and only one landslide (representing 12.5% of the total number of landslides) occurred under a forest cover. Similarly, in 2015, most of the landslides (at 27 locations) developed on agricultural lands, while under grassland (4), built-up (1) and forests (2) only limited number of landslides appeared. This implies that agriculture land is the most affected by landslides compared to other land uses/covers; possibly due to depletion of natural vegetation.

The LULC changes have an influence on slope failures that lead to landslides (Chen and Huang, 2012; Mugagga et al., 2012), due to inappropriate land coverage for stabilizing the slope material firmly. More often, changes in LULC are associated with some factors like undercutting the slope, vegetation removal and change in water flow directions which all weaken the soil capacity of absorbing water, thereby causing landslides. Former researches (e.g. Karsli et al., 2009; Reichenbach et al., 2014) proved that LULC changes on slopes contribute to slope instability and higher occurrence of landslide. The changes observed in the study area mainly refer to the decrease in agriculture land. Yet, the agriculture remains the main source of subsistence for the majority people in Nyabihu district. Also, the agricultural production from this district feeds other regions countrywide, including Kigali capital city.

The decline of agricultural land may lead to improper agricultural practices, like cultivation of unsuitable slopes, as the farmers would be interested in producing more yield while violating the soil protection measures, and hence exposing soils to erosion and landslides as well. With the same reasoning, the diminution of agricultural land (cropland) while the population increases, explains the pressure exerted on remaining scarce cropland, and hence inducing inappropriate agricultural practices in one way or another. Gurung et al. (2013) cited inappropriate agricultural practices as one of the landslide triggering factors, which might be the case in Nyabihu district as well, based on the obtained results. It was also noticed by Knapen et al. (2006) that the slope instability can be caused by cultivation on unsuitable steep slopes due to population growth pressure. The cultivation on steep slopes increases the chances to landslide occurrence when it is done without proper protection measures (Wasowski et al., 2010, as cited in Mugagga et al., 2012).

In the study area a greater number of landslides was detected in agricultural lands (cropland) than on other LULCs, as the croplands in the area are mostly characterized by short-term crops (e.g. potatoes, beans, carrots) having roots with limited penetration depth of soil, though the progression of plant roots in the soil depth could increase the slope stability (Noroozi et al., 2017). Furthermore, based on the argument that trees or woody vegetation increase the slope stability (MacNeil et al., 2001; Reichenbach et al., 2014), it confirms the prominent landslide occurrences in agricultural land, since growing crops usually involves the removal of trees or vegetation for soil preparation.

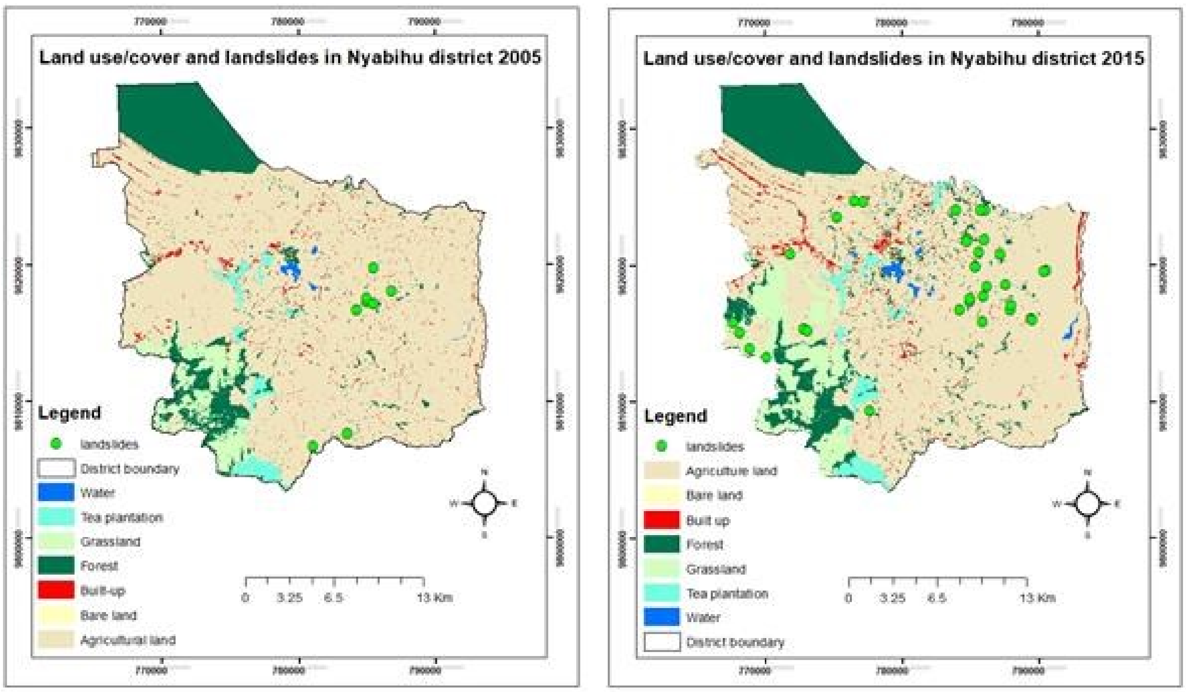

Fig. 5 Relation between land use/land cover and landslides in 2005 (left) and 2015 (right)

The occurrence of landslides in croplands can be also attributed to other factors, such as the absence of radical terraces and appropriate rainwater channels on steep slopes. This was also revealed by the obtained results of the presented research, as it was indicated that almost all landslides occurred in agricultural land with steep slopes, while the agricultural land on gentle slopes experienced few landslides, confirming the relation of LULC and slope gradient in inducing landslides.

CONCLUSIONS

This study analyzed the land use/land cover changes in Nyabihu district of Rwanda from 2005 to 2015. It was noted that there were various changes for each LULC category. The area of forests, grasslands, tea plantations, bare lands, and waters increased; while the territory of agricultural lands remarkably declined.

The results proved the effects of LULC changes on landslide occurrences, where the agricultural land experienced the majority of landslides identified in the study area. Changing LULCs, particularly into cultivation activities on steep slopes was noted to be among the factors that can easily destabilize the slope, and hence leading to landslides. Based on the results, the study draws the following recommendations:

- The government and other stakeholders should act together to promote efficient land uses aiming to minimize the possibility of landslide hazard occurrences.
- The farmers should avoid improper agricultural practices on steep slopes
- Consideration should be taken into proper canalization of water, especially rainfall related run-off that could erode the top soil and hence causing the instability of the slopes.
- The conservation measures focusing particularly on soil protection should be promoted.
- Radical terraces are specifically recommendable on steep places that are not yet terraced, as they have been proven essential in weakening the damaging capacity of the rainfall water flowing down the steep slopes.

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