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Assessing the Influence of Land Use, Forest Management, and Conservation on Forest Disturbance Dynamics

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-ABSTRACT

Forest disturbances play an important role in maintaining forest ecosystem functioning and heterogeneity. However, human action can change disturbance dynamics through changes in land use, forest management and conservation. Understanding the influence of human interventions on the disturbance dynamics is crucial for developing sustainable forest management schemes. To our knowledge, to date, there are only a limited spatio-temporal approaches used in assessing forest disturbance dynamics. This paper intends to address the question on how land use, forest conservation and management, affect the spatial and temporal patterns of forest disturbances in Zimbabwe's Eastern Highlands. Satellite imagery (Landsat) can aid in increasing the understanding of forest disturbance dynamics through analysis of sufficiently long time series forest data. Analysing of the time series forest data, covering a gradient of land uses, management and conservation regimes, will enable assessing the influence of human interventions to forest disturbance dynamics. The results of this research will help in developing a nationwide forest monitoring system and shed light on the complex dynamics of Zimbabwe forests.

Keywords: *Conservation, Forest disturbance dynamics, Land use, Satellite imagery,*

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INTRODUCTION

Disturbances are any event either natural or human-induced (anthropogenic), that changes the existing condition of an ecosystem. Disturbances in forest ecosystems affect resource levels, such as soil organic matter, water and nutrient availability, and interception of solar radiation. Changes in resource levels, in turn, affect plants and animals over time(Binelli et al., 2000, 2004). Disturbances often act rapidly and with great effect, to change the physical structure or arrangement of plants and animals in an ecosystem. Disturbances can vary in intensity and duration, but generally, include the following: fires, landslides, wind, and volcanic eruptions, outbreaks of insects, fungi, and other natural disasters(Dale, 2001).In addition, human induced disturbances such as logging, pollution, the clearing of land for urbanization or agriculture, and the introduction of invasive and alien species (Knorn et al., 2012) also affect forests. It is also important to note that not all forest disturbances are destructive or negative to the overall forest ecosystem (Yamamoto, 2000). Disturbance shapes the long term structure, composition, and function of composition, and function of most ecosystems and landscapes (Foster et al., 2003).

Zimbabwe is still fairly wooded with 66 percent of the country's land area being under various woodland types (MMET, 1998). Only 27 percent is under cultivation and the remainder being under other forms of landcover such as grasslands, wooded grasslands and exotic plantations.The key forms of disturbance that occur within Zimbabwean forests are natural disturbances (primarily wildfire during the burn season from September-November) and human disturbance (primarily land clearing for agriculture and settlement). These disturbances have resulted inZimbabwe's recent forest lost and gain being highly associated with human activities (Jansen et al., 2008). However, effective forest management and conversation has also contributed to forest growth. (Binelli et al., 2000). The availability of Landsat images and advances in Geography Information Science (G.I. Science) and Geography Information Systems (G.I.S computing technologies) have paved the way for broader and more innovative applications of Landsat data for forest monitoring (Masek and Healey, 2016, Verbesselt et al., 2012). Landsat data has proven robust for estimating the area affected by forest change processes (Masek and Healey, 2016).For example Hansen et al. (2008) noted that to overcome limitations of historical data availability and acquire more detailed information of the Earth's land surface, medium resolution satellite images (i.e., 30–80 m pixel size) such as Landsat TM and Landsat MSS, with greater spatial accuracy but lower revisit cycle, have been used for mapping and monitoring land cover and its changes.

To date, there has not been any robust remote sensing-based approaches developed to assess forest disturbance dynamics in Zimbabwe. This is despite the fact that the country has a parastatal mandated to forestry management: The Forestry Commission. At most they have only managed to map the different land uses and land covers of Zimbabwe. Thus, there is a clear need to develop robust GIS and Remote Sensing based approaches for use in forestry disturbance mapping and management.The results of this research will help in developing a nation-wide, GIS and Remote sensing-based forest monitoring system, and shed light on the complex dynamics of Zimbabwe forests.

Study Area

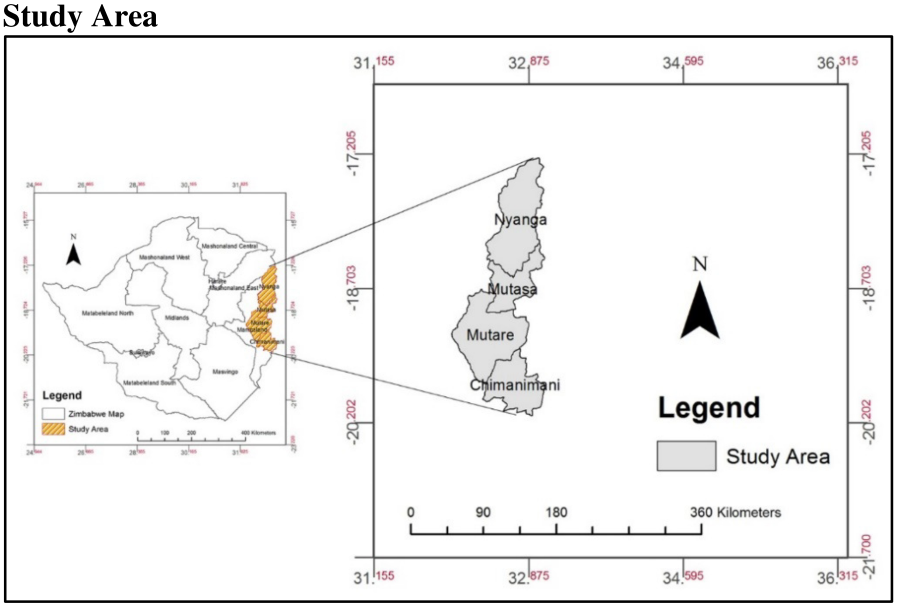

Figure 1: Map showing the Zimbabwean Eastern highlands (shaded study area).

The eastern border of Zimbabwe is majorly dominated for approximately 301 kilometres by hills and mountains that form the edge of the central plateau (Phipps, 1962). They are known collectively as the Eastern Highlands. They extend from 18.7230° S to 32.8420° E. The northern region is characterised by montane forest-grassland of Nyanga National Park. It is wetter than the surrounding areas as a result of higher rainfall. This high rainfall is as a consequent result of the low cloud cover, early morning mist and heavy dew. These conditions result from the high land forcing the moist ocean air masses from the southeast to rise and cool and fall as rain, or forms low clouds from which forest vegetation can extract moisture. The annual rainfall in the region is highly variable, from 741 mm to 2,997 mm per year with east-facing slopes receiving higher rainfall than those facing west (Timberlake, 1994b). Most of the rain falls in the summer months from November to April, while the months from May to July are drier. The annual mean temperatures range from a minimum of 9° C to 12°C to a maximum of 25° C to 28° C. (Phipps, 1962). Mutare is the capital of the region. It is close to the Mozambique border. It is characterised by and array of land uses and economic activities. These include being the industrial centre for the region which is dominated by forestry activities, including saw-milling, paper and furniture, leathertanning from the wattle plantations, tourism, and specialized agricultural crops such as tea and coffee.

METHODOLOGY

Image Classification of Landsat satellite imagery from 2000 to 2016 using the Random Forests was done to identify different land cover types and land uses influencing forest disturbance dynamics in the Eastern Highlands of Zimbabwe.The images were also classified for distinction and quantification of gains or losses of acreage on different land uses most importantly the forested area. Land Change Modelling (LCM) was done in IDRISI for assessing the influence of land use, forest management and conservation on forest disturbance dynamics in the Zimbabwean Eastern Highlands. Land change modelling was employed for change analysis and production of change maps as well to determine the influence of different anthropogenic activities on the forest dynamics. The satellite imagery used was acquired from Earth Explorer website (https://earthexplorer.usgs.gov/).

Image Acquisition

Landsat satellite imagery at a resolution of 30 m of 2000to2016was used for land use/cover classification and forest dynamics modelling. The satellite data covering study area wasdownloadedfrom earth explorer site (http://earthexplorer.usgs.gov/). These data sets wereimported intoIDRISI Selva, a satellite image processing software The Government/ Data Provider Formats option under the IDRISI data import function was used to import Landsat imagery band by band into IDRISI. The Composite panel which is an image compositing utility under the Display function was used to generate the false colour composition (FCC)for the study areas. The sub-setting of satellite images was done for extracting study area from both images by taking geo-referenced out line boundary of Zimbabweand perform a raster clip of the Eastern Highlands as the Region of Interest (ROI).

Image Correction and Enhancement

The Landsat satellite imagery was corrected for atmospheric and cosmetic effects using IDRISI. ATMOSC is an image correction module in IDRISI which performs calculations necessary to correct remotely sensed images for atmospheric and cosmetic effects.The satellite imagery was enhanced for clarity and detailed information. There are several methods of enhancement in IDRISI which include Stretch, Filter and Pan sharpening. Pan sharpening technique was used. It uses a high-resolution panchromatic image to increase the spatial resolution of low-resolution multispectral images.

Image Classification - Random Forests using Image RF

A non-parametric based classification technique calledRandom Forests was usedfor the land use/cover classification.An open-source software called EnMap Box houses ImageRF which is an IDL based tool for the supervised classification and regression analysis of remote sensing image data. It implements the machine learning technique of Random Forests (RF) (Jakimow, 2011)that uses multiple self-learning decision trees to parameterize models and apply them to satellite imagery for estimating categorical or continuous variables.

First, the Random Forest Classification (RFC) model was parameterized using a reference data set for training and internal validation. The result was then stored as *.rfc file. This made the model independent of the current working session. In a second step the model was applied to the satellite image to perform an image classification. Accuracy assessment was then carried out as the final step where observed estimations are compared with an independent validation set.

The study area was classified into five land use/cover types namely, (i) forested area (ii) reserves or conservations (iii) water bodies (iv) built-up land (v) agricultural land.

Table. 1: Land use classes and description

Land Cover Type	Description	Effects on Forest Dynamics
Forested: Montane forest Savannahforest (Miombowoodlands) Open woodland Montane grassland	A large area covered chiefly with trees and undergrowth. • a type of forest that consists a completely closed canopy of trees that prevents penetration of sunlight to the ground and discourages ground-cover growth. • an area covered with sparsely populated trees and more shrubs. • an area covered with trees with an open canopy due to spaced trees. • a large open area of covered with grass, with few sparsely distributed trees and shrubs.	
Reserve	A large area of land set aside as a protected area for wild life i.e., wild plants and animals.	Encourages forest growth since reserves face minimal anthropogenic activities.
Water body	A body of water forming a physiographical feature, for example a lake, dam or a reservoir.	Encourages forest growth by the supplementation of water in dry seasons.
Built-up	An area densely covered by buildings i.e., residential and or industrial buildings.	Discourages forest growth due to land clearing for urban expansion.
Agricultural Land	Land devoted to farming activities i.e., crop growing, plantation farming and or animal husbandry.	Discourages forest growth due to land clearing for agricultural land expansion.

Land Change Modelling and Analysis

Land Change Modeller for Ecological Sustainability is an Environmental modelling module in IDRISI. It was used for primary analysis of the influence of the different land uses and conservation schemes on the forest structure of the Zimbabwean Eastern Highlands. Land Change Modeller has got requirements before inputting data and obtaining results. It required that: (a) the legends from image classification in both maps are the same, (b) the categories or land use classes in both maps are the same and sequential,

(c) the backgrounds in both maps are the same and have a value of zero (black background) and (d) the spatial dimensions including resolution and coordinates are the same.The gains, losses and net change especially in the forested areas of the study areas depicted the influence of the associated land uses and conservation schemes on the forest disturbance dynamics.

RESULTS

Classified Land Cover Maps

Using Random Forests image classification techniques, land cover maps were produced. The maps showed seven different representative land cover types for years 2000, 2005, 2011 and 2016. The land cover types are water, bare ground, built up areas, plantations (representative of agriculture in the Eastern highlands), montane forests, savannah forests and grasslands.

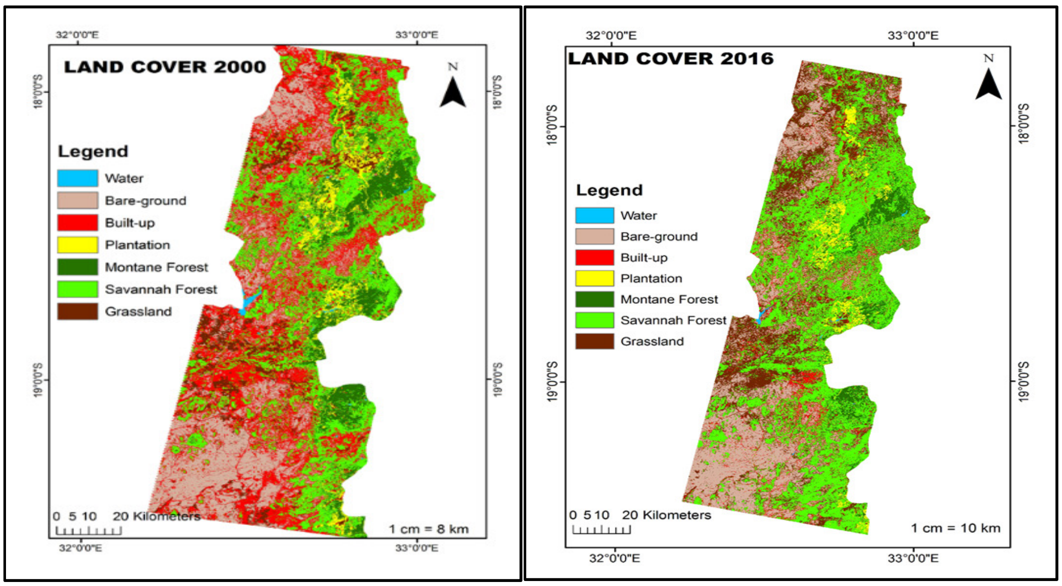

Figure2: Land Cover maps for Eastern Highland in 2000 and 2016 respectively.

Table 2: Land cover types for Eastern Highlands and respective area in hectares (2000, 2005, 2011 and 2016

Land Cover Type	Area (ha) 2000	Area (ha) 2005	Area(ha) 2011	Area (ha) 2016
Water	3120.3	2808.72	2808.72	1568.97
Bare ground	188228.34	160917.12	160917.12	161209.3
Built-up	283784.67	312006.27	312006.27	313784.21
Plantation	51172.85	56461.26	56461.26	60823.04
Montane	101928.78	79053.39	79053.39	59641.56
Savannah	264809.61	241033.17	241033.17	260364.62
Grassland	57209.49	103886.35	103886.35	131430.73

Accuracy assessment

The choice of image classification technique was motivated by the high levels of accuracy in image classification obtained using the RF technique. An estimated average of 98.55% kappa statistic was obtained after classifying all four satellite images. The table below shows class error for each image classification

Table 3: Confusion Matrix 2000 image classification accuracy assessment

Confusion Matrix	1	2	3	4	5	6	7	Class Error
1	217	0	0	0	0	0	0	0.000000000
2	0	249	1	0	0	0	0	0.204000000
3	0	0	213	0	0	0	1	0.264672897
4	0	0	0	269	1	0	0	0.333703704
5	0	0	0	0	252	0	0	0.137787401
6	0	0	0	0	0	244	0	0.000000000
7	0	0	0	0	0	0	262	0.000000000

The OOB error rate estimate was 1.102922268% and kappa statistic for 2000 was**98.9%.** The OOB error rate estimate was 2.12712936% and kappa statistic for 2005 classification was**97.8%.** The OOB error rate estimate was 1.12712936% and Kappa statistic for 2011 was **98.8%.**TheOOB error rate estimate1.11246291% and Kappa statistic for 2016 classification was **98.7%**

Land Cover Change Analysis

The study was mainly focused on establishing the influence of land uses and forest management and conservation on the forest disturbance dynamics. This is providing scientific evidence on whether a specific human interaction can result in negative disturbance (forest loss) or positive disturbance (forest gain). The forests being assessed was divided into two classes namely montane forests and savannah forest and grasslands were another natural ecosystem of interest. Therefore, the resultsprovide a pictorial and graphical depiction of the gains and losses of forests over a time line of sixteen years.

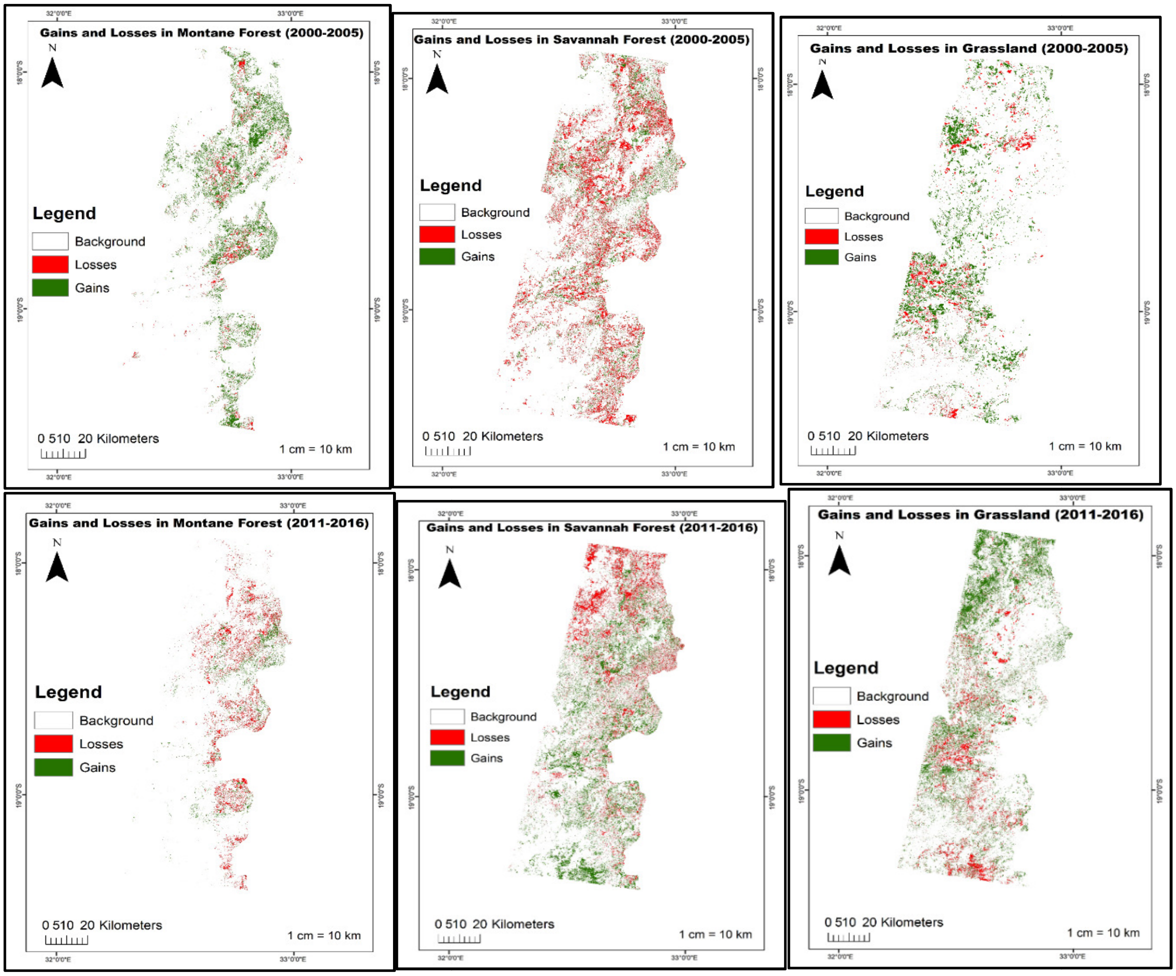

Figure 3: Map showing the Gains and Losses of the land classes.

Land Change Dynamic Trend Analysis

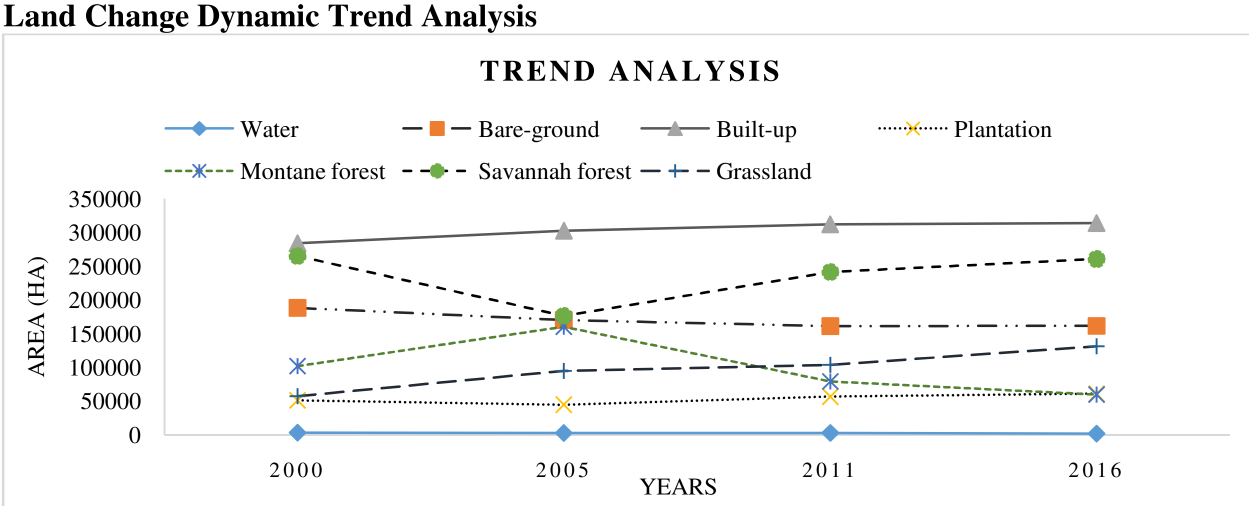

Figure4: shows the land change dynamics trend.

The land change trend shows that with increasing anthropogenic interference such as plantation farming and urban development fragile ecosystems such as the Montane Forest decline. This illustrates how human activities have a negative disturbance to the Eastern highland's forests. As a result of the decline of Montane forests which exhibits tropical rainforest-like characteristic, savannah forests and grasslands begins to expand showing how forests can influence their own dynamics. This is because the Montane forests' dense canopy is reduced allowing dispersed tree growth and also allowing undergrowth of grasses and shrubs which make up the savannah forests.

DISCUSSION

This study was testing for relationships between several anthropogenic activities (land use, forest management and conservation) and forest disturbances. And we found out that there are relations between several land use activities and the corresponding forest disturbance. Figure 2shows the changing trend of different forest types depending on the several land uses. We saw a decrease in the montane forest with an estimated 80 980 ha and 19 411.83 ha between 2005 – 2007 and 2011 – 2016 respectively as a response to an increase in the plantation farming with a net increase of 16 169 throughout the study area between 2005 and 2016. This therefore reflects how plantation farming is a major cause of negative disturbance in the montane forests ecosystem adjacent to the plantations thereby shaping these forests throughout the study region. Figure 4 shows the quantitative evidence of plantation farming being a major contributor of the gains and losses in the montane forest ecosystem. However, plantation farming being the major contributor in the changes of the montane forests human activities such as urban development also significantly to the gains and losses in the montane forest ecosystem. The study also found out that forest ecosystems are responsible of shaping each other. This is shown by the increasing savannah forest by an estimated 83 878 ha as a response to the decreasing montane forest. Figure4 also shows a quantitative analysis attributing the increase in savannah forest to the decrease in the montane forests. This is because as the close canopy ecosystems (montane forest) decrease undergrowth is allowed leading to the development of savannah ecosystems characterised by an open canopy structure and undergrowth of shrubs and grasses. Figure 4shows a trend analysis a negative relationship between the montane and savannah forests. The results of the study also show that with the increased growth of savannah forests, grasslands have also significantly grown (74 220 ha)also attributing these major changes to the montane forest decline.

The second hypothesis of the study tested for differences in disturbances and recovery schemes among different land uses and conservation practises. The study shows that with respect to different land uses forests experience different disturbances. Forests adjacent to plantations were experienced and complete turnover of land use with forested land turned into agricultural land. This type of disturbance has a permanent effect on the forest which is forest decline.

However, forests in conserved areas (Bunga Forest Botanical Reserve and neighbouring Bvumba Botanical Garden in figure 5) were affected by the changing dynamics of the forest structure butthese disturbances resulted majorly in forest conversion from a montane forest ecosystem to a savannah forest with minimal forest loss.

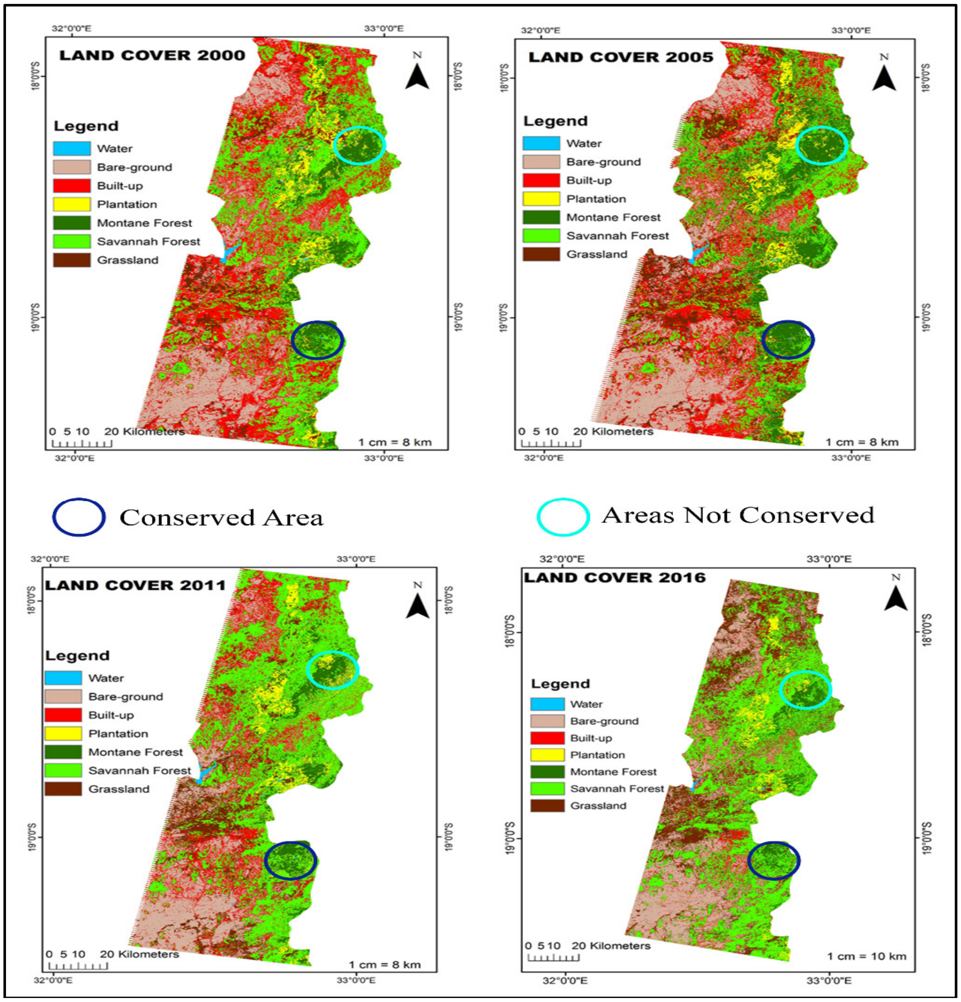

Figure5: Influence ofhuman activities on conserved areas.

This reflects how Reserves and Conservations protects the natural forests from human activities and encourages forest recovery and regrowth in case of any disturbances.

Similar to Chappie (2015) presentation the research finds out that anthropogenic activities such as agriculture interacts with well-established but fragile forests such as the Montane Forests of the Eastern Highland to cause negative disturbances. A partial decline of these closed canopy forests then paves way to the succession of Savannah forest especially under conducive climatic conditions. This is highlighted in the research by a corresponding increase in the acreage covered by the grasslands and savannah forests as a result of the decline of montane forests due to urban development and plantation farming. In agreement to Martínez-Ramos et al. (2016) the research identifies how different land uses cause different disturbance dynamics and how protected areas experience more of natural disturbances as compared anthropogenic disturbances encouraging forest growth.

For an accurate and robust forest disturbances monitoring system data for variables such as population information, urban development rates, agricultural land expansion rates must be incorporated. A system that provides a clear linkage of these variables and disturbance dynamics can help in monitoring the forest change.This is because these are the major anthropogenic factors which influence forest disturbance dynamics. A locally-based integrated system or software that incorporates the variables listed above must be developed. This enables predicting the change transitions of the Zimbabwean forests basing on the major influences of forest disturbances.

CONCLUSION

The major objective of the research was to analyse and map forest disturbance using Landsat Satellite Images across the Eastern Highlands of Zimbabwe so as to establish a relationship between anthropogenic activities and forest disturbance dynamics and assess differences in disturbance characteristics between different land use, management, and conservation categories. Conclusions derived from the research are:

1. The is a positive relationship between anthropogenic activities and forest disturbance. Increase in human influence by means of development and land use expansion results in an accelerated decline of fragile forests (negative disturbance). However, forest conservation and management as a positive disturbance on forest and minimal influence from anthropogenic activities.
2. Different land uses have different disturbances to forest, urban development and agriculture can result in permanent decline of forest while forest management schemes can result in forest conversion and partial decline allow forest regrowth and succession.

Conclusively forest conservation schemes with minimal human interaction are important in preserving native forests across the country for future generations since they facilitate forest regrowth and succession in a case of negative disturbance.

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