**Journal of Forests**
*2023 Vol. 10, No. 1, pp. 8-18*
*ISSN(e): 2409-3807*
*ISSN(p): 2413-8398*
*DOI: 10.18488/jof.v10i1.3378*


# Analyzing anthropogenic impact on Ibanda-Makera natural forest in Kirehe district

**Mory Vital Kalinda**[1]
**Pancras Ndokoye**[1,2+]
**Onesphole Ndagijimana**[1]

[1]*Faculty of Environmental and Development Studies, Department of Environmental Information Systems, University of Lay Adventists of Kigali, Kigali, Rwanda.*
[1]*Email: kalindamv2nd@gmail.com*
[2]*Faculty of Agriculture, Environmental Management and Renewable Energy, Department of Environmental Management and Renewable Energy, University of Technology and Arts of Byumba, Gicumbi District, Rwanda.*
[1,2]*Email: ipando2008@gmail.com*
[1]*Email: naones2013@gmail.com*


*(*Corresponding author)*

**Article History**
Received: 28 February 2023
Revised: 26 April 2023
Accepted: 10 May 2023
Published: 24 May 2023

**Keywords**
Deforestation
ERDAS and SPSS
Forest degradation
KIREHE district
GIS and Remote sensing
Land use change
Natural forest.

## *ABSTRACT*

Human pressure from farming activities on marginal lands, and on forest reserves in particular, have resulted in the loss of the large number of hectares of natural forests. This problem also occurred on Ibanda-Makera natural forest locating in Kirehe District, Eastern Province of Rwanda. In this study, we study anthropogenic impact on Ibanda-Makera natural forest. The identification of anthropogenic activities affecting Ibanda-Makera natural forest was done; their impacts on forest was analyzed; and the level of degradation in terms of forest cover of Ibanda-Makera was determined. The study adopted both qualitative and quantitative methods to collect data from a sample of 97 individuals in the target population of 3,330 people. Data were collected using questionnaire, interview guide techniques and documentation. Through SPSS analysis, Pearson correlation between anthropogenic activities and forest degradation, the results showed that people have an understanding on factors leading to the forest degradation and that land use activities surround the Ibanda-Makera area were not in way of protecting forest as priority. Change detection from analysis of 2012, 2017 and 2022 images under supervised classification using remote sensing data of Ibanda-Makera natural forest, showed spatial variation where degradation is high between 2012 to 2017 and low between 2017 to 2022 expressing that between 2017 to 2022 under some environmental guidelines the damaged area moved to the restoration mechanisms. The recommendation to government, regular monitoring of forest boundaries to prevent potential damages that may occur on the forest and set a local system of protection.

**Contribution/Originality:** The loss of forest products and services has been belonging to many factors. This paper results served as tool of policy makers as additional source of information of Ibanda-Makera natural forest regarding its forest landscape conservation under pressure of neighboring farming activities.

## 1. INTRODUCTION

Intensive human activities such as agricultural practices, animal husbandly, transport and communication, household activities, and mining have affected the microclimatic conditions, and led to overall environmental degradation [1]. Over exploitation of resources rendered crop production expensive, while the rearing of livestock and food processing exacerbated the decline of natural environment components such as wildlife, soil fertility and forests covers [2]. In the same sense, the land has been fragmented and other new ones have been cleared in a

response to pressure on the land [3]. Africa and worldwide currently require to double and reorganize sustainable development agenda, particularly to make it function in accordance with environmental sustainability principles [4]. The government of Rwanda (GOVR) is also concerned with the issue of integrating human activities in avoiding environment degradation (mainly Erosion and land degradation), as it is known that most of Rwandan live on carrying out agriculture (because most population live in rural area) activities or agriculture income [5].

In recent decade, the emphasis was placed on forest cover increase by governments and donors around the world [6]. Continent of Africa has endowed various forests ecosystem which provide a wide range of benefit to its population filled 31% of woodlands and 17% of the world's forests across region as well as in Sahel [7].

The forest cover in Rwanda was 29.8 % of national territory surface area both natural forests and planted, 11.9% and 17.9%, respectively. Greatest protected areas in Rwanda has been facing with the problem of fast-growing population (with the density getting up to 800 habitants/sq.km), and this is connected with firewood gathering, house construction, and illegal and legal trees harvesting [6, 8].

Kirehe district, as one of districts of Rwanda, has a total rate of forest cover of 17% by 2019 [9]. Besides, anthropogenic activities in Kirehe have been putting pressure on the environment, especially in Ibanda-Makera forests by seeking firewood, building trees, grazing domestic animals and even killing some wild animals; where Ibanda-Makera forest has lost 88% of its size during three decades ago [10]. These situations led our research to analyze the level of impacts from anthropogenic activities on forest by putting emphasis on Ibanda-Makera natural forests located in Kirehe District. This research covers the period of 10 years from 2012-2022.

## 2. MATERIALS AND METHODS

### *2.1. Description of Study Area*

This research was carried out in Kirehe District, Eastern province of Rwanda, at 133 km from Kigali (country's capital). The District of Kirehe has surface area of 1,118.5 km² and population of 401,575 comprised by 93,691 housed [11]. Ibanda-Makera natural forest is located in Kirehe District at the grid reference 260179E 9767347S and 262104E 9765251S. The total plot area is estimated at 169Ha [12]. The two forests, Ibanda and Makera constitute a complex made of a gallery forest of Ibanda located in the south and contiguous to the Akagera wetland, while Makera is located in the north on a hill of woodland and savannah vegetation in the eastern province. Ibanda-Makera covers an area of 168.88 hectares. A stream water called Nyamporogoma crosses the forest and is one of sources to water used by many local people. The papyrus swamp connected to the forest contributes to the reduction of water loss in forest land [10]. Figure 1 illustrates Ibanda-Makera natural forest in map of Kirehe Districy.

### *2.2. Methods and Techniques*

The present study is survey and correlative in natural, and adopted both quantitative and qualitative methods.

In this study 3,330 population were our targeted population, and were categorized into Farmers, Businessmen, Unemployed, and Others (Handcraft, Motorcyclists). A stratified random sampling technique was used where by the strata were composed those four subcategories and they were all coming from four villages surrounding the Ibanda-Makera forest, namely Nyawera I, Nyawera II, Pilote, and Mutwe villages, all in Nasho cell, in Mpanga sector, in Kirehe District. Farmers, Businessmen, Unemployed, and others (subcategories) were Purposively selected. A total sample size of 97 was calculated using Yamane Taro Table 1, as demonstrated in [13]. The formula is set as:

$$n = \frac{N}{1 + N(e)^2}$$

Where:

n is sample size.

N is the total population (and equals to 3,330).

e is the margin error which was be fixed at 10 percent.

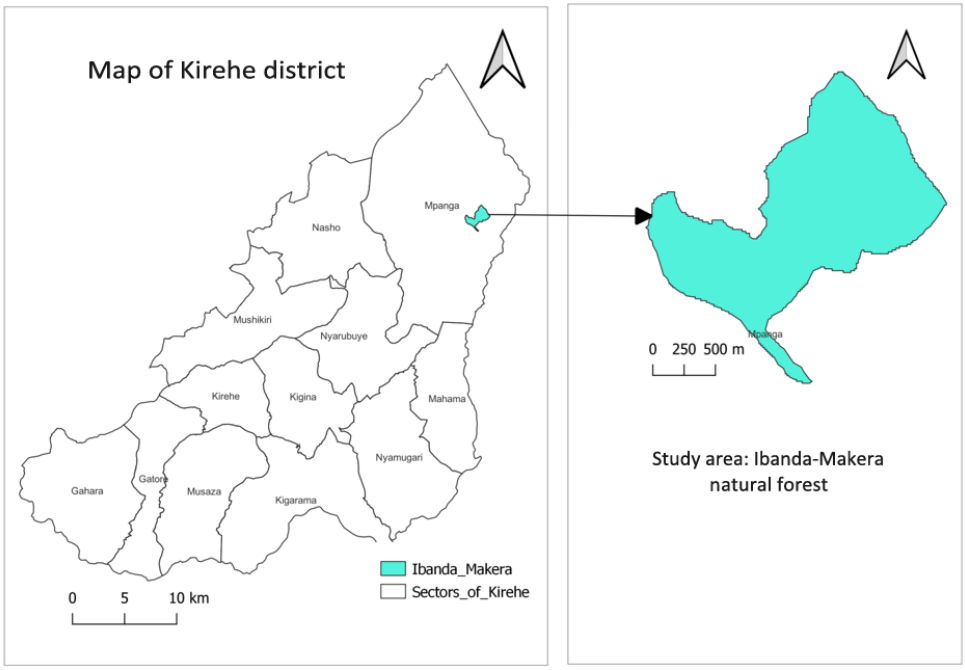


**Figure 1.** Location of Ibanda-Makera forests in Kirehe district.

**Table 1.** Displays the sample distributions based on both villages and population category.

| Villages | Population category | Population | Sample distribution |
|---|---|---|---|
| Nyawera I | Farmers | 346 | 10 |
| | Commercial | 128 | 4 |
| | Handcraft | 41 | 1 |
| | Unemployment | 25 | 1 |
| Nyawera II | Farmers | 434 | 13 |
| | commercial | 161 | 5 |
| | Handcraft | 51 | 1 |
| | Unemployment | 33 | 1 |
| Pilote | Farmers | 668 | 19 |
| | Commercial | 248 | 7 |
| | Handcraft | 73 | 2 |
| | Unemployment | 56 | 2 |
| Mutwe | Farmers | 681 | 20 |
| | Commercial | 253 | 7 |
| | Handcraft | 83 | 2 |
| | Unemployment | 49 | 2 |
| Total sample size | | 3330 | 97 |

Primary data were obtained using structure questionnaire administered to 97 people subdivided into their strata and villages Table 1, while secondary data linking to change in forest cover in Ibanda-Makera zone over the selected 10 years (2012, 2017, and 2022) have been gathered from three main sources, such as aerial photographs, spot imagery and aerial photograph maps of Kirehe district. Data were mainly analyzed using statistical package for social sciences (SPSS), Earth Resource Data Analysis System (ERDAS), and geographic information system (GIS). ERDAS imagine 9.2 and ArcMap 10.3 were used in data preparation for final meaningful information. Layer stacking followed by images sub-setting upon area of interest in order to quantify changes happened for three main land cover being natural forest, pasture and/or cropland and bare land within the study area. The results obtained from sample population were tested based on Pearson's correlation coefficient (r) whereas positive correlation

indicated the impact of anthropogenic activities (independent variables) and whereas negative correlation indicated that the impact of independent variable on forest degradation (dependent variables) and the Pearson's correlation decision:

0.75≤r≤1; very high correlation.

0.50≤r≤0.75; high.

0.25≤r≤0.50; low.

0≤r≤0.25; very low.

r=0; no correlation.

**Table 2.** Anthropogenic activities with its degradation impact perception.

| Anthropogenic activities | Frequency | Percent |
|---|---|---|
| Agricultural activities | 1 | 1.0 |
| Firewood and domestics materials | 4 | 4.1 |
| Mining | 0 | 0.0 |
| Grazing animals | 1 | 1.0 |
| Picking medicinal products | 7 | 7.2 |
| Picking the water or fodder | 3 | 3.1 |
| Footpaths to farm activities | 81 | 83.5 |
| Total | 97 | 100.0 |

## 3. THE RESULTS

### *3.1. Identification and Analysis Anthropogenic Activities Affecting Ibanda-Makera Natural Forest*

The Table 2 depicts the views of respondents on anthropogenic activities that may be affecting Ibanda-Makera natural forest. Clearly, more respondents rate of (83.5%) are standing to the foot movements of people in and around the forest are keys of degradation due to household needs may be found in forest, while the encroachments due to agricultural practices were at the level of only 1%.

**Table 3.** Negative impacts of anthropogenic activities on Ibanda-Makera natural forest.

| Negative impact | Frequency | Percent |
|---|---|---|
| Deforestation | 16 | 16.5 |
| Biodiversity loss | 9 | 9.3 |
| Habitat loss | 2 | 2.1 |
| Soil degradation and erosion | 1 | 1.0 |
| Increases of natural hazards | 2 | 2.1 |
| Lack of wood materials | 26 | 26.8 |
| Air pollution and climate variability | 41 | 42.3 |
| Total | 97 | 100.0 |

The results in Table 3 show the perception of local population near Ibanda-Makera natural forest on negative impacts from anthropogenic activities. More respondents are aware (42.3%) that movement of human in forest led to the climate vulnerability due to reduction of biodiversity (9.3%) especially deforestation (16.5%) and look for wood materials in households (26.8%). Soil degradation and erosion, natural hazards and habitat loss are the factor that are less recognized by respondents as negative impact of anthropogenic activity in Ibanda-Makera.

**Table 4.** Causes of degradation of Ibanda-Makera natural forest.

| Causes of degradation | Frequency | Percent |
|---|---|---|
| Changes in land uses for agricultural purposes | 7 | 7.2 |
| Infrastructure development | 2 | 2.1 |
| Households source of cooking energy | 10 | 10.3 |
| Unclear forest boundaries and other land tenure | 17 | 17.5 |
| Lack of human resources to monitor forests | 61 | 62.9 |
| Total | 97 | 100.0 |

The results in Table 4, more respondents (62.9%) are aware that lack of human resources to monitor forests is the key of forest degradation due to free entrance of humans in the forest and some of respondents put in cause the unclear boundary of the forest (17.5) increase the encroachments of forest boundaries mainly for the agriculture purpose (7.2%) or for cooking energy materials needs (10.3%). The respondents confirmed that infrastructures have low level on forest change.

### *3.2. Correlation between Anthropogenic Activity and Natural Forest Degradation Using Pearson's Correlation*

The Pearson correlation results has Pearson's correlation coefficient (r) whereas positive correlation indicates the impact of anthropogenic activities (independent) influenced either by increase or decrease of their intensity, and whereas negative correlation indicates that the impact of independent variable (anthropogenic activity) on forest changes (dependent variables) tend one's factors to increase and the others decrease. In addition, the "p" value and alpha "α" was used to determine where anthropogenic activities have significant impact on forest changes. Respect to the following conditions, at "p" value>alpha "α" anthropogenic activities has a significant change on forest degradation whereas at "p" value<alpha "α" anthropogenic activities has no significant changes on forest.

The following Table 5 illustrates the levels of degradation in terms of forest cover of Ibanda-Makera natural forest.

**Table 5.** Correlation between the causes of degradation and the forest restoration perception.

| Correlation | | The causes of forest degradation | The forest restoration | Anthropogenic activities that could be leading to the degradation | The negative impacts of anthropogenic activities |
|---|---|---|---|---|---|
| The causes of degradation | Pearson correlation | 1 | -0.486 | 0.751 | -0.476 |
| | Sig. (2-tailed) | - | 0.407 | 0.143 | 0.418 |
| | N | 5 | 5 | 5 | 5 |
| The forest restoration | Pearson correlation | -0.486 | 1 | -0.373 | 0.819 |
| | Sig. (2-tailed) | 0.407 | - | 0.536 | 0.090 |
| | N | 5 | 5 | 5 | 5 |
| Anthropogenic activities that could be leading to the degradation | Pearson correlation | 0.751 | -0.373 | 1 | 0.791* |
| | Sig. (2-tailed) | 0.143 | 0.536 | - | 0.034 |
| | N | 5 | 5 | 7 | 7 |
| The negative impacts of anthropogenic activities | Pearson correlation | -0.476 | 0.819 | 0.791* | 1 |
| | Sig. (2-tailed) | 0.418 | 0.090 | 0.034 | - |
| | N | 5 | 5 | 7 | 7 |

**Note:** * Correlation is significant at the 0.05 level (2-tailed).

### *3.3. Land Cover Change*

The satellite imagery analytics of Ibanda-Makera Land Cover (LC) 2012, 2017 and 2022 collected, from USGS (United States Geological Survey) and projected in Arc GIS to check if they are locally georeferenced. The classification of both images has been done using ERDAS Imagine 2015. The scheme classification had three (3) level where first classes (Table 6), was founded on the land use and land cover classification system established by Baynard [14] for interpretation of remote sensor data at numerous resolutions and scales.

**Table 6.** Land cover classification scheme.

| Land cover class | Description |
|---|---|
| Forest | Class composes of planted and natural forest within area |
| Grassland | This class is made of ground grasses or they have small height |
| Bare land | Class includes all types of free grass or forest or any other cover within study area |

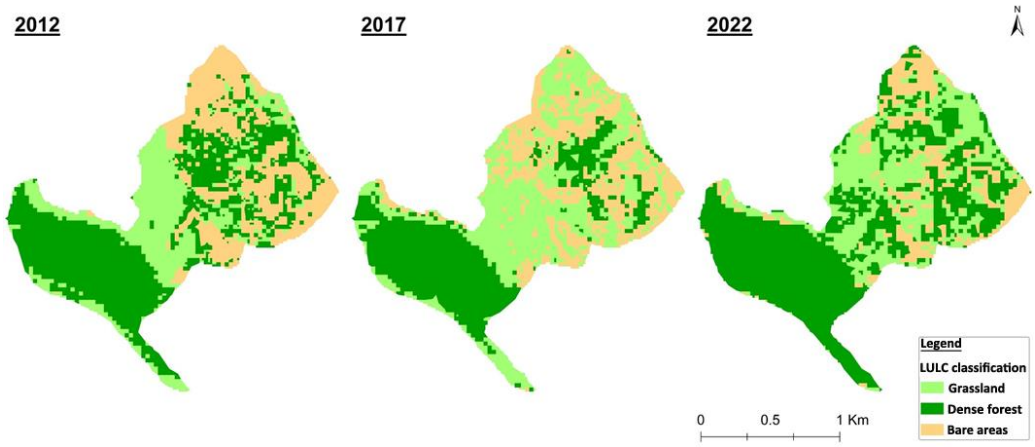


**Figure 2.** Classified images of 2012, 2017 and 2022 images in both false color and classified scheme colors.

Image of Ibanda-Makera LC 2012, 2017 and 2022 has been inserted in ERDAS 15 and multispectral band according to the class (in Table 6) were changed for sample point taking purpose. This has been done by zooming to extent that user may see, understand and reveal ground understanding according to the ground truth corrected. By using ERDAS for the Change detection of Land cover of Ibanda-Makera forest; the detection of change included the use of multispectral data sets for land cover change between dates of imaging. The detection procedures comprised analysis of sensor data, spatial resolution, viewing geometry, spectral bands, radiometric resolution and the time of day. Succeeding image pre-processing, multi-temporal thematic mapper (TM) images were post-processed to quantify the area of change and change rate, the spatial distribution of change types, change trajectories, and accuracy assessment of change detection results.

After detection change between Ibanda-Makera LC2012, 2017 and LC 2022 as in Figure 2; the classified images of Ibanda-Makera of 2012, 2017 and 2022 have been generated. Those are the products of analytic tool that ERDAS images provided to help user interact with the time series analysis of land cover changes. ERDAS comes into deep analysis where it exchanges various classes changes and produce finals extracted map of expected year in query. After spatial data visualization through colors, here there is a quantification analysis of each color and feature spatial statistical coverage.

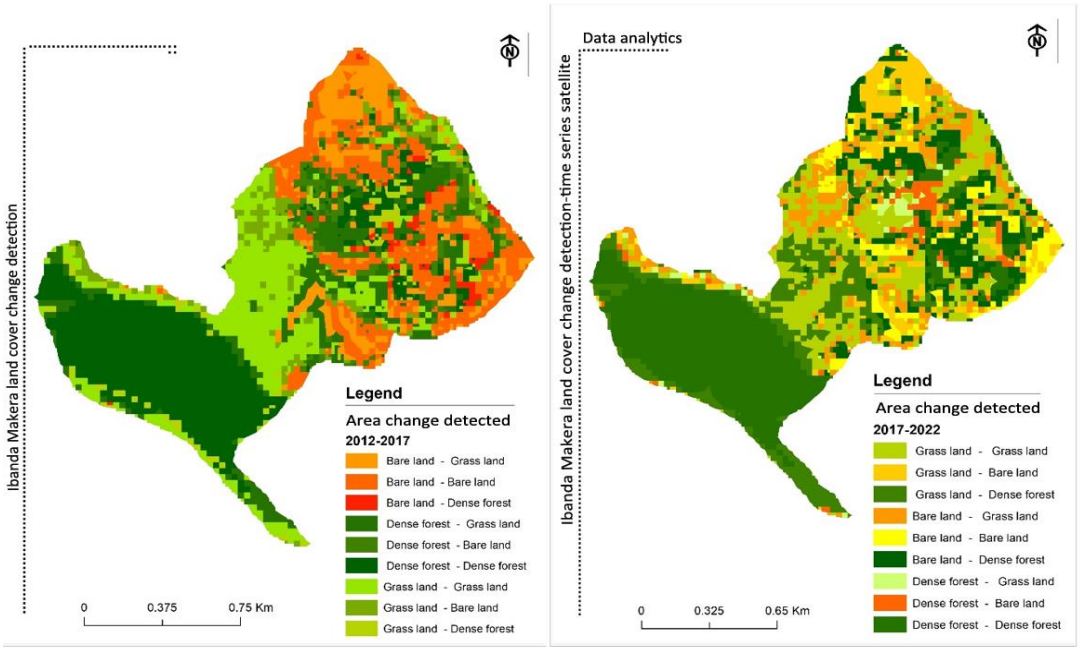


**Figure 3.** Changes detected from analysis of 2012 and 2017 and 2017 to 2022 images.

This map of changes detection in Figure 3; showed spatial temporal variation resulted made and may show clearly the impact made by dramatically and exponential increase of population towards deforestation of this natural forest. In general, the overall analysis was done under supervised classification using remote sensing data of Ibanda-Makera natural forest. Under environmental guideline done on natural resources, conservation, which is later, moved on forest restoration there was a set of proximity analysis, which is buffer. The analysis was made with intention of analyzing the land, which have been used for other activities. One of the activities to be analyzed was on the encroachment of agricultural activities that here we considered and classified it as grassland.

## 4. DISCUSSION

The Ibanda-Makera natural forest was known to contain many biodiversity habitat and various socio-economic aspects for community. Many years ago, the forest suffered from the facts of the presence of anthropogenic activities which in some aspects reading to the disappearance of many species due to destruction of their ecological niches and decline in richness ecological niches. The forest is surrounded by croplands and pastures farms. Figure 4 Illustrates the view of Ibanda-Makera natural forest landscape with its neighboring area.

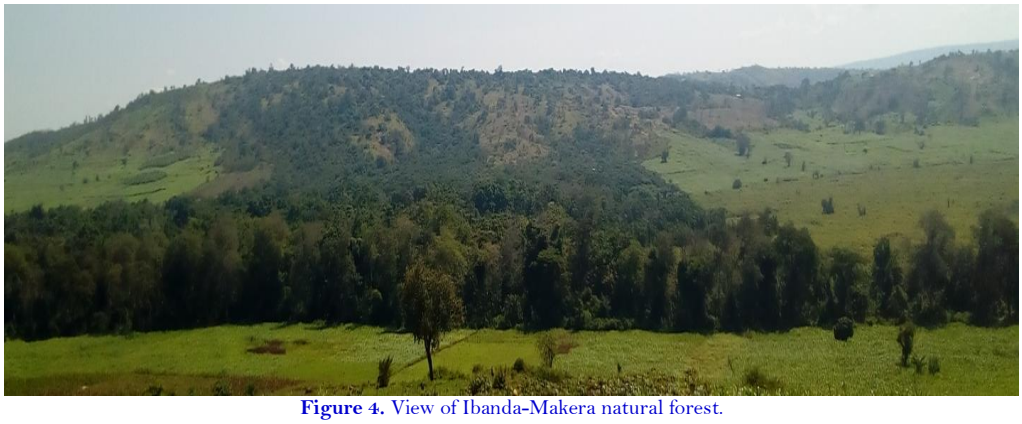

**Figure 4.** View of Ibanda-Makera natural forest.

**Figure 5.** Inside the Ibanda-Makera Natural forests.

Figure 5 Illustrates the view of some trees inside the Ibanda-Makera natural forest.

Based on anthropogenic activities that led to damage of Ibanda-Makera Natural Forest, the respondents strongly agree and agree, at 17.5% and 80.4%, respectively, that various activities done inside and neighboring area of natural forest affected the forest. The government policy of habitat in grouped settlement pattern led to develop two settlements (imidugudu) near the forest such Pilote settlement and Nyawera settlement. This increased the trend to access the forest looking for household's materials (firewood, timber, fodder) and some boundary

encroachments (Table 2). As results, forest changes were sorted out where in spatial analysis was considered an increase of grassland area from dense forest 2012 to 2017 (Figure 2).

### *4.1. Identification and Analysis Anthropogenic Activities Affecting Ibanda-Makera Natural Forest*

The forest disturbance was examined in this research through interview and image analysis. The factors as basis of forest degradation are belonging to socio-economic variables stressed by environmental variables and leading to loss of forest products and services. The Figure 6, expresses some activities exercised in forest leading to the degradation of forest. The main activities affecting the forest, at the 1st position, respondents mark Footpaths crossing the forest to farming zones (83.5%), firewood and domestics materials (4.1%) as listed in Table 2.

**Figure 6.** The presence of pathways across in forest.

As depicted in Table 2, 26.8% of respondents express that movements of local peoples in forest for illegal harvest of forest products led to the decrease of contribution of forest to the socio economic needs like timber with disappeared tree species as one of indicators (Table 3). Mitchard and Flintrop in their study [15] reported that illegal timber harvest and fire wood extraction are one of causes of forest degradation in Africa. Though, the same situation occurred in Ibanda-Makera natural forest. Wood still plays a major role in household human life, unfortunately, wood products are regarded as a major drive of deforestation. This kind of deforestation is confirmed by 16.5% of respondents (Table 3). As the wood is used in many different ways (fuel wood, timber, stakes in cropping), wood harvest is largely root cause of degradation through deforestation. Much of the wood used comes from plantation forests but where the natural forests exist a significant wood portion is extracted from there.

In Ibanda-Makera, even the forest is protected by law, the same threats occur due to the movement of local people in forest and make the forest vulnerable. Inside of Ibanda-Makera natural forest, there is also some spaces cleared for apiculture structures as exercises of people in forest considered in the present study to contribute in reduction of trees and vegetative cover in chosen spaces.

Figure 7 Illustrates the area in forest cleared for the apiculture purposes.

**Figure 7.** Tree clearance for apiculture structures in forest.

### *4.2. Negative Impacts of Anthropogenic Activities on Ibanda-Makera Natural Forest*

The Figure 6 and Table 2 represent some activities carried out in forest and this lead to the degradation of forest. Regarding the Table 2, a list of negative impacts caused by enthropogenis activities are ranked as follow:

a. Climate variability: 42.3% of respondents confirm that human activities destroyed the ability of Ibanda-Makera in influencing the climate as before (Table 3). In other words, it has been observed that prolonged drought is frequent in eastern regions where Ibanda-Makera zone is included. By this situation drought is often responsible for the famine, the reduction of animal and plant species. In some displacement of people in search of pasture and food. At this time also, the situation may lead to conflicts over different land uses such as protected area as Ibanda-Makera natural forest. This correlates with previous research report stating that the forest land degradation increases the disturbance in suitable micro-climate of are [16], resulting in people's instability.

b. Biodiversity loss: The deforestation does not only affect the regulating climatic services, but also the others are affected. As the forest is a shelter for several biological diversities, biodiversity loss may be often viewed as species loss from the ecosystem. Brancalion, et al. [17] reported on Rwanda tropical and biodiversity analysis that the country's biodiversity is well preserved in protected areas but highly endangered in unprotected ecosystems, mainly due to human pressure. Simon Lewis in the research, approved that forest degradation cause the biophysical changes [18]. Also, Ibanda-Makera is encroached and accessed by local community. Through the present study, the loss of biodiversity is recognized by 9.3% of respondents confirming that some tree species and wild animal's species have been disappeared under hunting or migration to Tanzania forests crossing Akagera river.

c. Habitat loss: as reported by respondents, lack of human resources to monitor forests and unclear forest boundary (Table 4) lead to various forest threats such as loss of favorable habitat for wild life as confirmed by respondents at the level of 2.1% (Table 3). By penetration of human in forest, he transformed the habitat environment for various biodiversity. This was sped up mainly by encroachment for agriculture activities, look for grass fodder and forest products for household purpose (Table 2), therefore, farming activities and households forest needs contribute to habitat change [19]. Through the changes, only resistant species adopt modifications while others subtitle the location.

d. Soil degradation and erosion: The reduction of vegetative cover in the forest indicates that the forest soil is endangered. Damage of forest soil represents the loss of physical soil body. In this situation, some forest community loss their ecological niche. The tree cutting leads to reduction of non-timber profits in landscape like wind break and pollination. In Ibanda-Makera, the respondents considered this kind of degradation at the level of 1% (Table 3); as stated by Nkonya, et al. [20], the changes in vegetative cover increase the soil degradation and have detrimental on livelihood.

e. Lack of wood materials: 26.8% of respondents express that movements of local peoples in forest for illegal harvest of forest products led to the decrease of contribution of forest to the socio economic needs like timber through disappeared tree species (Table 3). Mitchard and Flintrop in their study, reported that illegal timber harvest and fire wood extraction are one of causes of forest degradation in Africa. Though, the same situation occurred in Ibanda-Makera natural forest [15].

### *4.3. Correlation between Anthropogenic Activities and Forest Degradation on Ibanda-Makera Natural Forest*

In our country (Rwanda), the high people rate in rural area rely on wood products for the social development life [21]. The dependency on wood products creates tough conflicts between human and forest environment. As the population growth increase, the woody products demand increases. Thus, there is a severe gap between forest production and population meaning that the wood demand factors drive forest degradation. In the present study, the relationship between human activities and land forest sustainability has put out the reactions in terms of

correlation. That correlation has been measured through Pearson's scale, where, the Pearson correlation between anthropogenic activity level and the forest degradation level was r=-0.486; very low correlation (here, the negative correlation indicate the decreasing relationship between anthropogenic activities and forest degradation) and the *p* value= 0.407 at α=0.05 whereas *p* value >alpha "α" had significant change; this is due to the Government mechanisms to protect forests where any crime to damage forest is endorsed by a punishment. Noting that in Ibanda-Makera natural forest, human activity is outlaw and any activities inside the forest are done illegally. It is in this regard the local people are aware about the impact of on Ibanda-Makera forest degradation. This was confirmed by Pearson correlation about observations between anthropogenic impacts on forest that could lead to the degradation where r= 0.751 (with the range of $0.75 \leq r \leq 1$) expressing high correlation and where p value = 0.143 and α=0.05 showing that p value>alpha "α" (expressing significant difference).

## 5. CONCLUSION

The study on the analysis of anthropogenic impact on Ibanda-Makera natural forest in Kirehe district, Rwanda, was successfully conducted. Conclusively, the findings proved that main activities undertaken inside and outside the forest and exposing the forest to degradation, are farming activities (animals grazing and growing crops), non-timber products and looking for firewood, as the energy source. Anthropogenic activities have led to Ibanda-Makera natural forest degradation compared to the physical consideration in period of 2012-2022. Using Pearson correlation between anthropogenic activities and its negative impacts, Ibanda-Makera natural forest degradation is a quiet mean of degradation, while satellite imagery analysis of Ibanda-Makera Land Cover (LC) 2012, 2017 and 2022 shows negative impacts observed in a period ranging 2012-2017 while the period ranging 2017-2022, though measures and mechanism have been implemented to restore the natural forest patterns.

**Funding:** This study received no specific financial support.
**Competing Interests:** The authors declare that they have no competing interests.
**Authors' Contributions:** All authors contributed equally to the conception and design of the study.

## REFERENCES

[1] D. K. Maelle and B. A. Oghenerobor, "Effects of human activities on forest resources in the crystal mountains of gabon," *African Journal of Science, Technology, Innovation and Development*, vol. 4, no. 4, pp. 205-232, 2012.

[2] M. Brown and A. K. Hughes, "Is land tenure "secure enough" in rural Rwanda?," presented at the 2017 World Bank Conference on Land and Poverty, 28, 2017.

[3] T. F. Tsuma, "Human impact on forest resources: A case study of Mukogodo Forest, Laikipia District, Kenya," Doctoral Dissertation, University of Nairobi, Kenya, 2004.

[4] T. Kuhlman and J. Farrington, "What is sustainability?," *Sustainability*, vol. 2, no. 11, pp. 3436–3448, 2010. https://doi.org/10.3390/su2113436

[5] GoR, "Republic of rwanda ministry of lands and forestry Rwanda national forestry policy 2018," Retrieved: https://www.environment.gov.rw/fileadmin/user_upload/Moe/Publications/Policies/Rwanda_National_Forestry_Policy_2018__1_.pdf. 2018.

[6] J. D. Ndayambaje, "Impact of 2003-2015 forest cover changes on trees diversity in Gishwati landscapes," Retrieved: http://dr.ur.ac.rw/bitstream/handle/123456789/1226/final%20year%20thesis.pdf?sequence=1&isAllowed=y. 2018.

[7] R. Ariana, "An action plan for world bank engagement: Forests, trees, and woodlands in Africa,73026," Retrieved: https://www.profor.info/sites/profor.info/files/Africa-Forests-Trees-ActionPlan_0_0.pdf. 2016.

[8] UNEP, "Completion of technical assistance in environment and natural l resources management Akagera Upper catchment (Naku) 26/11/2020 catchment management plan," Retrieved: https://rema.gov.rw/fileadmin/user_upload/Nile_Akagera_Upper_catchment_Integrated_Pollution_Management__Plan-Final__Jan._2021_.pdf. 2020.

[9] MoE, "Rwanda forest cover mapping. November, 235," Retrieved: https://www.environment.gov.rw/fileadmin/user_upload/Moe/Publications/Reports/Forest_cover_report_2019.pdf. 2019.

[10] REMA, "Study to establish a national list of threatened terrestrial ecosystems and species in need of protection in Rwanda. In REMA," https://doi.org/10.7810/9780908321735_2, 2015.

[11] T. Ntaribi and D. I. Paul, "The economic feasibility of Jatropha cultivation for biodiesel production in Rwanda: A case study of Kirehe district," *Energy for Sustainable Development*, vol. 50, pp. 27-37, 2019. https://doi.org/10.1016/j.esd.2019.03.001

[12] N. S. Joram *et al.*, "Eastern gallery forest conservation project biodiversity survey a final research report," The RUFFOR Small Grants Fundandation, May, 2010.

[13] V. Agrasuta, "The adoption of green dentistry among dentists in Thailand the adoption of green dentistry among dentists in Thailand," A Dissertation Submitted to The University of Manchester for the Degree of ResearchGate, September, 1–58. https://doi.org/10.13140/RG.2.1.3355.4403, 2013.

[14] C. W. Baynard, "Remote sensing applications: Beyond land-use and land-cover change," *Advances in Remote Sensing*, vol. 2, no. 3, pp. 228–241, 2013. https://doi.org/10.4236/ars.2013.23025

[15] E. T. Mitchard and C. M. Flintrop, "Woody encroachment and forest degradation in Sub-Saharan Africa's woodlands and savannas 1982–2006," *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 368, no. 1625, p. 20120406, 2013. https://doi.org/10.1098/rstb.2012.0406

[16] J. C. Rodríguez and C. Sabogal, "Restoring degraded forest land with native tree species: The experience of "Bosques Amazónicos" in Ucayali, Peru," *Forests*, vol. 10, no. 10, p. 851, 2019. https://doi.org/10.3390/f10100851

[17] P. H. S. Brancalion *et al.*, "Global restoration opportunities in tropical rainforest landscapes," *Science Advances*, vol. 5, no. 7, pp. 1–12, 2019. https://doi.org/10.1126/sciadv.aav3223

[18] S. L. Lewis, D. P. Edwards, and D. Galbraith, "Increasing human dominance of tropical forests," *Science*, vol. 349, no. 6250, pp. 827-832, 2015. https://doi.org/10.1126/science.aaa9932

[19] L. Nahayo *et al.*, "Agricultural impact on environment and counter measures in Rwanda," *African Journal of Agricultural Research*, vol. 11, no. 25, pp. 2205-2212, 2016. https://doi.org/10.5897/ajar2016.10899

[20] E. M. Nkonya, A. Mirzabaev, and J. von Braun, "Synopsis, economics of land degradation and improvement: A global assessment for sustainable development," International Food Policy Research Institute (IFPRI). No. 90, 2015.

[21] O. Nishimwe, N. Hakizimana, L. Nahayo, A. Maniragaba, and T. Nirere, "Relationship between human activities and deforestation in Karongi District of Rwanda," *Journal of Forests*, vol. 8, no. 1, pp. 1-12, 2021. https://doi.org/10.18488/journal.101.2021.81.1.12