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Assessing Forest Cover Changes in Volcanoes Parks Region of East-central Africa Using Landsat Imagery

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Abstract

The Volcanoes Parks forest has been threatened by anthropogenic and natural factors including logging for wood products, mineral resources extraction, urbanization, volcanic eruption and cropland expansion. This study used remote sensing to determine the land cover and land use changes from 1986 to 2015. The analysis was focused on pre-conflict (1986-2000) and post conflict (2000-2015) periods to understand the impact of political instability on forest cover. Classification techniques and change detection methods were applied to detect and quantify the magnitude of change. The results revealed that land conversions varied both spatially and temporally depended on factors that contributed to forest dynamics across the region. The overall analysis highlighted that net annual rate of forest loss was 1.9% for 1986-2000 period while the net annual rate of forest gained from afforestation/reforestation was 1.8%. In the period from 2000-2015, 1.79% of forest was lost each year, which was higher than the rate of forest gained during the same period (1.56%). The general quantitative analysis indicated that 5.76% (0.2% each year) of forest cover was totally cleared in Volcanoes Parks region from 1986 to 2015. Based on the findings of this study, efforts in forest management and conservation are highly suggested to sustain forest resources in the region.

Keywords

Albertine Rift, Deforestation, Forest Cover, Remote Sensing, Volcanoes Parks

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1. Introduction

Forest fragmentation and loss have been major issues worldwide [1], which threatens biodiversity and species survival across wide range of forest ecosystems. The vulnerability of forest biodiversity along with the fact that the majority of terrestrial species depend on the forest ecosystem underlines the key role of forest conservation and management [1]. Human activities and climate change are often the dominant factors leading to the loss of forest biodiversity [2]. The level of these factors, their effects and the overcoming strategies vary from one area to another, depending on the nature of the landscape itself [3]. The tropical forests in Africa spanning from the Albertine Rift (Eastern part of Africa Rift valley) and extending through the Congo basin are recognized for their incredibility of serving as a carbon pool, storage of

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largest amount of carbon in living biomass and terrestrial reservoir of biodiversity that provide a number of important ecosystem services in shaping the human environment of the tropical countries [4]. However, changes in forest ecosystems due to coupled human and natural effects, e.g., slash-burn agriculture, drought, timber logging and mineral resources exploitation, has caused the rapid decline of wildlife populations.

Wars, conflicts and political instability have further exacerbated deforestation and forest degradation. Additionally, refugees, countless rebels and national armed forces continuously operating in this region leaded to poor management of forests and ecosystems in general [5, 6]. The degradation in this period has been exacerbated by volcanic eruptions that burned large areas of forest between 1986 and 2000 [7]. Since the majority of the population in this area relies on subsistence agriculture, lack of modern agriculture coupled with urban development and climate change significantly contributed to the alterations in landscape and ecosystems. These challenges are closely related to the expansion of human populations in the surrounding landscapes, where forest degradation, land conversions for agriculture, mining operations and charcoal production, all deleteriously impact the volcanoes region forest resources and future sustainability of forest ecosystems. The consequences of deforestation and forest degradation resulting in shrinkage and fragmentation of forests, negatively affecting the biodiversity and contributing to the increase of greenhouse gases emissions [8]. In this context, the analysis of forest cover changes in this highly sensitive region is imperative to reveal and offer pertinent information to ensure the prevalence and sustainable outcomes to the forest landscape. The quantification of forest changes necessitates a clear knowledge of the location area, landscape type, socio-economic and political drivers of the region's land cover changes for expanding on their consequences to forest ecosystems [9].

And elsewhere, forest cover may be documented locally through field studies but in complex areas with high elevation, high steep slopes (hazardous areas), and massive scales, forest cover change studies require an approach based on remote sensing [10]. Remote sensing is an important tool in measuring and acquiring information about the surface through properties attributed to the changes in land cover and biodiversity [11]. Landsat data have been widely used in forest monitoring [12]. Although there have been some studies focusing on the effects of climate change (temperature and precipitation dynamics) on biodiversity in the volcanoes region, little is known regarding the impacts of land use on forest cover especially pre- and post-conflict era. The objectives of this study are to (1) develop different land cover transitions during the period from 1986 to 2015; (2) identify forest cover changes; and (3) quantify the extent and the magnitude of forest gains and losses during the two periods namely the conflicts period (1986-2000) and post-conflicts period (2000-2015) in Volcanoes Parks region.

2. Materials and Methods

2.1. Study Region

The Volcanoes Parks region lies in the borderland between the Democratic Republic of Congo (DRC), Uganda and Rwanda. It is composed of Virunga National Park in DRC, Volcanoes National Park in Rwanda and Mgahinga National Park in Uganda [6, 13]. These parks were established in 1925 by Belgian colonialists under the name of the Albert park and they are the only parks providing home and habitat to mountain gorilla species world-wide [6]. The volcanoes parks region connects a big ecological corridor. The study site covers several countries and regions, including Goma and the South-East of Rutchuru in North-Kivu of Democratic Republic of Congo (DRC), northern part of Nyabihu, Musanze and Burera districts located in the north and north-west of Rwanda, and the south-west of Kisoro in Uganda. This study covers the total area of 8,766.35 km^2. This region encountered intermittent challenges including wars and conflicts sourced to the civil war and the 1994 genocide against Tutsis in Rwanda and political conflicts in Uganda in the period ranging between 1959 to 2000 which affected the living biomass and the environment of the entire region and caused high loss and degradation of forests [6]. Geographically, Volcanoes Parks are located on latitude 1°10'-1°40' South and 29°00'-29°50' East of longitude or on world reference system -1 and 2 (WRS-1 and 2, Path/Row) Landsat 173 Path and 61 Row. This is an equatorial area dominated by high mountains and volcanoes (Figure 1), characterized by the equatorial climate as the mean temperature ranges between 15°C and 25°C depending on the altitude [14].

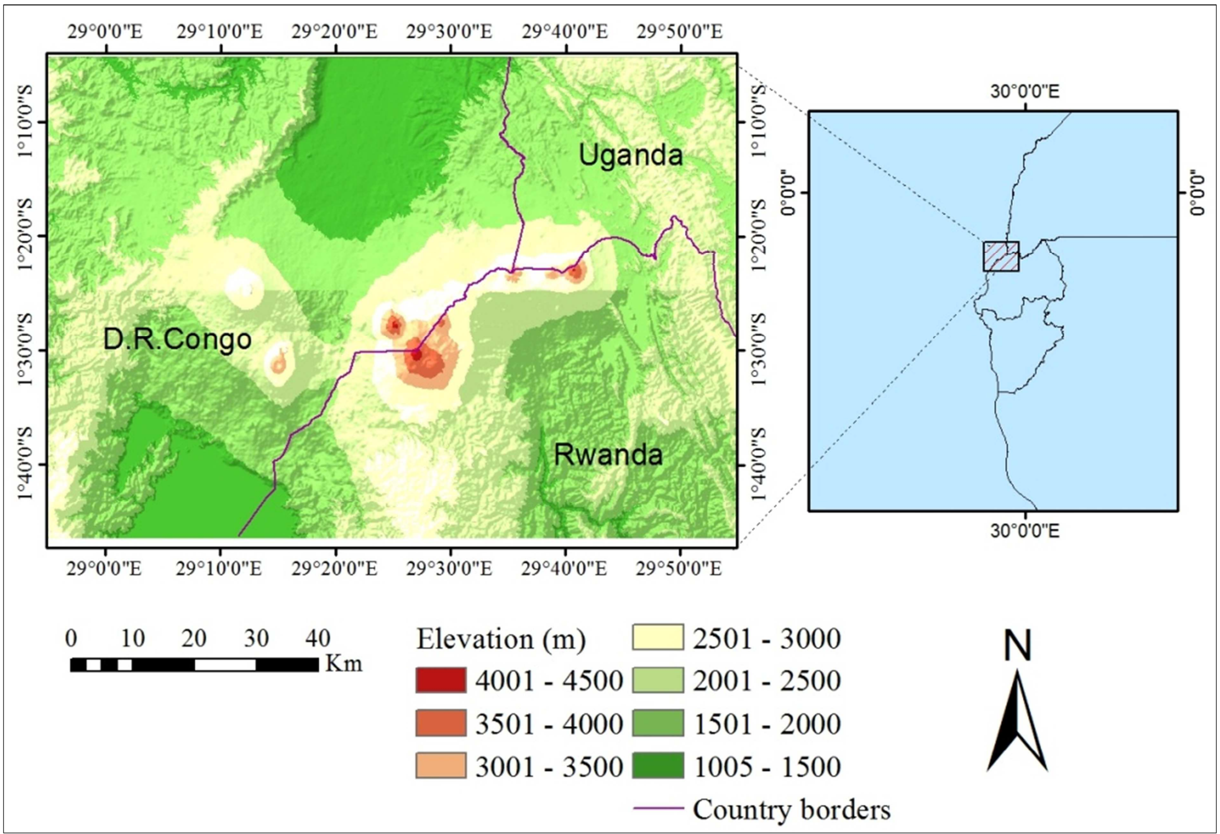

Figure 1. Image showing the location of the study area covering the scale of 736,150 hectares (ha).

2.2. Study Design and Data Analysis

This study examined forest cover changes (loss and gain) in volcanoes Parks region by evaluating forest effectiveness from pre-conflict, conflict and post-conflict periods. The land cover map-based attributed changes have been used to depict the periodical differences of forest cover and to quantify forest changes from 1986 to 2015. Forest cover has the potential impacts on biodiversity in this region, especially for daily living for Gorillas and other mammals and apes in this region and their surrounding landscape through spatial ecological interactions [15], and highlighted that the importance of identifying forest cover changes has a great opportunity to analyze its drivers and their influences to gorillas as the most dominant animal species in this region of study from conflict to post-conflict period. The comparative evaluation about forest changes and the driving forces were quantified. Moreover, the study has evaluated their influences to the gorilla's biodiversity.

Remote sensed Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imagery (OLI) and Thermal Infrared Sensor (TRS) were used from July 1986, July 2000 and July 2015. Satellite imagery was chosen on the basis of limited cloud cover and coincidence with the dry season (Table 1).

Table 1. Landsat data acquired for study site constituted by one scene on 172 Path and 61 Row.

Landsat Sensor	Scene ID	Resolution	Acquisition Date
Landsat 4-5TM	LT51730611986200xxx01	30m	7/1/1986
	LT41730611989264xxx03	30m	9/1/1987
Landsat 7ETM+	LE71730612000345SGS00	30m	7/1/2000
	LE71730612001073SGS00	30m	8/1/2001
Landsat 8OLI TIRS	LC81730612015040LGN00	30m	7/1/2015
	LC81730612015264LGN00	30m	8/1/2015

Elevation and topographic hillshade (i.e simulation solar incidence) were calculated from ASTER global Digital Elevation Model (GDEM) data version 2 acquired from The CGIAR Consortium for Spatial Information's website (http://srtm.csi.cgiar.org/selection/listImages.asp). Ground reference data were collected to estimate the accuracy for the land cover classifications; FAO (Food and Agriculture Organization) Land Cover and Land Use map produced and extracted for Sub-Sahara Africa of 2000 available on LADA (Land Degradation Assessment) in Drylands project [16] was geo-referenced and mosaicked with Land cover map acquired from Africover for Eastern Africa Module cover map obtained also from FAO [16]. These maps were used to validate Land cover classification map of 2000. Moreover, forest cover maps acquired from Central African Regional Programme for the Environment (CARPE) website [17] which were produced by FACET Congo (D.R Congo) was used for comparison analysis of land cover according to spectrally separable classes that resulted in our 2000 Land cover's accurate differentiation of forest and non-forest. Land cover validation data for 2015 were drawn from high resolution Google earth (GE) imagery and the orthophotos or geometrically corrected aerial photos produced by Rwanda land Center in their Rwanda Land management project were collected during government census in 2009 and 2015, and made available by the Rwanda National Land Center. For 1986 land cover classification, SPOT-1 images of 8m spatial resolution were used to determine ground truth since no other reference data was available for classification validation in this period for this study area.

2.3. Remote Sensing Analysis

The satellite imagery from 1986 to 2015 in the volcanoes parks region were encompassed and processed for obtaining forest cover changes from this differentiated dates (Table 1). A measure of forest cover change was derived from a multi temporal analysis of landsat data. The process was done in five steps, (1) image pre-processing, (2) classification, (3) post-classification, (4) accuracy assessment and (5) change detection and forest cover transition analysis.

In the first step, radiometric correction and atmospheric corrections have been applied to compensate for spectral characteristics that result from variations in the calibration parameters as well as distortions from sun-angle, earth-sun distances and atmospheric scattering effects adjustment from sensors' scanning errors in the Landsat images. These corrections were performed on original Landsat spectral bands (1-5 and 7). Also, in this step, Function mask (Fmask) algorithm [18] was involved for masking and removing clouds and cloud-shadows, thus, all TM and ETM+ images were calibrated to Top-Of-Atmosphere reflectance (TOA) and brightness temperatures. The generated TOA reflectance with threshold greater than 0.3 and brightness temperature greater than 27 degrees Kelvin were combined to create an additional band (band 7) which was used to calculate cloud and cloud-shadow covers [19]. TOA and cirrus band (band 9) in Landsat 8 OLI TIRS composite bands were composited to detect and mask clouds and shadows for 2015 Landsat 8OLI images [18, 20].

The buffer zone tool in Environment for Visualizing Image (ENVI) software version 5.3 established by the Exelis Visual Information Solutions [21] was used to extract the processed images by separating cloudy and shadowed with no-cloudy cells. The mask tool also in ENVI was interacted to mask no-data cells on original image. Thereafter, mosaic techniques were used to fill gaps or no-data on masked image by using another image of the same year of less cloudy and different cloud cover position compare to the masked image. ASTER GDEM data were used to correct for topographic and illumination angle effects that might lead to misclassification and classification errors due to the rugged terrain [22]. In this case, a pixel-based Mannaert (PBM) correction was chosen among other topographical correction methods [23] where the slope and aspect angles of the volcanoes and mountainous terrain were computed from the ASTER DEM as the input to the terrain illumination correction reflectance (Equation 1).

$$\mathrm{P}_{\mathrm{H},\lambda} = \rho_{\mathrm{T},\lambda} \frac{con\theta n}{(Cos\beta Cos\theta_n)^{k\lambda}} \tag{1}$$

$$\mathrm{Cos\beta = Cos\beta_s Cos\theta_n + Sin\beta_s Sin\theta_n(\phi_t - \phi_a)}$$

Here, κ_λ is the slope of regression between x = log ($\mathrm{Cos\beta Cos\theta_n}$) and y = log ($\rho_{\mathrm{T},\lambda}\mathrm{Cos\theta_n}$). $\rho_{\mathrm{H},\lambda}$ is the normalized reflectance of a horizontal surface; $\rho_{\mathrm{T},\lambda}$ is the observed reflectance on an inclined terrain; β is the incident solar angle; $\theta_s$is the solar zenith angle in degrees; θ_n is the slope angle of the terrain; $\Phi_t$is the aspect angle of the terrain; andΦ_a is the azimuth angle in degrees.

In the second step, we used polygon-based training site as suggested by Chen et al. [24, 25] to create training samples for the region of interest (ROI), the choice based on heterogeneous land covers. Supervised classification algorithms using Maximum likelihood, a well-known parametric classifier method, [26] was used to classify land cover and land use changes (LCLU). This classification method operates in form of correlation and thus covariance matrix where the statistics of each class at each band are normally distributed and calculates the probability that a given pixel belongs to a specific class [27]. The Landsat image of each year of the study period was classified using FAO classification system by applying classification level one, where we obtained eight physical land cover classes in the volcanoes area as illustrated in Table 2.

Table 2. Description of Land cover Land use classification in Volcanoes region.

Class	Description (Land Use Type)
Dense forest	Evergreen, deciduous forest
Open/dispersed forest	Sparse trees and shrubs
Grassland	Mosaic grassland, bushland, needleaf vegetation
Bareland	Volcanic lava flows and barren lands
Agriculture	Cultivated areas and open land
Urban	Built-up areas and settlement in villages.
Water	Lakes, reservoirs and streams
Wetland	Mix of water, herbaceous plants and vegetation, Swamps.

Due to the complexity of the terrain, the classification results represented significant classification errors on wetlands and built-up area pixels occurring on upland sites. To compensate for these errors, a spectral mixture analysis (SMA) was conducted to derive a sub-pixel land cover fraction owing to important variation in the landscape that occurred at the scale finer than 30 m Landsat resolution. The SMA resulted in pixel-level fractions for considered and observed spectral endmembers to linear combination of three spectrally land cover types: vegetation, high albedo, and low albedo [21]. The sub-pixel variation from SMA where the chosen original landsat spectral bands (1-5 and 7), Near Infrared (NIR) band a slope gradient map and DEM maps were used where a slope of 5 degree and elevation of greater than 2500m were used as predictors in a Random Forest Classification, an iterative clustered algorithm The Random Forest Algorithm was run for 1000 decision trees. The choice of the 5 degrees of slope and 2500 meters above sea level was referred to the construction policies and regulations established by the Ministry of Refugees and Disaster Management in Rwanda (MIDMAR) and Rwanda Housing Authority (RHA) [28].

Post-classification step (3) was undertaken to remove noise and reducing salt-and-pepper effects in final classification results where a 7x7 majority filter was applied to classified maps to smooth and only show the dominant classes in all classified images.

Step four was carried out for determining accuracies of classified images where at least 75 points were randomly over-scatted on ground reference images for big land cover classes and at least 30 points for small land cover classes respectively, those points were initialized on classified images, therefore, the overall accuracy, user and producer accuracies were assessed and accuracy matrix error was produced for each classified images from 1986 to 2015. Therefore, the Kappa statistical analysis and Kappa coefficients were calculated from each thematic map (each year) using the following equation 2:

$$\widehat{K} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} * x_{+i})} \quad (2)$$

Where: r= the number of rows in the matrix,x_{ii}= the number of observations in row and column i, x_{i+} and x_{+i} are the marginal totals of row $i$and column i respectively; and N= the total number of observations, in this case the total number of observed points for each classified images was 520 points.

The last step (5) carried out to address the hypothesis of detecting forest cover change in Volcanoes Parks region from 1986 to 2015, Land cover types of interest were forested areas (dense forest and dispersed forest). In this case, the forest classes were combined and created as a binary image in ArcGIS 10.2 where forest cover was assigned to the values of "1"and the combination of all other classes was named "Non-forest" and assigned to the values of "0". Image differencing was then undertaken and recent scenes were subtracted from the older ones to detect spatial and temporal patterns of forest changes in time using Raster calculator tool under ArcGis 10.2 to separate and statistically evaluate the intact forest covered by non-forest areas and estimate forest losses (deforestation) and forest gains (regeneration).

3. Results

3.1. Land Cover Land Use in the Volcanoes Region

The results from produced land cover and land use thematic maps showed the dominance of agriculture and the forest covers in this region. In 1986, forest area was 44.56%, and agriculture was 46.23%. In 2000, agriculture decreased to 45.88% and forest expanded about 1.47%. In 2015, the statistics showed a gradual increase of agriculture to 51.60%, and forest cover decreased to 38.88% correspondingly. The overall accuracy of image classification in 1986 was 96%, 94.9% in 2000 and 95.5% in 2015 (Table 3) while the kappa coefficient was excellent on average of 93%.

Table 3. Table showing the accuracies of each class and cover percentages during the study periods in the entire study area (unit: Percentage (%)).

	1986			2000			2015		
Classes	**P. A**	**U. A**	**cover**	**P. A**	**U. A**	**cover**	**P. A**	**U. A**	**cover**
Water	97.2	90	5.56	95.94	93	5.54	92.91	89.68	5.15
Built-up	91.85	60.94	0.18	90.4	78.44	0.61	98.17	94	1.23
Wetland	81.47	95	0.20	72.08	96	0.19	49.24	89.27	0.18
Bareland	100	99.5	3.00	91.06	87.77	3.76	78.22	90.59	2.99
Grassland	90.52	82.63	0.27	100	80.13	0.93	88.91	91.09	0.05
Agriculture	87.49	90.27	46.23	88.22	88.62	45.88	95.3	92.66	51.60
Forest	75.42	78.12	44.56	90.61	88.26	43.09	94.94	95.92	38.80

P.A: Producer's Accuracy; U.A: User's Accuracy and %: Percentage

For better understanding these contemporary forest cover changes, land cover and land use patterns were examined in Volcanoes Parks region using remote sensing as indicated in Figure 2.

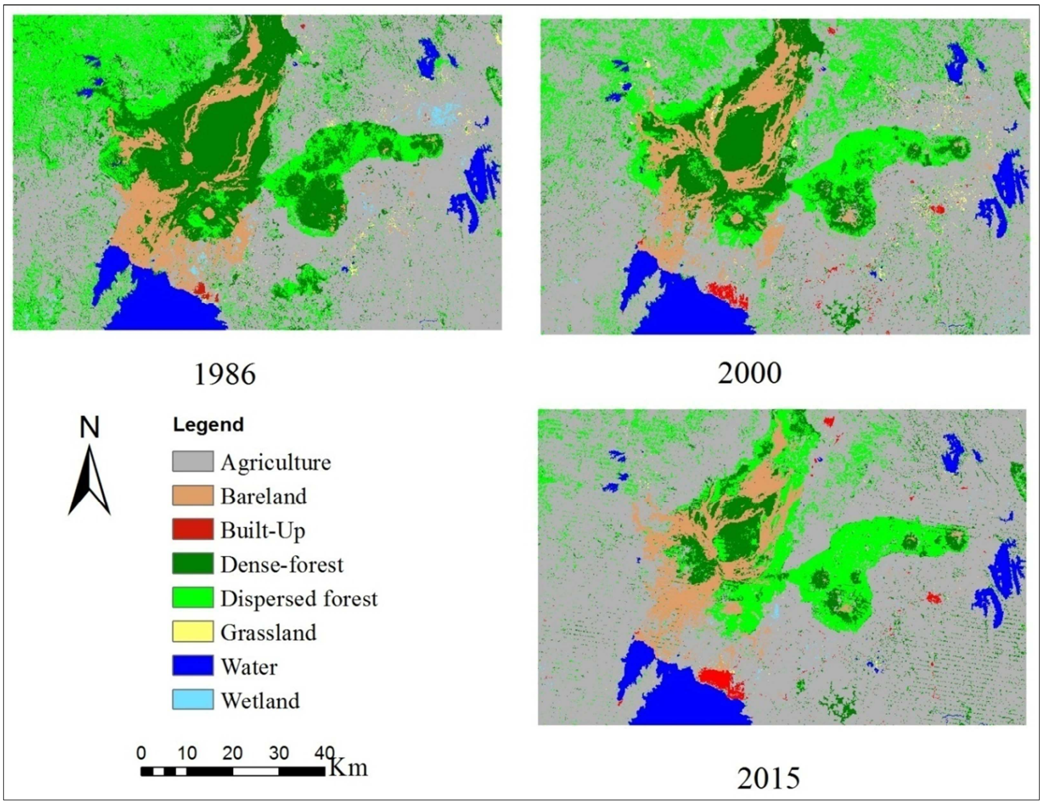

Figure 2. Thematic maps showing land cover and land use changes in volcanoes parks region for 1986, 2000 and 2015.

3.2. Land Covers Change Detection

All land cover types and landscape variables in this region represented the dynamism in both increasing and decreasing manners except built-up class, which continuously underwent positive changes while water bodies and wetlands have decreased throughout the study period as illustrated in Table 4.

Table 4. Change detection in each class during the periods of study area (positive=increase, negative=decrease, unit=percentage).

	Water	Built-up	Wetland	Bareland	Grassland	Agriculture	Forest
1986-2000	-0.02	0.44	-0.01	0.75	0.66	-0.35	-1.47
2000-2015	-0.39	0.61	-0.01	-0.77	-0.88	5.72	-4.29
1986-2015	-0.41	1.05	-0.02	-0.01	-0.22	5.37	-5.76

From 1986 to 2000, dense forests have severely shifted to degraded forest. From 2000 to 2015 both open/dispersed forest and dense forest reduced on their current sizes by 3.39% and 0.91%, respectively (Figure 2). From 1986 to 2015, total forest cover reduced up to 5.76%, agriculture has increased by 5.37% while water body decreased by 0.41%, urban and settlements expanded to 1.05%.

3.3. Land Cover and Land Use Transition Trends

Land cover conversions were ascertained to explain the spatial-temporal dynamics, causes and implications on the basis of observing the shift of land cover from loss to gain among the land cover types to inventory the spatial-scale of forest loss and forest gain that have been occurring primarily in volcanoes parks region. The information on the type of land conversions provides the overall picture of land-changes dynamics. The most common land change was conversion of forest to agriculture and urban areas in general but volcanic eruptions induced changes where lava flows, considered as bare land in this study, have removed approximately 153.10 km^2 forest, especially after Nyamuragira eruption in 1990's [29]. It is also estimated that at least 1195.43 km^2 of forest was harvested or cleared and shifted to agricultural practices and open lands between 1986 and 2000 and the increase of urban and settlements in this region caused the conversion and loss of approximately 19.1 km^2 from forest. Furthermore, between 2000 and 2015, 57.55 km^2 of forest were decimated by lava flows due to Nyiragongo eruptions in 2002 [30]. These losses of forest in Volcanoes Parks region were largely accelerated by intensive agriculture at a scale of 1227.43 km^2 between 2000 and 2015 as indicated in Table 5 and 6.

Table 5. Land cover transition from 1986 to 2000 (unity: square-kilometers (km^2)).

2000			1986				
Classes	**Water**	**Built-up**	**Wetland**	**Bareland**	**Grassland**	**Agriculture**	**Forest**
Water	468.26	0.00	0.00	0.00	0.00	10.83	6.10
Built-up	0.00	10.48	0.00	1.82	0.54	35.76	0.00
Wetland	0.88	4.86	9.82	1.86	0.00	4.03	0.59
Bareland	1.15	0.00	0.00	154.69	0.00	19.91	153.10
Grassland	3.46	0.47	0.00	5.77	14.86	44.44	12.54
Agriculture	10.17	3.19	5.97	66.65	4.65	2732.85	1195.02
Forest	3.78	1.35	1.19	33.28	3.61	1213.70	2520.04

Table 6. Land cover change transition from 2000-2015 (unity: square-kilometers (km^2)).

2015			2000				
classes	**Water**	**Built-up**	**Wetland**	**Bareland**	**Grassland**	**Agriculture**	**Forest**
Water	444.35	0.41	0.00	0.34	1.27	4.19	1.22
Built-up	1.59	38.30	0.02	1.35	0.77	46.33	19.15
Wetland	0.02	0.00	5.51	0.03	0.00	9.83	0.32
Bareland	0.05	0.03	0.65	190.86	0.04	13.22	57.55
Grassland	0.00	0.04	0.00	0.00	3.75	0.31	0.21
Agriculture	32.44	11.55	9.01	60.91	61.85	3121.11	1227.43
Forest	7.34	3.50	1.13	75.87	14.06	826.50	2471.94

3.4. Forest Cover Change Trends

Forest cover loss over 14 years (1986 to 2000) was approximately 15.62% (1369.76 km^2). This was compared to the total loss of 14.97% (1312.69 km^2) from 2000 to 2015 within 15 years. Similarly, the extent or gain in forest cover during the two time periods, in terms of percentage, was estimated at 14.30% (1254.09 km^2) and 10.66% (934.51 km^2) from 1986 to 2000 and 2000 to 2015 respectively (Figure 3).

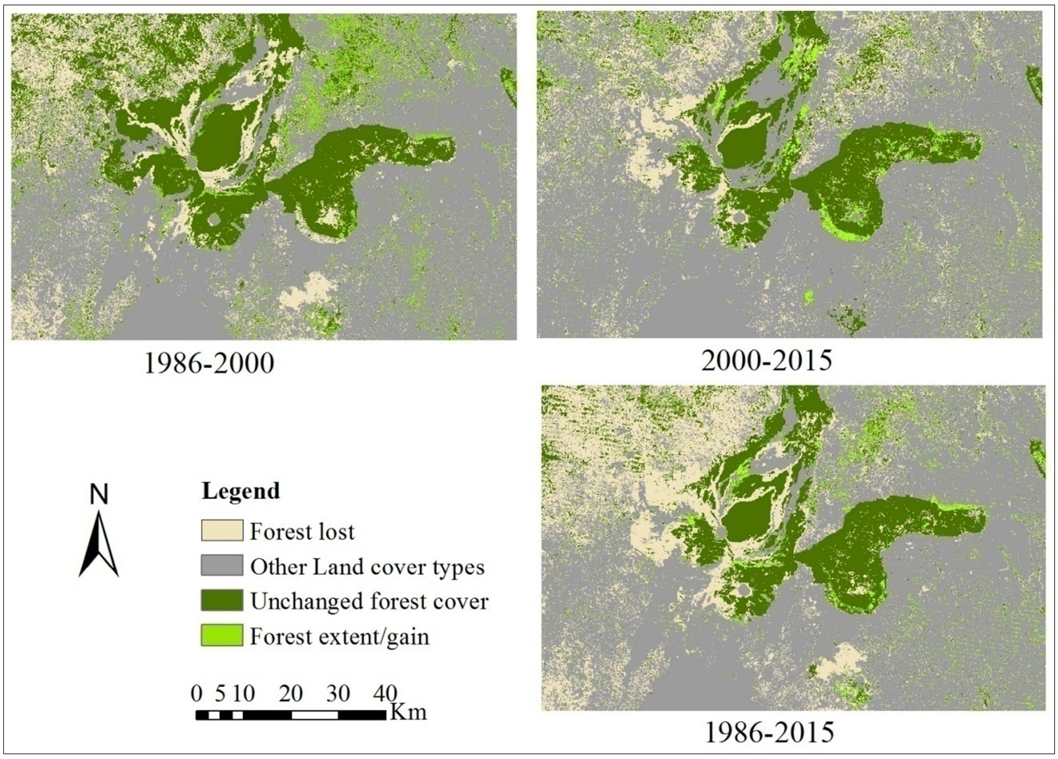

Figure 3. Forest cover change results, change in forest cover was quantified in the Volcanoes Parks region in the period of 1986-2000 and 2000-2015. Areas of Forest loss were depicted in tan color, Forest extent or gain was depicted in very light-green color.

Puyravaud's formula [31] provides a standardized method to calculate the net annual rate of change from forest cover data at different time periods to reduce confusion and misinterpretation where the annual rate of change abbreviated as "r" is extrapolated for each time period as follows

$$r = \left(\frac{1}{t2-t1}\right) \ln\left(\frac{A2}{A1}\right) \quad (3)$$

Where A1 and A2 are the cover area of forest at time one (t1) and time two (t2) respectively. The calculations show that from 1986 to 2000 the net annual rate of deforestation was approximately 1.9% (26 km^2/year) while approximately 1.8% (22.5 km^2/year) was afforested/reforested comparing to the period from 2000-2015 where the deforestation was approximately 1.79% (23.5 km^2/year) and the afforested/reforested was approximately 1.56% (14.56 km^2/year). The difference between the lost and gained forest in entire study period (1986-2015) have proven that the forest lost was approximately 487.9 km^2 (equivalent to 5%) higher than forest extended/gained. These results indicate that atleast 0.2% of forest cover area has been lost from 1986 to 2015 in the Volcanoes Parks region.

4. Discussion

Forest ecosystem in the Volcanoes Parks region experienced significant changes. The large loss occurred from the increase of intensive clear-cutting, large-scale forest decline in association with demographic pressures and climate change that exacerbated forest change in this region as main drivers. The findings of this study are consistent with World Bank's census data [32] regarding the forests cover change for each of the three countries spanning the volcanoes parks region. Our results showed that 31.140 km^2 forest decreased from 1990-2000 and 46.710 km^2 from 2000-2015 in the Democratic Republic of Congo (DRC) while in Uganda 8.820 km^2 forest was lost from 1990-2000 and 17.920 km^2 from 2000 to 2015.

Forest cover change detected in the Volcanoes Parks region has a reflection of change in the entire region (changes in these three countries) (Figure 3). Nevertheless, the drastic increase in population in this region is likely to be the main driver of deforestation and forest degradation. The population growth has almost been doubled in these years. Specifically, the population density which was 294 person/km^2 in 1986 grew up to 459.7 person/km^2 in 2015 in Rwanda, from 87 to 188.4 person/km^2 in Uganda and from 15.4 to 33 individual/km^2 in DRC [32]. Furthermore, the population density in Volcanoes Parks region and its surrounding landscape in 2006 was 600 person/km^2 [33] and is projected to proportionally increase in relation to these three country's population density. The increased population density boosted the gradual increase of urban and settlements therefore the demand for food and goods [34]. These factors accelerated the increase of deforestation and land conversions to agricultural lands. The deforestation practices are highly playing a crucial role in climate change; the most frequent disaster is soil erosion in high land zones. Thus, the soil erosion creates the open lands in high slope and steep lands [35]; this increases the variability of lands, transforming into open lands and agriculture through a process which interrupts the afforestation initiatives and efforts taken by each of these countries.

The examination of multiple time periods and the analysis of patterns across the volcanoes parks landscape highlighted a juxtaposition of forest loss and forest gain where in 1986-2000 the annual rate of gain was 1.8% and loss was 1.9% while during the period from 2000-2015, the annual loss and the annual gain were 1.79% and 1.56% respectively (Figure 3). The shift from loss to gain across the landscape shows great need of concern from all countries involved by establishing policies in tree plantation and harvesting cycling balances to eliminate imbalances between forest losses and gains as shown in this study. Forests act as source of subsistence resources such as firewood and timber which is usually needed in housing constructions and sometimes mistaken for free lands to be converted for agriculture as these countries' economy greatly relies on agriculture [36]. However, there is need of agreement on the harvesting procedures that should favor the forest sustainability, particularly such regions like Volcanoes Parks Forests. Examining the forest cover change in the region in further details would contribute to the assessment and verification efforts spearheaded by parks and surrounding landscape's forests conservation initiatives by policy makers and other stakeholders.

5. Conclusion

This study explored different land cover transitions, forest cover changes and quantified the extent and the magnitude of forest gains and losses during the two periods namely the conflicts period (1986-2000) and post-conflicts period (2000-2015) in Volcanoes Parks region using remotely sensed datasets. The results indicated that in the Volcanoes Parks region, the forest cover is gradually decreasing. Statistically, the forest cover decreased by 5.76% since 1986 through 2015, being converted into cropland and built-up areas as previously illustrated in Table 4. Based on the findings of this study, it is suggested to (1) strengthen the joint efforts among local governments, conservation practitioners and development agencies regarding the resiliency of this area and the dependencies on future investments on conservation, (2) identify appropriate protection and conservation mechanisms for the sustainability of forests ecosystems in countries in which the Volcanoes Parks are located, (3) safely and sustainably preserve the remaining forest areas against the high speed of deforestation through monitoring and improving awareness of population through sensitization on programs for sustainable use of environment and controlling population growth which has been highlighted as the main driver of deforestation and forest degradation and finally, (4) Volcanoes Parks forest sharing countries are encouraged to seek better energy alternatives other than wood related products uses.

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Authors' Contribution

Alphonse KAYIRANGA designed the research, processed data and wrote the manuscript; Alishir KURBAN supervised the research. Lamek NAHAYO and Felix NDAYISABA, provided technical assistance. All authors contributed to the completion of this research by bringing in the valuable ideas.

Conflict of Interest

The authors declare that they have no competing interests.

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