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‘‘SPATIO-TEMPORAL EVALUATION OF LAND COVER CHANGE & HABITAT FRAGMENTATION USING GEOSPATIAL TECHNIQUES AND LANDSCAPE METRICS.”

The Case of Akagera National Park, Rwanda

Thesis submitted to the University of Rwanda: College of Science and Technology in partial fulfilment of the requirements for the award of the Degree of Master of Science in Geo-Information for Environment and Sustainable Development.

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‘‘Spatio-Temporal Evaluation of Land Cover Change & Habitat Fragmentation using Geospatial Techniques and landscape metrics.” The Case of Akagera National Park, Rwanda

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(Reg. Number: 220017902)

A research dissertation submitted in partial fulfilment of the requirements for the award of a Master’s of Science in Geo-information for Environment and Sustainable Development

In the School of Architecture and Built Environment

College of Science and Technology

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DECLARATION

I hereby declare that this research Project ***"Spatio-Temporal evaluation of Akagera National Park land cover change & habitats fragmentation using Geospatial techniques and landscape metrics"*** *i*s my original work towards MSc and that to the best of my knowledge. It contains no material previously published by another person nor has material which has been accepted for the award of my other degree of the University, except where due to acknowledgement been made in the next.

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Signature

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CERTIFICATION

This to certify that this Project work titled ***"Spatio-Temporal evaluation of Akagera National Park land cover change & habitats fragmentation using Geospatial techniques and landscape metrics"*** was carried out by Jean Marie Vianney NIYONZIMA under my supervision.

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Date …/August/2024

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LIST OF ABBREVIATIONS AND ACRONYMS

EDC: EROS Data Center

EROS: Earth Resources Observation and Science

ETM+: Enhanced Thematic Mapper plus

GDP: Gross domestic product

GIS: Geographic information system

GoR: Government of Rwanda

GPS: Global positioning system

HDF: Hierarchical data format

LC: Land Cover

LODA: Local Administrative Entities Development Agency

LPDAAC: Land Processes Distributed Active Archive Center

LU: Land Use

LULC: Land use land cover

LULCC : Land use and land cover change

MINIRENA: Ministry of Natural Resources

MODIS: Moderate resolution imaging spectroradiometer

NDVI: Normalized difference vegetation indices

NIR: Near infrared

NISR: National Institute of Statistics of Rwanda

OLI: Operational Land Imager

RDB: Rwanda Development Board

REMA: Rwanda environmental Management Authority.

RNRA: Rwanda natural resources Authority

RS: Remote sensing

USGS: United States Geological Survey

UTM: Universal transversal Mercator

WGS: World geodetic system

ABSTRACT

Several studies on the park environmental monitoring have mentioned that Akagera National Park area and size has been reduced (African Parks, 2016). Accurate and up-to-date land-use and land-cover maps produced using geospatial techniques and landscape metric are proven to be important inputs to biophysical and environmental assessment models required for decision-making and resource planning, monitoring and evaluation fragments (Zhang and Johnson, 2017). The aim of the study is to undertake spatio-temporal evaluation of Akagera National Park land cover change and ecosystem fragmentation using geo-spatial techniques and landscape metrics. The first specific objective was to describe and map the LCU types of the Eastern savanna ecosystem and define habitat for specific flora and fauna. With help of maximum likelihood classifier on time series Landsat imagery land cover/use types maps of Akagera National Park during last three decades (1990, 2005, to 2020) were generated and further used to detect the changes of main LCU between 1990 and 2020. The second specific objective was to analyse the impact of land covers/uses changes on park fragmentation during the study period. GIS techniques were also used for landscape metrics calculation using FRAGSTATS software. The results revealed that from 1990 to 2005; grassland/savannah area, water and wetland decreased by -3561.98ha, -442.30ha and -2435.83ha respectively with a rate of change of -237.47ha/year, -29.53ha/year and -162.39ha/year respectively. Whereas, bare land increased to 4582.190 ha with a rate of change of 305.48ha /yr. Shrub/forested land also shows significant changes with an increase of 1858.6 ha with a rate of change of 123.91ha/year. In 2020, 57% of the study area covered by grassland area which was increased to 4829.678038 Ha in 2020 with 321.98ha/year while area occupied by water has increased to 4296.450ha with 286.43ha/year. On the other hand, the land use land cover categories like bare land, wetland and forested land showed decreasing pattern with -455.24ha/year, -128.15ha/year and -25.02ha /year of average rate of changes respectively. Considering the overall study period (30years), there was a remarkable increase in a real extent of grassland/savannah area of land from 60274.2ha (55.8 %) in 1990 to 61541.9ha (57%) in 2020. From landscape analysis at class level, landscape level and patches level, the results indicated that the values of overall patches decreased proportionally from 28509 to 13054. Since changes are dynamic in time and space, the continuous monitoring of land covers/uses changes and their impacts on habit fragmentation are recommended.

Keywords: ANP, *Land cover/land use, Fragmentation, Landscape metrics, GIS and RS*

CHAPTER ONE: INTRODUCTION

1.1 Background

Land use/land cover (LULC) pattern controlled by both natural and socio-economic processes, offers an inclusive understanding of the interactions and associations of Earth's terrestrial surface with anthropogenic activities (Barnieh *et al.*, 2020, Meshesha, Tripathi and Khare, 2016). LULC changes (LULCC) have emerged as one of the most profoundly human-induced impacts on the Earth's ecological system. Analysing the origins, procedures and outcomes of LULCC in addition to the relation between human-induced activities and land-use systems is acknowledged as the fundamental research topics in landscape ecology (Krajewski, Solecka and Mrozik, 2018, Hamad, Balzter and Kolo, 2018). In the last few decades, studies have indicated that unprecedented industrialization and persistent rapid urbanization lead to LULCC that have emerged as the primary underlying drivers impacting on ecology, agriculture, biodiversity, climate, wildlife and regional habitats from global to regional scales (Bennett, Smith and Betts, 2011). Therefore, it is well worth investigating the spatio-temporal dynamics of LULC, which aims at providing planned decision for promoting sustainable management of natural resources (Zhang and Johnson, 2017).

Rwanda as well as other countries on the globe are experiencing rapid, wide-ranging changes in land use and land cover. Land use/land cover change (LULC) is the major underlying cause of global environmental change (Silva, Vieira and Thalês, 2021). Only a few landscapes on earth in peripheral sites and remote areas still have their natural state maintained (Kayiranga *et al.*, 2016a). The alarming growth rate of the global population that in turn leads to an increase in anthropogenic activities has greatly altered the land use and land cover (LULC). Human abusing land is the main factor of large-scale land degradation. This lead not only to the deterioration of ecological environments and the decline of land bearing capacity (Tlapakova *et al.*, 2013) but also produce a far-reaching effect of the surrounding area in a direct or indirect mode and the reduction in size of the park ecosystem (Martins *et al.*, 2018). Loss of biodiversity has been resulted in habitat loss and fragmentation. Human interference on the environment have altered natural ecosystem due to increase in human settlements and fragmented agricultural land (Novianti *et al.*, 2017). Many natural reserves are enclosed by altered environment and later get functional as a separate natural ecosystem.

Fragmentation is a changing phenomenon that leads to change in the habitat in the landscape over a period of time. The term "Fragmentation" has been defined as simultaneous reduction of forest area, increase in forest edge and subdivision of large forest areas into smaller non-contagious fragments (Bekalo, 2009). The consequences of fragmentation include habitat loss for some plant and animal species, habitat creation for others, decreased connectivity of the remaining vegetation, decreased patch size, increased distance between patches, and an increase in edge at the expense of interior habitat. The degree of fragmentation has been described as a function of the varying size, shape, spatial distribution, and density of patches (Zhang and Johnson, 2017). Scientists have been using metrics for assessing fragmentation and its impact (González-González *et al.*, 2021, Hashem and Balakrishnan, 2015). The ecological consequences of forest fragmentation may depend on the spatial configuration of the fragments within the landscape and how the configuration changes both temporally and spatially. Three spatial attributes of fragmentation may be particularly important: core area, shape, and isolation of forest fragments (Zhang and Johnson, 2017).While ecologists and/or biologists routinely measure the abundance of species or the structure of biological communities at point locations within fragmented landscapes and then relate these measures to metrics of habitat fragmentation. Such studies typically focus on biological responses to one or a few attributes of the fragments or landscape such as area, edge effect, shape, isolation, landscape forest cover, or matrix quality. The term "spatial metrics" can be defined as measurements derived from the digital analysis of thematic-categorical maps exhibiting spatial heterogeneity at a specific scale and resolution (Rajani, 2017). Fragstat landscape metrics are algorithmic program that quantify specific spatial characteristics of patches, classes of patches, or entire landscape mosaics. Fragstat metrics has developed to quantify landscape structure and spatial heterogeneity based on landscape composition and configuration.

As the present study is specifically aimed to understand and compare the magnitude of forest fragmentation in Akagera landscape due to the influence of forest management and changes in land use within a period of 30years. The area currently known as Akagera National Park, along Rwanda's eastern boundary with Tanzania was discovered in 1876 by John Rowlands, this area was established as a national park in 1934 (Gatali, 2013). In spite of being a protected area, the Park has a long history of human occupation. The size of the Akagera National Park has been sequentially reduced as the force of human advance in the context of civil conflict 1990-1994 and political change has been applied to the area over time (Gatali, Callixte and Wallin, 2015). Land degradation means the process of soil quality degradation which includes soil erosion, saline-alkalized and fertility decline (Mlotha, 2018). As for the level of land use, land degradation represents the vegetation cover rate reduce, biomass lessen, biodiversity losing, and the land use grade debasing. If one or several factors were combined, there will be directly conduced the biology or economic productivity loses in arid or semi-arid region (Kogo, Kumar and Koech, 2019). Following years of political and civil war 1990 unrest resulting from the 1994 Genocide against Tutsi in Rwanda, intense human pressure on Akagera National Park had led to the widespread habitat degradation, wildlife population declines, and extirpation of both lions and black rhinos in the park (Nkundabose *et al.*, 2020).

Satellite-based tools have been proven as the appropriate way to study land cover changes in different landscapes due to their capacity to cover a large-scale area (Mueller *et al.*, 2010; Jia *et al.*, 2018). Additionally, it provides the time-series information that can guide planners and decision makers (Mlotha, 2018). In that framework, degradation in protected areas like parks can be understood by analysing time series data from the satellite imageries processed (Zhang, Zhao, Liu, & Li, 2015). Landsat data have been mostly used for determining land cover and measuring land cover changes and the rate of change in protect areas worldwide and they are the most substantial and widespread remote sensing applications (Shalaby & Tateishi, 2007)

1.2 Problem Statement

The Akagera National Park (ANP) was created in 1934 with an area of 2,500km² to protect its wildlife and fauna which were under threat as it was famous for its rich bio-diversity in flora and fauna species (Abbas, 2016; ANP, 2013). The ANP is mainly consisting of savannah, woodland, marsh, and swamps but currently the park management (Abbas, 2016) reports that it covers 1,122km². (Since 2010 it had been managed by Akagera Management Company after a joint agreement between Rwanda Development Board and African Parks to manage the national park) (Abbas, 2016; ANP, 2013). Knowledge about spatio-temporal Land cover variation is very limited because inadequate assessment of long-term monitoring and mapping of land use land cover over time. However, studies on the park environmental monitoring have mentioned that park area and size haves been reduced but tools like GIS and remote sensing were not extensively applied to better monitor the land cover dynamics of the park (Ndayisaba *et al.*, 2017). ANP have been undergone the reduction in content and physical extent, its landscape fragmentation wasn't documented before (Ndayisaba *et al.*, 2017). In the context of climatic condition and their variation over time, factors like climate change, park shirking, overgrazing, desertification and reintroduction of new species should lead to influence forest fragmentation (González-González *et al.*, 2021). There was a study that focused on evaluating the spatio-temporal changes of wetlands along Akagera river, not specially focused on the park (Ndayisaba *et al.*, 2017). Research on long-term monitoring of vegetation change dynamics is still missing. Analysis of landscape scale was not studied for this park, while it is also necessary to distinguish the state of patches, important to detect the spatial temporal changes of habitat suitability with regards future planning, management and conservation of the park.

It is therefore fundamental to assess spatio-temporal land cover changes of Akagera national park and its impact on ecosystem fragmentation using Geo-spatial techniques and landscape metrics. In order to bridge the gap, research on reliable means of assessment and modelling spatio-temporal land cover changes over a longer period of time it is imperative to provide critical information for future planning and conservation of the park. In this study, Landsat imageries were used to map changes in land cover and to monitor landscape fragmentations over time. It was reported that the anthropogenic activities and population increase in that province were the major causes of the threatening of the Akagera National Park over time (Ndayisaba *et al*., 2017; Sharma & Hategekimana, 2018; Wasige, Groen, Smaling, & Jetten, 2013). Since many years ago, it has been known that the park reduced in size due to human activities and its LC and its patches status haven't been assessed to guide further management of the park. Spatially explicit assessment of Akagera National Park land cover change & ecosystem fragmentation using adequate approaches in space and time such as geospatial techniques and landscape metrics are needed.

1.3. Contribution and Significance of the Study

With the advent of the spatial data acquisition using GIS and remote sensing technology, the assessment of parks and natural forest resources is now becoming more advanced and accurate (Hasan, Shi, & Zhu, 2020). They were being extensively used in mapping resources, land cover and land uses. Furthermore, they allow us to create spatial distribution and changes in times that are useful in translating impacts prediction results into appropriate management plan and policy measures. It is one of the viable techniques to monitor the changing patterns of Akagera National Forest. Satellite data from the several moments in time allows the creation of land cover maps over large scale extends and more frequent time steps than with expensive and detailed field studies. Because these classifications are spatially explicit, they provided not only the information on percent changes in land cover of Akagera National Park, but also allow for evaluation of the spatial location of these changes and their association with landscapes parameters that could be critical associates of these changes (Hassan *et al.*, 2016). Recent improvements in satellite image quality and availability have made it possible to perform image analysis at much larger scale than in the past (Yang *et al*., 2020; Yanan Zhang, Jin, Zhu, Zhang, & Zhang, 2020). Geographic Information System technologies have greatly increased ability to map and classify land cover and forest cover, providing managers and researchers with a tool to analyse data and address specific problems at a variety of spatial scales, in less time, and in more cost effective manners (Hasan, Shi, & Zhu, 2020). Remotely sensed land use/ land cover information integrated with those of Landscape metrics could provide a good reference for planning future management of the park.

The findings of this research highlighted LC types, their spatial distribution and changes in time. It shows the impact of LC changes on natural habitat fragmentation during the study period of 30 years. Those main findings have to support the Rwanda's journey of biodiversity conservation and park management. Also, the findings of this research should help other researchers and students from any university in Rwanda to regional. It also strengthens application of GIS and remote sensing for the monitoring of the changes in land cover of Akagera National Park. The park management should be informed on the impacts of land cover changes on park ecosystem and what can be done to minimize them.

1.4 Objectives

1.4.1 Main Objective

The aim of the study was to evaluate Spatio-Temporal change of Akagera National Park land cover and habitats/ecosystem fragmentation using geo-spatial techniques and landscape metrics.

1.4.2 Specific Objectives

The Specific objectives are:

- **a)** To describe and map major LC types of eastern savannah ecosystem (ANP) over time (1990, 2005 and 2020)
- **b)** To detect the changes of main LC types between 1990 and 2020;
- **c)** To analyse the impact of LC changes on natural habitat (park) fragmentation during the study period.

1.4.3 Research Questions

- **a)** What is status and rate of LC transformations between 1900 to 2020 and major LC types of eastern savannah ecosystem and habitat for specific flora and fauna?
- **b)** What are the spatial and temporal patterns of the LC within the study area?
- **c)** What is impact of LC changes on natural habitat (park) fragmentation during the study period?

1.5. Organization/structure of the research thesis

This report consists of five chapters successively structured as steps followed to achieve the specific research objectives. First chapter briefly explains the general introduction to the study. It introduces the background information on the study, states the research problem, and presents the research objectives and research questions. Furthermore, it presents the scope of the study area. Chapter 2 presents a literature overview on the land cover changes and landscape fragmentations. Third chapter describes the methodology used to achieve the study objectives. This chapter presents the study area and also identifies and details the methods and techniques used in data collection, data processing, and data analysis. Chapter 4 provides the research findings and their discussions. It explains the meaning of the findings, their importance, and policy implications. It also provides a comparison of findings related to the similar previous studies as discussions parts of this thesis while the last chapter presents conclusions and recommendations made from the results of this research. Finally, references and appendices are also included.

CHAPTER TWO: LITERATURE REVIEW

The planet earth has been in a state of continuous change since a long time ago and has faced with the problem of overwhelming increase as compared from year to year (Kogo, Kumar and Koech, 2019). Land-use/land-cover (LU/LC) changes caused by natural and human processes or & have played a major role in global as well as regional scale patterns of the climate and other aspect of the earth (Padmanaban, Bhowmik and Cabral, 2017).

2.1. Definition of key concepts

2.1.1. Land-uses/land-covers

Explanation of Land Cover and Land use change (LCLUC) often reflects divergent social theories of environmental change and alternative explanatory variables. The earth's surface has been changed considerably in the past decades by human's as a result of human induced factors of deforestation, agricultural activities and urbanization (Ogbole, 2013). Land is the ultimate resource of the biosphere and the definition LU/LC has been used as one in different research. However, these two terms explain two different issues and have different meanings. Land-cover refers to the observed biophysical cover on the earth's surface, including water bodies, vegetation, soil and hard surfaces. Land-use is the exploitation/utilization of the land by human activities for the purpose of settlements, agriculture, forestry, and by pasture altering land surface processes including biogeochemistry, hydrology and biodiversity (Janssen, 2005). In this context, as variation in the surface component of the landscape and is only considered to occur if the surface has a different appearance when viewed on at least two successive occasions (Ogbole, 2013). The definition also given by FAO (1999) for land-use is as the arrangements, activities and inputs people undertake in a certain land cover type to produce change or to maintain it. According to Lambin, *et al.*, 2003, transition in LU/LC can be caused negative socio-ecological feedback that comes from a rigorous (severe) degradation in ecosystem services/ as a result of from socio-economic changes and innovations.

2.1.2. LULC Changes

Land-use and land-cover (LULC) changes are reshaping landscapes all over the world at unprecedented rates, affecting environmental processes and agricultural production at multiple scales (Meshesha, Tripathi and Khare, 2016). The ever-increasing demand for land resources (e.g. food, crop, fresh water, and fuel) together with unsustainable land management practices have Land use and land cover changes in the past is crucial to understand the current changes and predict future ones. Therefore, land use and land cover change (LULCC) research needs to deal with the identification, qualitative description and parameterization of factors which drive changes in land use and land cover, as well as the integration of their consequences and feedbacks (Bosco and Thomas, 2019). However, one of the major analysis is to link activities/behavior of people to biophysical information in the appropriate spatial and temporal scales using geospatial technology (Patakamuri, Agrawal and Krishnaveni, 2014). However, it is argued that land use and land cover change trends can be easily assessed and linked to population data, if the unit of analysis is city level. The local human activities expressing the drivers can be determined by measuring the rates and types of changes and analyzing other relevant sources of data like demographic profiles, household characteristics and policies related to land resources administration. To achieve this, it is crucially important to consider multiple sources of information and to acquire temporal, spatial and other non-spatial forms of data. This is due to the fact that land use attributes are complex and the boundaries between different types of data are quite diffuse (Hawchar *et al.*, 2020). LUCC studies have been designed to improve understanding of the human and biophysical forces that shape land use and land cover change. Thus, linking human behavior and social structures to biophysical attributes of the land is a fundamental aspect of LUCC research (Hamad, Balzter and Kolo, 2018).

Some authors believe that population growth causes land degradation and deforestation as growing population converts forest to agriculture and fuel or over use agricultural land (Ogbole, 2013). Other argue that increased population is associated with intensification of the use of existing agricultural land through the use of more labor and technologies rather than conversion of forest. Many studies distinguish between proximate causes-directly implicated in a land-cover or land use change and underlying causes that explain the deeper roots of land use dynamics. Land use and land cover changes may be grouped into two broad categories as conversion and modification. Conversion refers to changes from one cover or use type to another, while modification involves maintenance of the broad cover or use type in the face of changes in its attribute (Nkundabose *et al.*, 2021;p33). Land cover changes is a real priori classification system in the sense that, for the classifiers considered, it covers all their possible combinations (Hawchar *et al.*, 2020). The classification is also hierarchical and the more classifiers used, the greater the detail of the defined land cover class**.** Built-up area" is defined as the presence of buildings (roofed structures). This definition largely excludes other parts of urban environments or human footprint such as paved surfaces (roads, parking lots), commercial and industrial sites (ports, landfills, quarries, runways) and urban green spaces (Traore *et al*., 2021; p13). Agricultural land use patterns Over the past decades, agriculture has been the major anthropic activity exerting “pressure” on the environment in this region, and was responsible for drastic landscape transformation (Rukundo *et al.*, 2018).

Land use and land cover plays an important role in global environmental change and sustainability, including response to climate change, effects on ecosystem structure and function, species and genetic diversity, water and energy balance, and agro-ecological potential. Land use and land cover mapping is one of the most important and typical applications of remote sensing data (Hamad, Balzter and Kolo, 2018). Remotely sensed data are a useful tool and have scientific value for the study of human- environment interactions, especially land use and land cover changes (Dalantai *et al.*, 2021).

2.1.3. Habitat

The term habitat must be properly defined and understood. Habitat has been defined by many authors but they have often confusing it with the term vegetation type (Girma, Mamo, and Verma, 2017) point out that , habitat is a term that is widely misused in the published literature. The key features of the definitions of habitat are that habitat is specific to a particular species, can be more than a single vegetation type or vegetation structure, and is the sum of specific resources needed by a species (Fahrig, 2003). Habitat for some species can be a single vegetation type, such as a specific seral stage of forest in a region (e.g., old forest). This might be the case for an interior forest species where old forest interiors provide all the specific resources needed by this species (Girma *et al.*, 2017). However, habitat can often be a combination and configuration of different vegetation types (e.g., meadow and old forest). In a combination of old forest and meadow are needed to provide the specific resources for a species (Fischer and Lindenmayer, 2007).

In addition to considering habitat versus non-habitat (the intervening matrix), habitat can have a gradient of differing qualities (Maclean, Boar and Lugo, 2011) where habitat quality is defined as the ability of the environment to provide conditions appropriate for individual and population persistence (Hall *et al*. 1997; p17). The idea that habitat can be a specific combination and configuration of vegetation types can be extended further to different combinations and configurations representing different levels of habitat quality. Poor habitat quality may result from too much of one vegetation type relative to another. Too much meadow may provide sufficient resources for reproduction, but not enough for survival. Habitat quality is influenced by the mix and configuration of the two vegetation types (Dimobe, *et al*., 2017).

2.1.4. Habitat fragmentation

Habitat fragmentation can be described as the splitting of natural habitats and ecosystems into smaller, more isolated patches it is the process of subdividing a continuous habitat into smaller pieces. It implies a loss of habitat, reduced patch size and an increasing distance between patches, but also an increase of new habitat It is defined as the breaking apart of the connectivity of habitat (Maclean, Boar and Lugo, 2011). The term fragmentation has been used to encompass a broad variety of changes in landscapes, changes that include reduction in habitat area, increased isolation of habitat patches, extension of the length of edges between habitats, and amplified contrast between habitat and the surrounding matrix (Fahrig, 2003). Fragmentation is the dissection of landscapes into spatially isolated parts, is a major driver of environmental change worldwide (Fischer & Lindenmayer, 2007). Usually, the process of fragmentation is caused by human activities (roads, agriculture and logging). It also reduces the value of the landscape as habitat for many species. It alters natural habitat in many ways, including reduction of patches sizes, increase of distances between similar patches and increase of edges (Robinson, Mandleco, Roper, & Hart, 2001). Landscape fragmentation customarily refers to a reduction in connectivity between parts of a landscape or the conversion of the landscape into a mosaic of cover types, some of which differ from the original habitat. Ecological implications of these changes remain unknown (Rajani, 2017).

Habitat fragmentation is often defined as a process during which a large expanse of habitat is transformed into a number of smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original (S. K. Robinson & Wilcove, 1994). By this definition, a landscape can be qualitatively categorized as either continuous (containing continuous habitat), or fragmented, where the fragmented landscape represents the endpoint of the process of fragmentation. This definition of habitat fragmentation implies three effects: (a) reduction in the extent of habitat, (b) increase in number of habitat patches, and (c) increase in isolation of patches. These effects form the basis of most quantitative measures of habitat fragmentation. However, fragmentation measures vary widely; some include only one effect (e.g., reduced habitat or reduced patch size), whereas others include more (Dimobe *et al.*, 2017).

2.1.4.1 Adverse effects of habitat fragmentation

Habitat fragmentation results in both a quantitative and qualitative loss of habitat for species originally dependent on that habitat type (Temple, 1986). As a consequence, the abundance and diversity of species originally present often declines, and losses are most noticeable in smallest fragments. Most importantly, fragmentation affects movement and dispersal and modifying behavior (Haila, 2002). The process of habitat fragmentation involves three factors, which have important repercussions on plant and animal species that originally occupied large continuous areas of wild habitat (Schmiegelow & Mönkkönen, 2002). First, fragmentation leads to the breaking of large patches into numerous smaller, resulting in a net habitat loss. This results in a decrease in the number of resources and shelter areas available to wild species and, therefore, leads to a general reduction in the number of individuals that can be hosted (Mullu, 2016). The most obvious effect of fragmentation is an outright quantitative loss of habitat for species dependent on the original habitat type in a region group of species directly impacted by habitat loss through fragmentation including those with large home range requirements, very specific microhabitat requirements, and poor disposal abilities. Second, by opening core areas, fragmentation of continuous habitat patches, leads to a dramatic increase in edges. Edges present distinct micro-climatic conditions from the core and therefore might become less suitable for species (Forman, 1999). These edges also lead to higher predation rates by favoring generalist predator influx, which in turn greatly impacts the population of resident species. Third, habitat fragmentation results in the geographic isolation of islands of habitat among a matrix of urban or agricultural land-uses. This might greatly restrict the mobility of certain organisms, and thereby isolate some populations. However, small isolated populations can be threatened by inbreeding, which represents a serious problem for their survival and could lead, in case of severe inbreeding to population extinction (Mullu, 2016). Moreover, small populations are more sensitive to stochastic events, such as fires or epidemic outbreaks that could drive local population to extinction (Schmiegelow & Mönkkönen, 2002).

The isolation of habitat patches increases and the probability to be recolonized decreases. Therefore, long-term survival of isolated populations cannot be assumed in any case. Nonetheless, not all species have the same sensitivity to habitat fragmentation (Mullu, 2016). Naturally rare, sedentary species, with specialized in habitat requirement show an important decline whereas abundant mobile generalist species are less affected or even favored, in the case of edge specialists. Also, the degree of isolation of habitat patches might depend on the migration capacity of each species living within them. As a consequence, habitat fragmentation cannot be generally described, and should be specified for every individual species (Parker & Mac Nally, 2002). Habitat fragmentation creates landscapes made of altered habitats or developed areas fundamentally different from those shaped by natural disturbances that species have adapted to over evolutionary time (Meffe, Carroll, & Groom, 1997). Generally, according to (Parker & Mac Nally, 2002), adverse effects of habitat fragmentation to both wildlife populations and species include: Increased isolation of populations or species, changes habitat plant composition, often to weedy and invasive species; changes the type and quality of the food base; changes microclimates by altering temperature and moisture regimes, changes flows of energy and nutrients; changes availability of cover and increases edge effect, bringing together species that might otherwise are not interact, potentially increasing rates of predation, competition and nest parasitism and increases opportunities for exploitation by humans, such as poaching or illegal collection for the pet trade (Fahrig, 2003). Habitat fragmentation diminishes the landscapes capacity to sustain healthy populations or metapopulations in five primary ways: loss of original habitat, reduced habitat patch size, increased edge, increased isolation of patches and modification of natural disturbance regimes (Forman, 2014).

2.1.4.2 Causes of habitat fragmentation

Fragmentation is caused by both natural forces and human activities, each acting over various time frames and spatial scales. Physical Features of the landscape, associated with very slow geomorphic processes (e.g., erosion) may also cause some patches to remain isolated over evolutionary time-scales (Schüle, 1990).

- **Fragmentation Due to Natural Causes**

Over long-time frames (thousands or millions of years), landscapes are fragmented by geological forces (e.g., continental drift) and climate change (e.g., glaciations, changes in rainfall, sea level rise). Over short periods (decades or months), natural disturbances, such as forest fires, volcanoes, floods, landslides, windstorms, tornadoes, hurricanes and earthquake modify and fragment landscapes (Wiens, 1995). In addition, landscapes are naturally fragmented by mountain ridges, canyons, rivers and lakes. Some ecosystems also commonly occur in discrete patches and are thus naturally fragmented. Natural processes create the habitat heterogeneity and landscape diversity upon which many species depend (Gu, Heikkilä, & Hanski, 2002).

- **Fragmentation due to Human Activity**

The most important and largest-scale cause of changes in the degree of fragmentation is anthropogenic habitat modification, with nearly all fragmentation indices being strongly correlated with the proportion of habitat loss in the landscape (Fahrig, 2003). Humans have modified landscapes for thousands of years. Early hunters influenced the landscape by burning areas to favor certain game species, as currently ranchers burn grasslands. Many human activities such as agriculture, settlement, resource extraction (e.g., mining, timber), industrial development (e.g. the construction of hydroelectric dams) alter and fragment landscapes. Of these activities, agriculture is the leading cause of ecosystem loss and fragmentation throughout the world today (Tilman *et al*., 2001).

2.1.4.3 Management of habitat fragmentation

Habitat fragmentation has a variety of impact on the environment and its organisms. Fragmentation benefits some species, and at the same time put other species at a great deal of risk. As a result, there is necessity to take effective actions to maintain biodiversity in fragmented landscapes. It is possible to establish effective corridors and buffer zone management (Mullu, 2016). Inclusion of corridors as a protection strategy in habitat fragmentation is imperative to maintain biological diversity (Rosenberg, Noon, & Meslow, 1997). Corridors function as connection channels between separated fragmented patches (Noss, 2001), so they are crucial in managing habitat fragmentation. Corridors serve two purposes: facilitating movement between various types of patches, including breeding, feeding and birthing; and facilitating immigration and emigration of individuals among such patches (Meffe *et al*., 1997). Moreover, corridors can improve the population viability in both fragmented and isolated landscapes if they are appropriately designed (Meffe *et al*., 1997). Through well-planned projects, buffer zones provide protection for wilderness from human activities and developments (Noss, 2001). It can increase the ratio of rare and common population by softening the edge effect (Martino, 2001).

2.2. Causes of land-use and land-cover changes

Changes in the land-use reflect the history and, perhaps, the future of humankind. Such changes are influenced by a variety of factors related to human population growth, economic development, technology and environmental changes (Houghton, 1997). Land-cover changes, which is conversion of the land-cover from one type of to another and modification of the conditions within a category and land-use change occurs initially at the level of land parcels when land managers decide that a change towards another land utilization type is desirable (Meyer & Turner, 1992). Population growth is one of the major factors for LU/LC change. People are the most important natural resources, which is mutually inter-related and interdependent for their sustainable development. However, Land-use reflects the importance of land as a key and finite resource for most human activities such as forestry, agriculture, industry, energy production, recreation, settlement and water catchment and storage (Traore *et al*., 2021). During the past 3 centuries, the extent of earths cultivated land has grown by more than 45% increasing from 2.65 million km² to 15 million km² and at the same time, other natural resources (land-cover) such as forest has been shrinking due to agricultural land expansion and urbanization (Alperstedt and Bulgacov, 2015) . High rate of deforestation in many developing countries is most commonly associated with population growth and poverty. Land-use/land-cover changes have become major problems for the world, and it is a significant driving agent of global environmental changes (FAO, 1999). Such a large-scale land-use classes through the increase of agricultural land at rural area, deforestation (clearance of trees), and urbanization with other natural phenomena and human activities are inducing changes in global systems and cycles. However, the major change in land-use, historically, has been the worldwide increase in agricultural land (Houghton, 1997). Climate change refers to long term or permanent shift in climate of the area. Some of the evidence for climate change includes increased frequency of the occurrence of drought, global temperature rise, tropical cyclones, flood, and reduced annual rainfall reduction in glacial cover over mountain and rising sea levels (Alemayehu, 2008). Land-use and land-cover (LULC) changes are reshaping landscapes all over the world at unprecedented rates, affecting environmental processes and agricultural production at multiple scales (Meshesha, Tripathi and Khare, 2016).

The ever-increasing demand for land resources (e.g. food, crop, fresh water, and fuel) together with unsustainable land management practices have Land use and land cover changes in the past is crucial to understand the current changes and predict future ones. Therefore, land use and land cover change (LULCC) research needs to deal with the identification, qualitative description and parameterization of factors which drive changes in land use and land cover, as well as the integration of their consequences and feedbacks (Bosco and Thomas, 2019). However, one of the major analysis is to link behavior of people to biophysical information in the appropriate spatial and temporal scales (Patakamuri, Agrawal and Krishnaveni, 2014). Nevertheless, it is argued that land use and land cover change trends can be easily assessed and linked to population data, if the unit of analysis is city level. The local human activities expressing the drivers can be determined by measuring the rates and types of changes and analyzing other relevant sources of data like demographic profiles, household characteristics and policies related to land resources administration. It is crucially important to consider multiple sources of information and to acquire temporal, spatial and other non-spatial forms of data. This is because land use attributes are complex and the boundaries between different types of data are quite diffuse. LUCC studies have been designed to improve understanding of the human and biophysical forces that shape land use and land cover change. Thus, linking human behavior and social structures to biophysical attributes of the land is a fundamental aspect of LUCC research (Hamad, Balzter and Kolo, 2018).

2.3. Technologies for Mapping LULC and their Changes

Remote sensing change detection techniques can be broadly classified as either pre- or post-classification change methods. A pre-classification process refers to operations carried out to bring satellite images to the desirable geometric and spectral standard by correcting errors, and it is performed prior to image classification (Ahmad, Fatima and Butt, 2013). Whereas, post-classification methods refer to activities done after classification of images like computation of class statistics, accuracy assessment, and map preparation. Pre-classification methods can further be characterized as being spectral or phenology based. Originally, the post-classification approach was considered to be the most reliable approach and was used to evaluate emerging methods (Dhanda *et al.*, 2015). Factors that limit the application of post-classification change detection techniques include cost, consistency, and error propagation (Gebre and Andualem, 2018) . The satellite instruments employed some decades ago provided images with coarse resolution. With advancement in remote sensing science, various sensor instruments with improved radiometric, temporal and spatial resolution were being developed. Hence, this allowed the integration of satellite images acquired by various sensor types in order to better understand land resources dynamics. The use of data from different sensors poses a serious challenge to many change analyses, which can be addressed through use of post-classification comparisons (Fenta *et al.*, 2017).

There is significant variation between various sensor instruments' capability and wealth of information captured and also the applicability depends on the objective of the intended study. There is also clear variation in the spatial and spectral properties of satellite images acquired by different versions of a particular sensor instrument. Landsat instruments can be taken as a good example of showing continuous improvement in radiometric and spectral property of images enabling better understanding of land resources. Remote sensing has played a key role in the past decades, providing cost-effective ways to detect and monitor changes at various scales (Wang, 2012) and have a great potential for deriving indicators, which respect elementary requirements of science and specifically statistical requirements. Still, understanding the dynamics, causes, and consequences of man-induced land changes requires interdisciplinary approaches, which combine for example, land observation and spatially explicit modeling, assessment of vulnerability, resilience, among others (Aliani *et al.*, 2019). A great deal of research has used remote sensing techniques for mapping and assessing land use/cover changes within a temporal window, from global to local scales. Change detection involves quantitatively identifying the differences between multi-temporal data sets to see the dynamics of the phenomena of interest. The repetitive and synoptic data acquired from remote sensing has been a major source for change detection in past decades (Li, 2021). It was pointed out that change detection gives an in-depth understanding of the relationships between human and natural phenomena for better management of resources. Accordingly, studies should involve the following information: change and rate of change, spatial distribution of change, and change trajectories of land cover types (Wang, 2012).

Nevertheless, post-classification change detection is widely used, as it circumvents problems associated with multi-date images such as radiometric and atmospheric differences and registration errors. In assessing land cover changes and its effects on agriculture production, the post classification method for change detection can be used and combined with results from interviews and questionnaire survey. Other studies in Africa which sought to quantify LULC dynamics also applied the post classification detection technique (Khan *et al.*, 2016; Muthama, Mubea and Mundia, 2016). Agricultural expansion, policy change and social unrest, population pressure, shortage of farm land, and biophysical factors were major driving forces of the LU/LC changes (Han, Yang and Song, 2015; Halefom *et al.*, 2018). Environmental implications such as biodiversity loss, scarcity of basic forest products, habitat alteration and crop yield reduction are the consequences of the LU/LC change and to understand these issues. Combined techniques such as GIS, remote sensing, and socioeconomic factors has been used in similar studies and could be applied in other places where similar challenges occur where expansion of agricultural land has negative implications on the natural resources and the livelihood of local people (Zhang *et al.*, 2011; Grecchi *et al.*, 2014). Hence, appropriate measures need to be employed to reduce the dramatic change in land use and to harmonize environmental conservation and agriculture production with human livelihood.

Remote sensing and geographic information system techniques have been widely used over the world for the study of historical changes in LU/LC and LST analysis. Remote sensing has been used to identify vegetation cover, air pollution, LST and other surface characteristics (Zhang *et al.*, 2018). Furthermore, understanding the correlation between land degradation and LU/LC is important to manage the land. It provides a large variety and amount of data about the earth’s surface for detailed analysis, change detection with the help of various airborne, and space born. With the availability of historical remote sensing data, the reduction in data cost and increased resolution from satellite platforms, remote sensing technology appears ready to make an even greater impact on monitoring land-cover change. Land-use/land-cover changes can be analysed over a period using Landsat sensors such as Landsat Multi Scanner (MSS) data and

Landsat Thematic Mapper (TM) data by image classification techniques (Kayiranga *et al.*, 2016b).

Since 1972, Landsat satellites have provided repetitive, synoptic, global coverage of high-resolution multispectral imageries. Their long history and reliability have made them a popular source for documenting changes in LU/LC over time (Khan *et al.*, 2016) and their evolution is further marked by the launch of Landsat7 (Enhanced Thematic Mapper Plus sensors) by the United State in 1999. Remote sensing is the capability to gather information without being in direct contact with it (Wang and Yu, 2012). The modern use of the term remote sensing has more to do with technical ways of collecting airborne and space born information. The earth observation from airborne platforms has 150 years of history, although the majority of the innovation and development has taken place in the recent decade's years. The first earth observation-using balloons in the 1860s were regarded as an important benchmark in the history of remote sensing (Zhang *et al.*, 2018). Information is gathered by instruments at the natural level by our eyes, or by cameras (radiometric which measure radiation). Satellite based remote sensing provides valuable information that can be used in the assessment of the various aspect of atmospheric environment, climatology, meteorology, ecology, agronomy and environmental protection (Lu *et al.*, 2022).

The essence of remote sensing is measuring and recording of the electromagnetic radiation emitted or reflected from the earth's surface. This technique enables us to investigate and know the tendency of LU/LC change through time. Geographic Information System is a system designed to capture, store, manipulate, analyse, manage and present spatial or geographic data (Coppin *et al.*, 2004). The data type in GIS can be classified into two major groups as spatial and non-spatial data. The spatial data are the data that have location value and that non-spatial data are a data, which describe more the spatial data in the form of a table. According to (Hassan *et al.*, 2016), data in GIS is composed of three dimensions that mean spatial (geographic), time and attribute. Some people believe that geographic information system as the system of hardware and software, which contribute to analyse applications or information processing (Pfeiffer and Stevens, 2015). Geographic information system is not only digital store of spatial objectives (areas, points and lines) but also capable of spatial analysis based on the relation between these objects, including the r/ship between objects defined by their location and geometry. According to (Appiah Mensah, Akoto Sarfo and Partey, 2019), there the following are four LU/LCs change detection (aspects of change detection), which are important when monitoring natural resources:

- Distinguishing the nature of the change
- Detection/finding of the changes that have occurred.
- Measuring the area extent of the change
- Assessing and investigating spatial pattern of the change

2.4. Landscape metrics and patches dynamics

Forests refers to those landscapes with natural tree stands sparsely, whether productive or not and excludes the tree stands in agriculture production systems. Forest fragmentation is the process through which formerly large and continuous extensions of forests turn into a set of small and isolated patches, increasingly affected by edge effects (Hussain *et al.*, 2022). Forest Fragmentation encompasses three interrelated processes, -reduction in total amount of original vegetation, subdivision of remaining vegetation into fragments, remnants or patches and incorporation of new forms of land use to replace lost vegetation. Three spatial attributes of fragmentation are: core area, shape and isolation of forest fragments. The fragment edges as a range of physical and environmental transitions. Irregular shape of fragments due to forest fragmentation increases length of edges and restrict commutation of native organisms. Forest landscapes are at stake of fragmentation because of changes in land cover due to processes of agricultural activities, intensification, logging, and infrastructure development. Landscape metrics act as quantitative link between landscape patterns and ecological or environmental processes (Pham *et al.*, 2014). They display numerical information about landscape composition, configuration and dimension, and allow for comparisons of different times and even help to recreate future scenarios (Kayiranga *et al.*, 2016a). Consequently, landscape metrics are widely used in the literature to study large natural areas, forest dynamics, natural parks or urban expansion among others (Kayiranga *et al.*, 2016a; Mugiraneza, Haas and Ban, 2017). These metrics can be derived for one of three levels: patch level (defined for individual patches), class level (characteristics of all patches in a given class), and landscape level (integrated over all patch types or classes over the extent of the data). In this study landscape and class level metrics was used as patch level metrics are useful for our purposes. Class metrics represent the spatial distribution and pattern within a landscape of a single patch type; whereas landscape metrics represent the spatial pattern of the entire landscape mosaic, considering all patch types simultaneously (Ghazoul and Chazdon, 2017). Patch metrics are excessively disaggregated and can be particularly useful when analysing single patches for specific purposes (e.g., habitat studies, reserves delineation, edge effects) (Zhang *et al.*, 2018).

2.5. Protected area in Rwanda

2.5.1 Background

Rwanda's protected areas cover around 8.5 % of the country's total land area of 26,338 km2. An important proportion is made of the three national parks (Rutagarama & Martin, 2006). The protected areas in Rwanda are comprised of four types: national parks, namely the Akagera National Park (ANP), the Volcanoes National Park (VNP) and the Nyungwe National Park (NNP); forest reserves, including Gishwati Forest Reserve, Iwawa Island and Mukura Forest reserve; forests of cultural importance (Buhanga forest); and wetlands of global importance (Rugezi-Burera-Ruhondo wetland complex). Besides these legally protected forests, there are forests of cultural importance and other remnant natural forests which are only protected to the extent that Rwandan law prohibits human activities in natural forests. Management of conservation has not been easy in Rwanda (REMA, 2007).

Rwanda has the highest population density in Africa (310 per km2) and a population growth rate of 3.1% per annum (MINISANTE/ONAPO 2003). Local dependence on natural resources is high with continuing trade-offs with conservation resulting from demands for farmland, fuelwood and bushmeat. Dependence is associated with poverty (Masozera & Alavalapati, 2004) and poverty levels are high. The current status of protected areas represents a 65% reduction in size over the past 40 years (MINAGRI, 2003) and there are important species and habitats not covered by the existing protected areas network (De Klerk, Crowe, Fjeldså, & Burgess, 2004). A decade of instability has eroded the institutional capacity for managing protected areas, temporarily militarized large areas of parks, forced huge movements of refugees and created demand for land for resettlement. Prior to the 1994 genocide, 417 000 ha were covered by the protected areas network; this has been reduced to 220 000 ha (Bizoza & Havugimana, 2013). The fate of Rwanda's forest reserves may be even worse, with an estimated 80% lost during the last 40 years. The management of the remaining protected areas is made difficult by weaknesses in political and institutional frameworks, lack of human resources and funding, and widespread poverty (USAID, 2014).

Akagera National Park has suffered more than others in terms of insecurity, lack of human and financial resources and conflicts of interest between local livelihoods and conservation. From 1990 to 1994 the park was a war zone between the government and former rebels of the Rwanda Patriotic Front (Masozera & Alavalapati, 2004). An aerial survey of the park showed that between 1994 and 2002, wildlife declined by 50–80% due to human activities, including cultivation, pastoralism and hunting (Lamprey & Reid, 2004). The demand for land and grazing, together with conflicts between wildlife and agriculture, continue to undermine conservation efforts (Rutagarama & Martin, 2006).

2.5.2 Policy framework with protected areas

Recent policy documents underline the need to combine strong protection of the environment with the incorporation of local government and communities into environmental decision making (Rutagarama & Martin, 2006). Measures undertaken by the government and other partners to resolve contested claims include establishing park management infrastructure, enforcing laws and regulations, building community capacity, introducing more biodiversity conservation measures, revenue sharing, initiating alternative livelihood projects (e.g. water harvesting infrastructures, off-farm activities through cooperatives), and engendering community participation (Bizoza & Havugimana, 2013). The Government of Rwanda must find mechanisms through which it ensures the effective management of protected areas. The sustainable utilization of these protected areas can contribute to reduced poverty, community development and conservation of these ecological areas to meet the needs of future generations (USAID, 2014). A number of laws and policies relevant to the management of protected areas have been put in place. These include: the Constitution of the Republic of Rwanda as amended to date, the Environmental Policy (2003), the ORTPN Law (2003) the National Land Policy (2004), the Environment Law (2005), the Akagera Law (2010), the Forestry Policy (2010), the Rwanda Wildlife Policy (2013), and the Land Law (2013). Rwanda has also ratified international conventions such as the Convention on Biological Diversity and Convention on International Trade in Endangered Species of Fauna and Flora (Bizoza & Havugimana, 2013).

Protected areas are legally classified as state land in the public domain which is reserved for environmental protection. Law no. 43/2013 of 16/06/2013 Governing Land in Rwanda, in accordance with policy and legislation, various rights and restrictions can be established by the relevant competent authorities that define each stakeholder’s access to direct and indirect use of wildlife resources (Bizoza & Havugimana, 2013). Law no. 33/2010 of 24.9.2010 establishing Akagera National Park states that the management of the park and its buffer zone is entrusted to the institution in charge of the management of national parks, which is RDB. Only ANP and NNP have buffer zones; management of these is entrusted to those institutions in charge of park management (Ndangiza, 2014). No management role of protected areas or buffer zones is assigned to ordinary citizens, although the National Land Policy assigns responsibility to all Rwandans to improve the protection and the management of protected areas

(Gatali, 2015). Rather, the role of the surrounding communities within protected areas is limited to provision of labor, participating in awareness campaigns, and monitoring engagement of their neighbors in illegal activities through overnight patrols (Ndangiza, 2014).

2.5.3 Management of Protected Areas

Each of Rwanda's protected areas has its own history of contested claims to natural resources, both within the protected areas themselves as well as in the buffer zones (Rutagarama & Martin, 2006). Use of resources in protected areas, such as water harvesting, clearing land for cultivation, harvesting forest products, hunting, and mining, constitutes a major source of conflict between the State and local communities (Rutagarama *et al*., 2006).

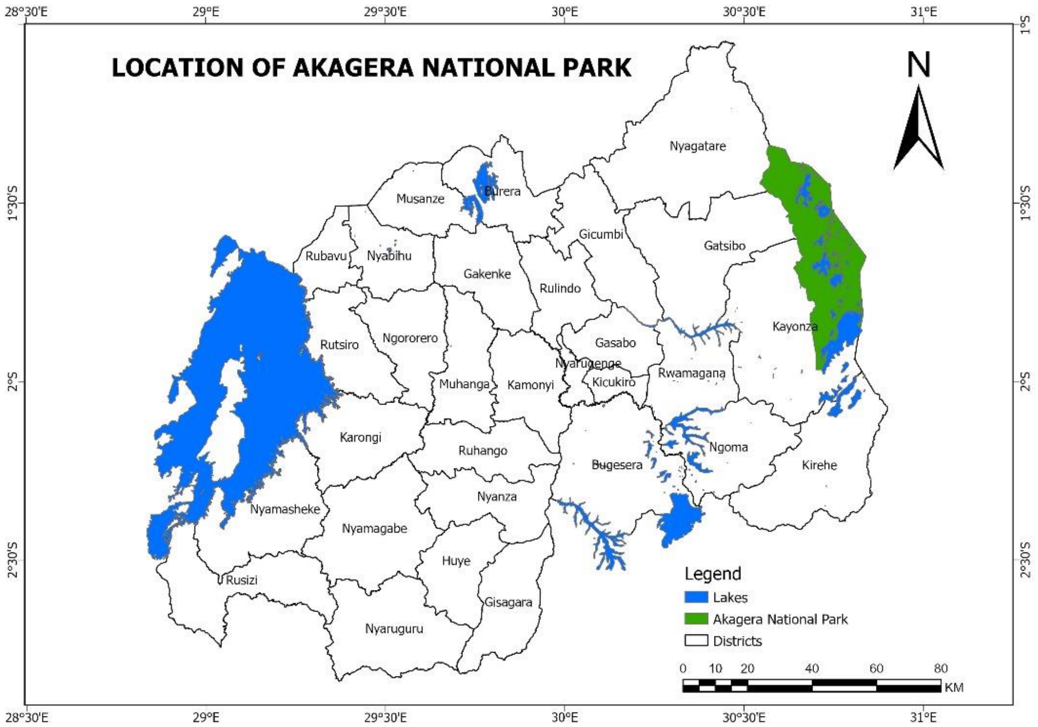
The protected areas shall continue to be managed in accordance with the fundamental purpose of conserving their scenery, wildlife, and natural and historic objects (GoR, 2014). The development of concessions operations in national protected areas shall be limited to the accommodations, facilities, and services that fall within certain conditions specified in already established laws, policies and institutions relevant to the management of protected areas (GoR, 2018). The protection of national parks and payment of ecosystems count among significant conservation achievements in Rwanda. This has been achieved through the expansion of the Akagera National Park buffer zone, the long-term protection of Nyungwe and Akagera national parks through a unique partnership with African Parks, and the rehabilitation and establishment of Gishwati-Mukura National Park (GoR, 2014). Rwanda's conservation efforts aim to maintain and expand the country's protected areas as key economic assets supporting climate-resilience, and acting as havens for biodiversity and sources of vital ecosystem services (Nkundabose *et al.*, 2020).

CHAPTER THREE: MATERIALS AND METHODS

3.1. Study Area Description

3.1.1. Geographical Location

Akagera National Park lies in eastern Rwanda and it is extending between Kayonza, Gatsibo and Nyagatare Districts (Ndayisaba *et al.*, 2017) and it is hugging the border with Tanzania. Woodland, swamps, low mountains and savannah characterize it. The varied terrain shelters wildlife including zebras, giraffes, elephants, lions and hundreds of bird species, such as the rare shoebill stork (Gatali, 2015). In the southern part of the park, vast Lake Ihema is home to hippos and crocodiles, where it forms the borderland between Rwanda and Tanzania in East Africa. The region experiences four climatic seasons in which long rainy (March–late May) and short rainy seasons (end September–early December) alternate with long dry (June–September) and short dry (mid-December–February) seasons (Macpherson, 2013a). Under the shield of the natural reserve protection laws in Rwanda, human activities are limited in this area. Furthermore, park managers have put a coordinated fishing framework in some lakes in place. However, there are still some anthropogenic activities that continue to exacerbate pressure on these park swamps, notably agriculture, cattle grazing, production inside the park (Ndayisaba *et al.*, 2017).



Source: REMA, 2015

3.1.2. Biophysical Characteristics

The Akagera National park is within the trans-boundary and one of the largest wetland systems in the basins surrounding Lake Victoria (Macpherson, 2013b). Parts of this wetland system are protected in Rwanda (Ndayisaba *et al.,* 2017). Akagera National Park is one of the largest protected wetlands in East Africa. In Rwandan side, it was reportedly to be the second richest habitat for mammals inside the national parks. This area is characterized by two main seasons: the dry season with the annual average temperature varying between 20.3 °C and 21.7°C and the rainy season (Gatali, 2015). The steep slope of study area including watershed is moderately covered with Savannah vegetation and wetland. Akagera National Park area consists primarily of clays neo-formed. These deposits have probably experienced during their evolution, a secondary enrichment in alkaline earth metals (especially Ca and Mg) from colluviums. The chemical point of view, because their high content of clay minerals of type 2:1, they show high CEC and wealth in certain bases: Ca, Mg and K. The soils are rich in organic compounds. They are low in kaolinite and montmorillonite-rich, which gives them a high natural fertility. The relief is flat and the slope is medium and does not exceed 30% (Macpherson, 2013b).

The hydrographic network is very limited in Nyagatare, Kayonza, Kirehe and Gatsibo region. There are number of lakes in Akagera National Park that make this Savannah National Park in Rwanda all the more beautiful and inhabitant a variety of wildlife on the top of being great sources of water to the animals (Gatali, 2015). Those lakes include Lake Ihema, lake Hago, lake Mahindi, lake Rwanyakizinga, lake Gishanju, lake Kivimba, lake Murambya, lake Murambi lake Shakani and lake Birengero. Apart from lakes, there are a number of rivers. Akagera National Park is home to a couple of lakes that are fed by the famous Akagera River that forms part of the Nile River. Akagera River is the section of the river that starts in Burundi and flows east to Rwanda's lake Ihema and continues to Tanzania (Ndayisaba *et al.*, 2017)

Apart from the lakes and rivers in the Akagera national park, there are a large variety of vegetation, birds and animals. There are more than 480 recorded bird species in the park, making it the most diverse Rwanda bird area. Some of the animals are lions, leopards, elephants, buffalos, rhinos, giraffe and much more (SNV, 2021). Most of the park features savannah, montane and swamp vegetation. The national park derives its name from River Akagera which flows through the national park and on-wards into Uganda. Wetlands, savannah, grasslands/woodland, shrub/forests, lakes and rivers dominate Akagera national park (Gromada, 2022)

3.1.3. Socio-economic Characteristics

Akagera offers employment to locals as tour operators, rangers, guides, doctors and more. It brings in revenue from both foreign and local visitors and has attracted foreign investors to support Rwandan schools, hotels and restaurants (Gromada, 2022). As a result of conservation and management efforts, since 2010 tourism revenue in Akagera has increased by more than 300%, with Rwandan nationals making up over half of the park's annual visitors (Apio, 2015). Beyond tourism, the boost in Akagera has had an impact on agriculture, mining, transport and industrial sectors Well-managed parks generate revenue from job creation, tourism and other sustainable development projects, stimulating a conservation-led economy (SNV, 2021).

Community development where Akagera's income-generating activities enhance the acceleration of economic development, and includes projects such as honey harvesting, a fishing cooperative, and a women's chicken cooperative. Overall, nearly US$1 million of economic activity flowed from the park into the surrounding communities in the form of revenue sharing, casual wages, local purchases, rentals and payments in 2022. Through its community development strategy, Akagera National Park is increasingly interwoven into the fabric of its neighbouring communities. Working with the more than 500,000 people living in these areas is critical to the park's long-term viability. More than ten years of community development and ensuring that the park delivers tangible benefits to the local communities has made Akagera a source of pride and a valued asset in the region (African Parks, 2016).

On other side, community engagement is yearly gatherings with the communities ensure good communication and engagement. Akagera plays a key role in communication and engagement, from the government level to village meetings where two-way conversations take place. Over 6,000 community members participate annually in gatherings to discuss conservation and human-wildlife conflict issues, and engagements with cooperatives to assist in business development. Sporting events are regularly hosted by the park attracting thousands of spectators, and building goodwill and positive relations (SNV, 2021). For education and environmental awareness, eco-clubs focus on environmental messaging such as the importance of planting trees. In addition to building and supporting schools, Akagera educates local schoolchildren on the importance of biodiversity, which is critical to creating a constituency for conservation. The park has hosted regular environmental education awareness sessions each year, with over 1,500 students and teachers from 55 schools bordering the park visiting in 2022. Regular eco-club teacher training and eco-club events help convey strong conservation messages to thousands of adults and children (Macpherson, 2013b). With community infrastructure development, Gishanda Fish Farm is a new sustainable socio-economic development project for Akagera and its community's infrastructure projects that improve the quality of life for local communities have expanded year on year. Other projects includes: constructing schools, health centres and libraries; building water-provision sites; and helping develop local associations and small enterprises (Macpherson, 2013a; Durydiwka, zajadacz and Duda-gromada, 2022).

3.2. Conceptual Framework of the Methodology

The figure (1) below shows the general framework and chain starting by the acquisition of data which are processed to give a meaningful information to respond to research objectives.

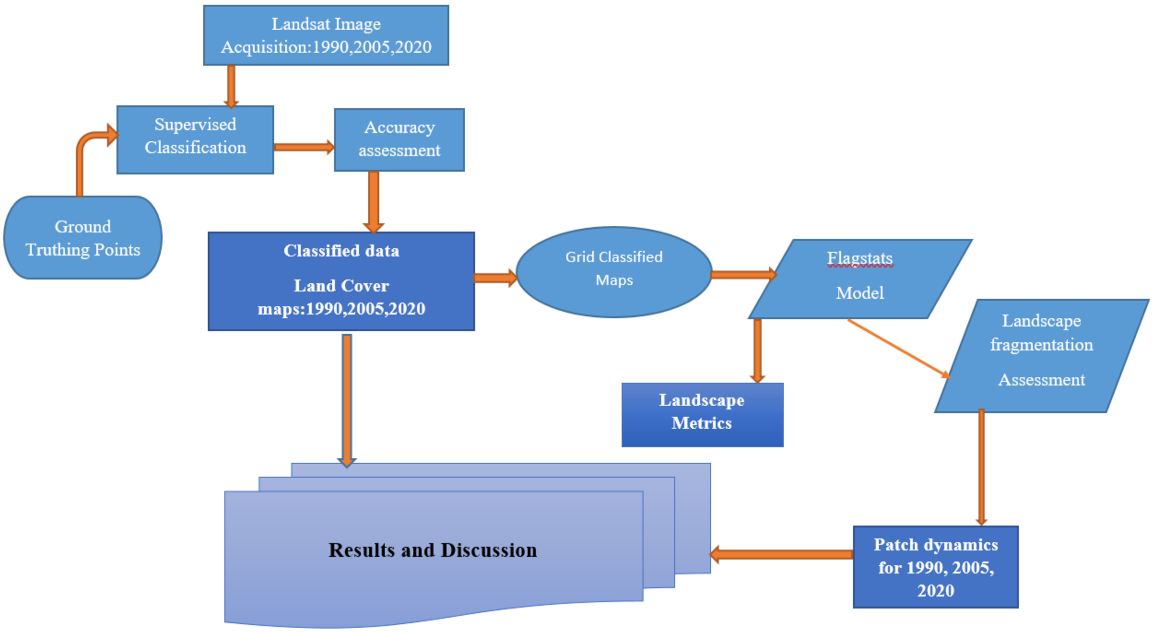


Figure 1: Flowchart of the Methodology

The table below details the matrix of this research

Table 1: Research Matrix

Research objectives	**Research questions**	**Data required**	**Tools &software**	**Methods**
To describe and map major LC types of eastern savannah ecosystem (ANP) over time (1990, 2005 and 2020)	What is status and rate of LC transformations between 1900 to 2020 and major LC types of eastern savannah ecosystem and habitat for specific flora and fauna?	-Landsat Images -Classified images	ERDAS Imagine, ArcGIS 10.8	-Supervised Classification &Image analysis -Change detection
To detect the changes of main LCU between 1990 and 2020.	What is the status and rate of LULC transformations between 1990 and 2020?	Maximum likelihood classification	ERDAS image, ArcGIS 10.8	Change detection
	What is the status and rate of LULC transformations between 1990 and 2020?	LCU maps	ERDAS Imagine 9.2 FRAGSTATS 4.2	Modelling
To analyse the impact of LCU changes on natural habitat fragmentation during the study period.	What is impact of LCU changes on natural habitat fragmentation during the study period?	Existing researcher paper &Library	Microsoft excel, word	Desk review.

3.3. Method of data collection and techniques

3.3.1 Literature selection and collection

A desk review was used to gain an understanding of the existing research and debates relevant to a particular topic or area of study, and to present that knowledge in the form of a written report (Komossa *et al*., 2018). Different papers and books on the similar topic were consulted to identify inconstancies: gaps in research, conflicts in previous studies, open questions left from other research while noting the need for additional research (justifying your research). Generally, as among other methods, literature reviews are essential for: (a) identifying what has been written on a subject or topic; (b) determining the extent to which a specific research area reveals any interpretable trends or patterns; (c) aggregating empirical findings related to a narrow research question to support evidence. Desk review involved reading scientific articles, books and reports about land use land cover changes and their impacts. Reading published materials on urbanization and land use land cover changes contribute to a better understanding of impacts LULC Changes and its impacts. Furthermore, desk review involved exploring the existing data, publication and research articles from either library or other online academic research platform (Jia *et al*., 2018).

Savannah is a major prerequisite for suitable and sustainable land management and conservation purposes (Dimobe *et al.*, 2017). However, mechanisms for frequent update of the status and trends of land cover change and landscape dynamics are still missing (Padmanaban, Bhowmik and Cabral, 2017). The knowledge of the spatial distribution of vegetation types is an important information source for all social benefit areas. Remote sensing techniques are essential tools for mapping and monitoring of land cover (Yang *et al*., 2020). The development and evaluation of concepts for integrated land cover assessments attracted increased interest in the remote sensing community since evolving standards for the characterisation of land cover enable an easier access and inter comparability of earth observation data. Land cover, describing the physical state of the earth's surface, is a key information source for a variety of social sectors (Ibitoye, Aboyeji and Adekemi, 2016). Geographic information products describing the spatial distribution of land cover are key management resources for environmental and socio-economic planning but also constitute an essential parameter for environmental modelling at all scales. Substantial progress in all technical engineering disciplines yielded to increasing accessibility of environmental geo-information data. Satellite and airborne technologies play a crucial role for the measurement, provision, and processing of land cover information (Jia *et al*., 2018). As a result, the user and producer community of remotely sensed land cover data increased during the last decades, subsequently the implementation of earth observation technologies found its way into a wider range of scientific disciplines.

3.3.2. Primary and secondary data collection

3.3.2.1. Satellites images acquisition

Three clouds free images were downloaded from U.S Geological Survey (USGS) https://earthexplorer.usgs.gov/ being L5-ETM+(1990), L7-ETM+(2005) and L8 OLI/TIRS (2020) to evaluate Akagera National Park landscape and other land covers in three different time scales. In two different spectral forms that are 30m resolution (multispectral bands) and 15m (panchromatic bands), those images were downloaded to merge the two spectra for strong resolution images. An area of interest was digitized and taken from google earth images to be used in the downloaded images, which corresponding with the former area of the park. In addition, high-resolution images (Google Earth images) were used as reference to create sample points to train and validate the Landsat image classifications. The high-resolution images were acquired as close as possible to the acquisition dates of the Landsat images. The spatial data used in this study were geometrically adjusted (co-registration) to the Landsat images and geo-referenced to WGS84. All three images were free of clouds. Image-to-image co-registration were performed in order to ensure good alignment of pixels in the respective images

3.3.2.2. Ground truthing and others spatial data collection

Segment and sampling techniques were used for creating points that represent different land covers types inside the park. Those points (geographical coordinates) were used during image classification process as ground trothing points (see appendix A) in the study. The shapefile of Akagera national park were collected from REMA as secondary. Besides this, field observation (see appendix B) was made to have better information about the nature of the various land use and land cover classes prevailing in the study area.

3.4. Data analysis and Interpretation

3.4.1. LC Mapping and Changes Detection

3.4.1.1. Image Classification

Image classification supervised classification was performed using the maximum likelihood algorithm (MLC) on each image in order to generate LULC maps for 1990, 2005 and 2020.

Six LULC classes natural forest, woodland, tree savannah, shrub savannah, bare soil, and water body representing the dominant LC categories was finally identified in the study area. As a prerequisite to supervised classification, training sites were developed for all the LULC classes mentioned above for each image. Field data enabled the generation of training and validation data for the classification. Two main software ERDAS Imagine 9.2 and ArcMap 10.8 were used in data preparation for a final meaningful information. Maximum Likelihood classifier (MAXLIKE) scheme and land cover changes on three Landsat's images 1990 L5 ETM+, L7 ETM+, and 2020 L8 OL/TRS were used in order to quantify change happened for land cover as well as natural forest, woodland, tree savannah, shrub savannah, bare soil, and water body. Polygons of homogeneous pixels were drawn around; each truth point for each LULC class and saved as vector layer of training areas. Landsat pixels that overlap the training areas was then used to perform the classification. Two sets of training data that was been collected from the Landsat images using image analysis tools in ERDAS imagine.

Land cover classes are typically mapped from digital remotely sensed data through digital image classification and interpretation (Song *et al.*, 2016). Image classification process replaces visual analysis of the image data with quantitative techniques for automating the identification of features in a scene. This normally involves the analysis of multispectral image data and the application of statistically based decision rules for determining the land cover identity of each pixel in an image covering ANP. The overall objective of the image classification procedure is to automatically categorize all pixels in an image into land cover classes (Meshesha, Tripathi and Khare, 2016). In this study, two approaches (unsupervised and supervised classification were used for image classification and mapping of LC of the study area. (Dhanda *et al.*, 2015) The three-time period images of the study area were first classified through computer automated supervised method in ERDAS IMAGINE 9.2 classifier. This Supervised classification of all images was carried out using the Maximum Likelihood Classifier Technique in ERDAS Imagine software version 9.2. Moreover, the ground coordinates points from segment and sampling techniques assisted to perform supervised classification and accuracy assessment (Pham *et al.*, 2014). The data was entered into a spreadsheet and subsequently overlaid on the satellite images. These points made up the training areas where representative polygons for each classification were drawn. These training areas were then used to define the digital signature used for the supervised classification.

3.4.1.2. Accuracy assessment

For a meaningful information on Akagera national park land cover change, the performance of accuracy assessment is of high importance for understanding, estimating the changes occurred from 1990 to 2020. This gives us correspondence certainty on classification and ground reality. Random samplings sites points were generated and plotted on google earth images of 1990,2005 and 2020 respectively. A classification is not complete unless its accuracy is assessed (Congalton, 2001) . Thus, the classified images were validated using one-third of field data selected randomly and at each point, the classified image pixel was compared with the reference data of LULC class. Overall accuracy for the 2020 LULC map is assessed using ground coordinates points which was collected using segment and sampling techniques. Pixels in these validation sites has been generated randomly and used to generate a classification error matrix for each classified image. Afterwards, overall accuracy user's and producer's accuracies and the kappa statistic was then have derived from the error matrices.

Once images had been classified (supervised) then accuracy assessment of an image classification was done by creating the classification error matrix. In this confusion matrix, classification results were compared to ground truth data obtained during fieldwork. A measure for the overall classification accuracy can be derived from this table by counting how many pixels were classified the same in the satellite image and on the ground and dividing this by the total number of pixels (Dhanda *et al*., 2015). The user and producer accuracy widely used measures of class accuracy. The producer's accuracy refers to the probability that a certain land-cover of an area on the ground is classified as such, while the user's accuracy refers to the probability that a pixel labelled as a certain land-cover class in the map is really this class. After classification of satellite images, the accuracy of the classification derived from remote sensing sources is required to be assessed. One of such a method is the use of a confusion matrix, which is produced from the random sample of individual pixels/clusters compared to known cover conditions over the same pixel areas.

3.4.1.3. LC changes detection

Change detection is defined as a process of identifying fluctuations in the state of an object or phenomenon by observing images at different times (Balew and Semaw, 2022). Change detection help us to know the pattern of land cover change and processes of forest cover change (Koruyan *et al.,* 2012). Evaluating coverage change using RS and GIS technologies has been found to be effective and efficient by many researchers (Shalaby and Tateishi, 2007).

The success of change detection from imagery depends on both the nature of the change involved and the success of the image preprocessing and classification procedures (Dhanda *et al., 2015)*. If the nature of change within a particular scene is either abrupt or at a scale appropriate to the imagery collected then change should be relatively easy to detect; problems occur only if spatial change is subtly distributed and hence not obvious within any image pixel (Sajjad *et al*., 2015a). In the case of the study area maximum likelihood supervised classification and post-classification change detection techniques were applied to Landsat images acquired in 1990, 2005 and 2020, respectively, to map land cover changes in Akagera national park (ANP). A supervised classification has been carried out on the reflective bands for the 3 images individually with the aid of ground truth data. Post-classification change detection technique helped to produce change image through cross-tabulation, thus changes among different ANP land cover classes were assessed.

3.4.2. Landscape metrics and habitat fragmentation

3.4.2.1. Landscape metrics

In order to calculate landscape metrics, LULC maps were converted into grid format using ERDAS imagine and introduced into the FRAGSTATS 4.2 software. The following metrics was quantified: Number of patches (Han, Yang, & Song, 2015), which is the number of patches of the corresponding patch type (class). Higher NP indicates greater fragmentation while lower NP indicates lower fragmentation, (b) Patch density (PD): is the number of patches of the corresponding patch type divided by total landscape area (m^2), (c) Largest Patch Index (LPI): the area of the largest patch in each class (in hectares), (d) Class percentage of landscape (PLAND). It equals the percentage of the landscape comprised of the corresponding class type. Other metrics are patch density PD Landscape, largest patch index LPI landscape, patch area, landscape, Euclidean nearest neighbour distance, patch cohesion index COHESION class connectivity and Shannon's diversity (Hassan *et al.* 2016).

3.4.2.2. Analysis of habitat fragmentation of Akagera NP using Fragstat spatial metrics

Different types of landscapes have an impact on different types of biological processes which involves biotic and abiotic environment. Hence, when that natural link is disturbed, it has an impact on multiple ecological processes and there is a break in the link. This process is called fragmentation (Zhang *et al*., 2017). The major reason for this fragmentation is human interference. This may further lead to disruption and degradation of ecosystem. The whole process of the disruption process can be summarized as perforation, dissection, dissipation and shrinkage. Landscape metrics is used here to understand the level of disruption. Hence, the study of spatial metrics to study the extent of landscape fragmentation has become an important area of research (Han, Yang, & Song, 2015).

The availability of satellite data at different resolutions the study of fragmentation metrics has become important and comparison between images has become significant. The selection and calculation of spatial metrics can be applied (Dhanda *et al.*, 2015) The landscape metrics is often called as spatial metrics is used for other environments like urban areas. The term "spatial metrics" can be defined as measurements derived from the digital analysis of thematic-categorical maps exhibiting spatial heterogeneity at a specific scale and resolution. Landscape metrics are algorithmic program that quantify specific spatial characteristics of patches, classes of patches, or entire landscape mosaics (Pham *et al.*, 2014). Many landscape metrics have been developed to quantify landscape structure and spatial heterogeneity based on landscape composition and configuration. Some class-level parameters quantifying landscape fragmentation metrics at each time were calculated using Fragstat tool: CA: absolute class area, PLAND: Percentage of Landscape, NP: number of patches, PD: Patch density, LPI: Largest patch Index, AWMSI: Area-Weighted Mean Shape Index and SI: Shannon Index and they are described in Table 2 (Zhang *et al.*, 2017).

Table 2: Landscape indices used in the study area.

≠	**Index**	**Symbol**	**Definition**	**Formula**	**Key reference**
1	Number of patches	NP	Number of patches divided by area	NP =Ni	(Martins *et al.*, 2018)
2	Patch richness	PR	Patch richness (Lamprey & Reid) measures the number of patch types present; it is not affected by the relative abundance of each patch type or the spatial arrangement of patches. Therefore, 2 landscapes may have	$PR = m$	(Bekalo, 2009)

			very different structure yet have the same richness.		
3	Large patch index	LPI	LPI quantifies the % of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance	LPI = MAX(a1……an)*100/A	(Martins *et al.*, 2018)
4	Total Class Area	CA	The sum of the areas of all patches of the corresponding patch type	CA=sum(P1+P2+… …..+Pn)	(Yakubu, Hassan and Asiribo, 2018)
5	Total Core Area	TCA	Indicates that landscapes A, B, C contain progressively more core area, and because total landscape area is similar, they represent a continuum from most to least patchy. Note that all core area indices are affected by the interaction of patch size, patch shape, and edge width	TCA=CA1+CA2+… +CA…n	(Martins *et al.*, 2018)
6	Percentage of landscape	PLAND	It equals the sum of the area (m2) of all patches of the corresponding patch type, divided by the total landscape area (m2), and multiplied	$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A} (100)$	(Mugiraneza, Ban and Haas, 2019)

			by 100 (to convert to percentage)		
7	Shannon's diversity index	SHDI	SHDI is a popular measure of diversity in community ecology, applied here to landscape. SHDI is somewhat more sensitive to rare patch types than Simpson's diversity index.	$SHDI = -\sum_{i=1}^{m}(Pi \cdot \ln Pi)$	(Gao *et al.*, 2014)
8	Shannon's Evenness Index	SHEI	SHEI is expressed such that an even distribution of an area among patch types results in maximum evenness.	$SHEI = \frac{\sum_{i=1}^{m}(P_i \cdot \ln P_i)}{\ln m}$	(Bekalo, 2009)
9	Core Area Percentage of landscape	CPLAND	t is the percentage of core area of class in relation to the total landscape area	$CPLAND = (\frac{\sum_{j=1}^{n} a_{ij}^{core}}{A}) * 100$	(Zhang, H. Te Kung and Johnson, 2017)

Source: (Zhang *et al.*, 2017)

CHAPTER FOUR: RESULTS AND DISCUSSIONS

The purpose of this chapter is to use data from the study area to test and investigate land cover change and habitats/ecosystem fragmentation using geo-spatial techniques and landscape metrics. This section presented the results of this study based on the research methodology adopted by author; with reference to the data collected from the field. It presents an analysis of the findings, their meaning and discussion based on the outcomes of the present study. It began by describing the LULC classes in the study area and presenting results of each objective of the study. Although, the chapter provides the findings of each of the research objectives. Then it concluded with a concise summary by discussing the findings of the whole chapter.

4.1. Results

4.1.1. The LCU types of eastern savannah ecosystem and defined habitat for specific flora and fauna

The supervised image classification for Akagera National Park (ANP) produced maps for LULC of the area from ETM+ images downloaded from the website of United States geological survey for the year 1990, 2005 and 2020. The classification categorized the area into five main land use/ cover classes as elaborated as follows:

Table 3: LC class description

LULC class	**Descriptions**	**Image features**
Grasslands	Grasslands are areas dominated by grasses, with few trees or shrubs. In Akagera National Park, grasslands cover a significant portion of the park and are an important habitat for many different types of wildlife. The grasses provide an important source of food for herbivorous animals such as antelopes, zebras, buffaloes, and giraffes. The open landscape allows these animals to graze and move freely, while also making them more visible to predators such as lions and hyenas	Colour Texture Hue Shape
Water	Permanent natural water and/or flowing water bodies including lakes, rivers, and streams. In Akagera National Park, there are several lakes, including Lake Ihema, which provides an important habitat for a variety of aquatic species such as fish,	Colour Texture Hue Shape

	crocodiles, and hippos. The Akagera River also flows through the park, providing an important source of water for wildlife and supporting a variety of aquatic and riparian species	
Forest/Shrub	These areas dominated by trees, with a dense canopy that can limit the amount of light that reaches the forest floor. In Akagera National Park, there are areas of woodland dominated by acacia trees, as well as areas of riverine forest along the banks of the Akagera River. These forested areas provide important habitat for a variety of mammal species, including giraffes, elephants, and primates such as baboons and vervet monkeys. They also provide important ecosystem services such as carbon sequestration and soil conservation	Colour Texture Hue Shape
Bare land	Uncovered, permissive land/soil. Bare land are areas of land that have no vegetation cover, or very little vegetation cover. These areas can be important for certain types of wildlife, such as reptiles, which require bare ground for nesting.	Colour Texture Hue Shape
Wetlands	Wetlands are areas where the land is saturated with water, either permanently or seasonally. In Akagera National Park, wetlands include swamps, marshes, and floodplains. These areas are an important habitat for a variety of bird species, including the rare shoebill. They also provide a crucial habitat for aquatic species such as crocodiles, hippos, and fish	Colour Texture Hue Shape

4.1.2. Land cover types in Akagera National Park during last three decades (1990, 2005 to 2020)

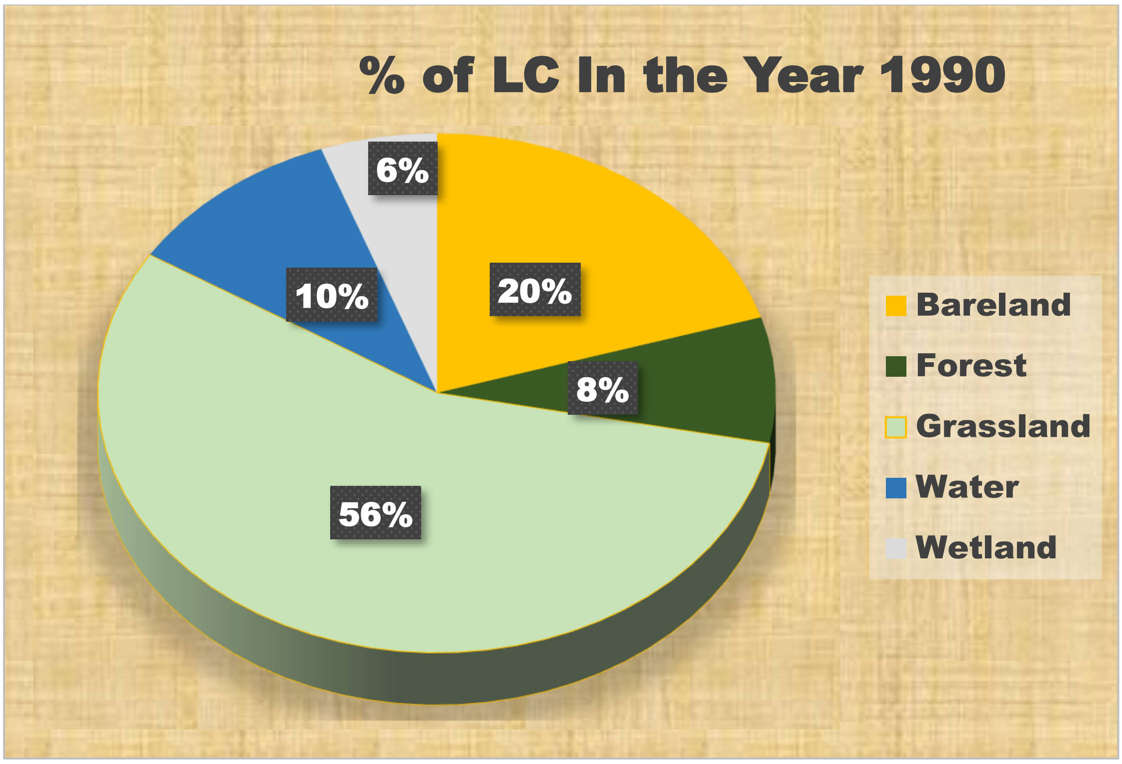
For observing the land use land cover of the study area, it was undoubtedly paramount important once to select major classes. Accordingly, only the most important major LULC classes in the study area was selected, and these classes are bare land, forest/shrub, grassland (savannah), water and wetland. The contingency tables obtained from the remote sensing-based classification shows the extent of each type of land use/ cover class at different study periods of the area.

Table 4: Overall LC classes distribution in ANP from 1990-2020

LC Class	1990		2005		2020	
	Area in Hectares	Percentage	Area in Hectares	Percentage	Area in Hectares	Percentage
Bare land	21915.10192	20.29%	26497.29178	24.54%	19668.67439	18.21%
Forest/ Shrub	8441.1683	7.82%	10299.77183	9.54%	9924.480338	9.19%
Grassland	60274.21267	55.82%	56712.224	52.52%	61541.90204	56.99%
Water	11357.1162	10.52%	10914.14325	10.11%	15210.59334	14.09%
Wetland	6000.307833	5.56%	3564.476065	3.30%	1642.25682	1.52%
Total	**107987.907**	**100.00%**	**107987.907**	**100.00%**	**107987.907**	**100.00%**

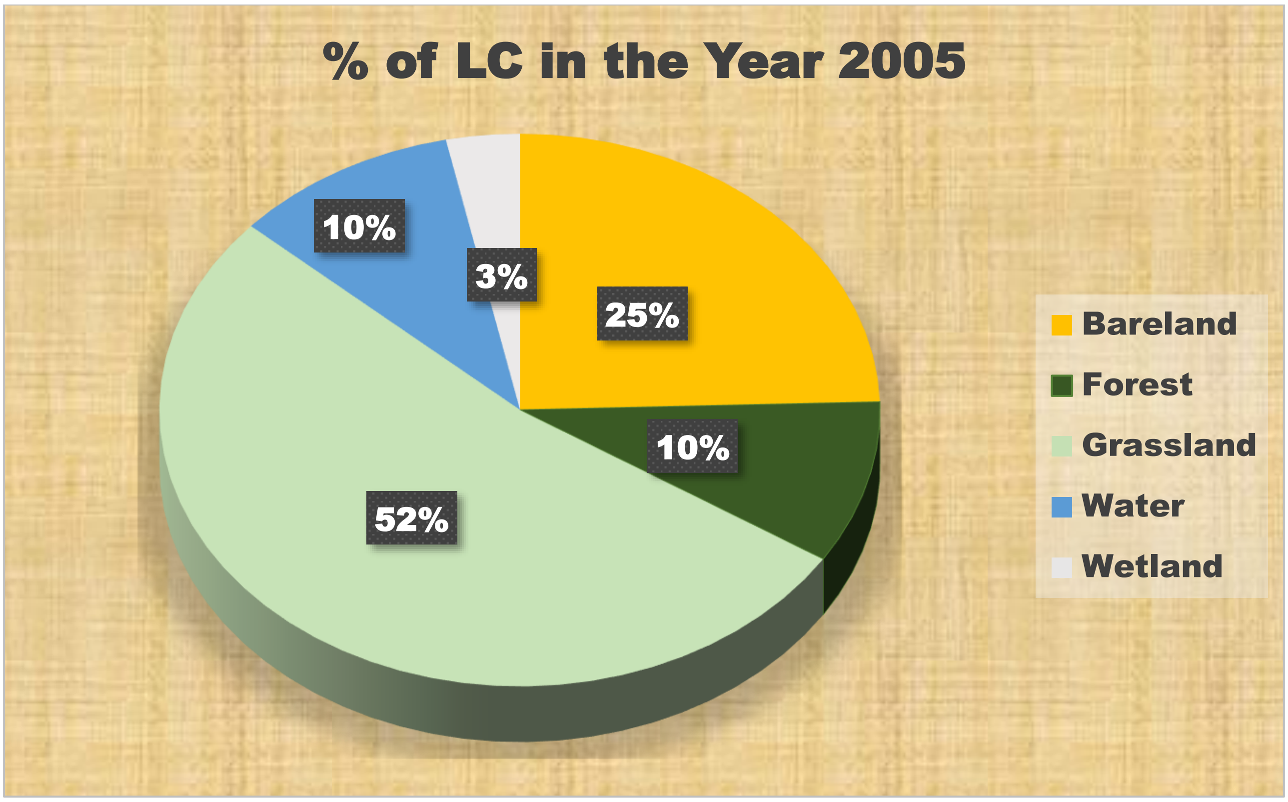
4.1.2.1. LC of ANP in 1990

The result obtained from the classified Landsat image of 1990 show that; the dominant land cover of the study area within this period is grassland/savannah land that account 56% of the of ANP. The other dominant land cover class is bare land, water, forest/shrub and wetland that account 20%, 10%, 8% and 6 % respectively.



4.1.2.2. LC of ANP in 2005

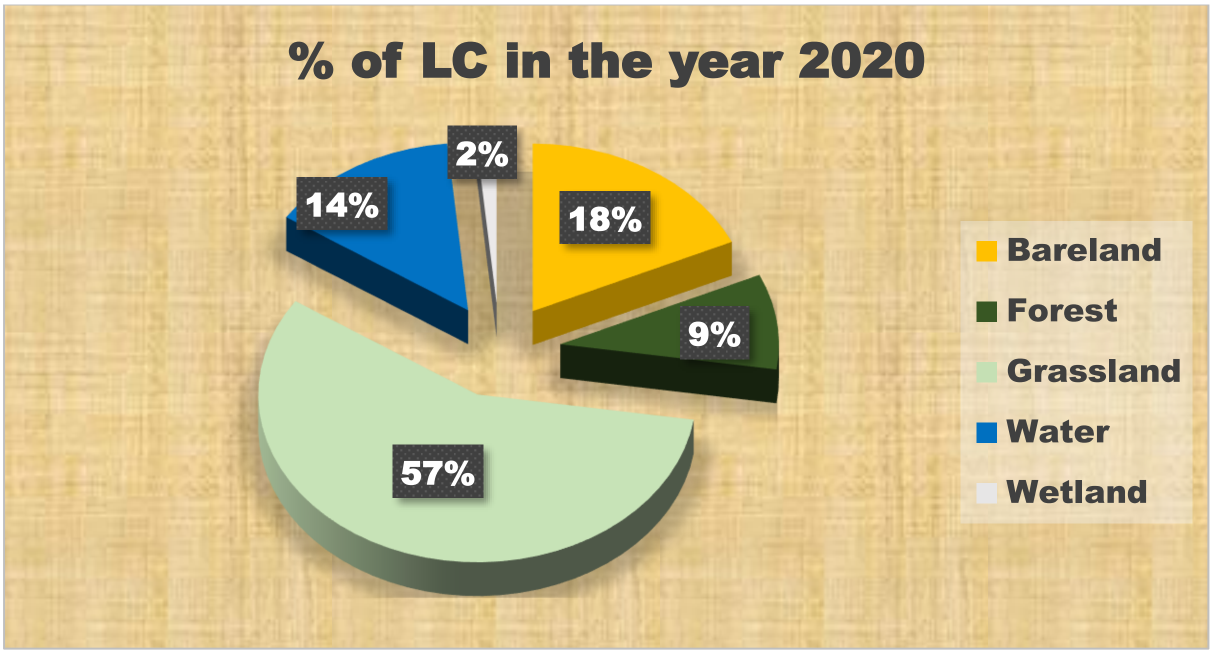
The result obtained from the classified Landsat image of 2005 show that; the dominant land cover of the study area within this period is grassland/savannah which account 52% of the ANP. The other dominant land cover class are bare land, water, forest and wetland that account 24.5%, 10.1%. 9.1% and 3.5 % respectively.



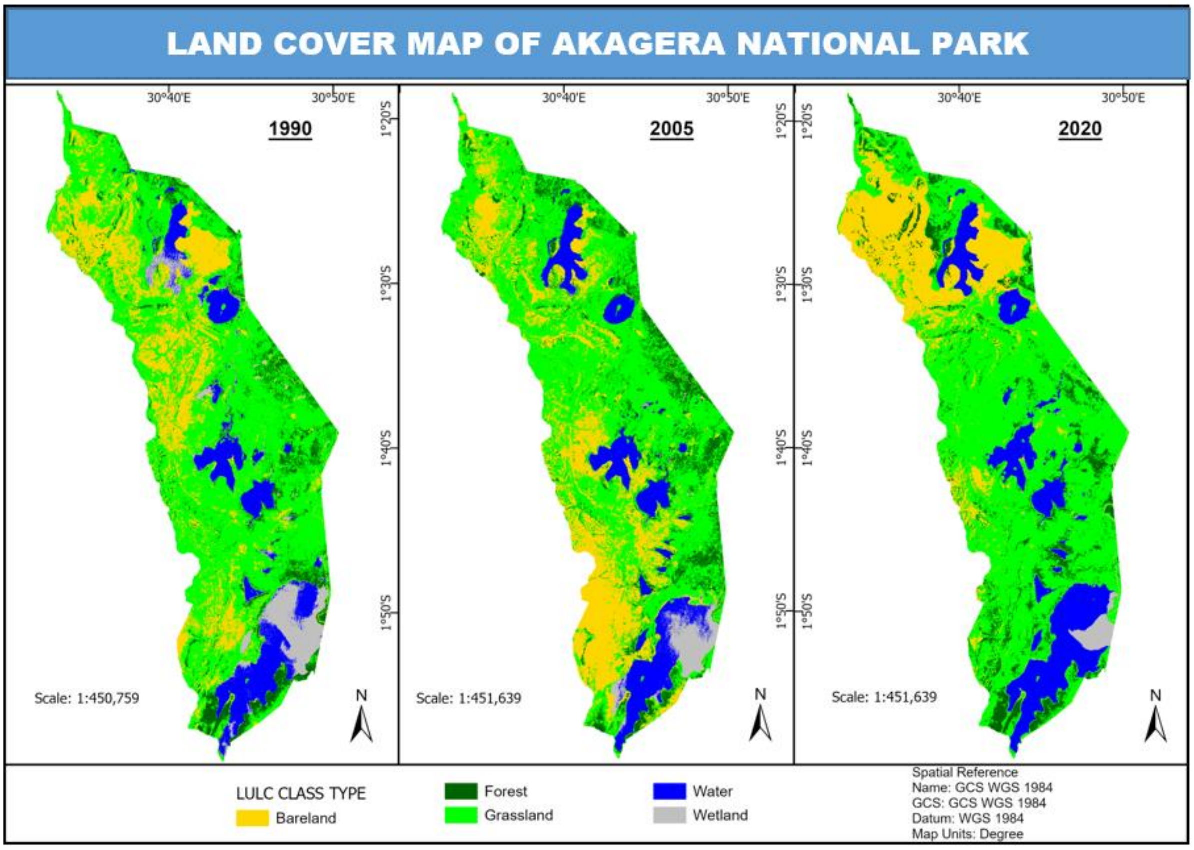
After classifying Landsat image of 2005, statistics showed that grassland/savannah has 56,712.2ha, bare land has 26,497.3ha, and water has 10,299.8ha while forested/shrub land and wetland has 10,914.1ha and 3564.5ha respectively.

4.1.2.3. LC of ANP in 2020

Classification showed that Landsat image of 2020 show that; the dominant land cover of the study area within this period is grassland/savannah which account 57% of the total study area. The other dominant land cover class are bare land, water, forest, and wetland which account 18%, 14%, 9% and 2% respectively.



The result obtained from the classified Landsat image of 2020 show that; savannah or grassland area have 61,541.9.64 ha of the study area which account 57% of the total area of ANP.



4.1.3 Land cover change detection

Change detection of LC was the key aspect of this study by using satellite images. The supervised classification method has been used in this study, which is well established. This classification method helps in grouping the LC sensed from satellite imageries. The researcher assessed the changes in LC classes from 1990 to 2005, 2005 to 2020 and 1990 to 2020. Accuracy of the classified Landsat images of 2020 was evaluated by taking a total of 100-ground truth coordinates point from the google earth by using segment and sampling techniques for each land cover categories.

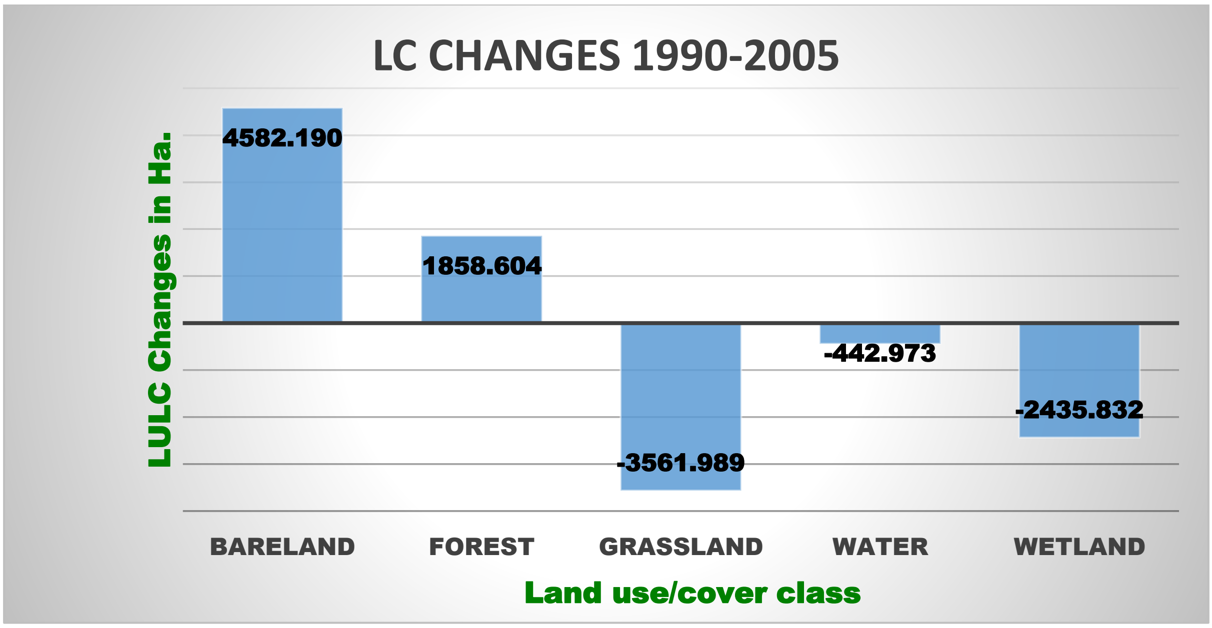
Table 5: Accuracy evaluation result of classified image 2020

LC Classes	Grassland	Forest/shrub	Bare land	Water	Wetland	Total	User's Accuracy
Grassland	33	4	0	0	11	**48**	66
Forest/shrub	3	72	5	1	0	**81**	88.9
Bare land	2	3	100	4	10	**119**	84
Water	0	1	0	30	16	**47**	57.7
Wetland	0	0	0	3	150	**153**	98
Total	**38**	**80**	**105**	**38**	**187**	**448**	
Producer's Accuracy	86.84	86.67	80	78.95	80.21		**Overall: 85.95%**

The overall classification accuracy of the classified Landsat images of 2020 was 85.95%. The User's accuracy and producer accuracy was 86.84% and 86.67% for grassland/savannah and forest/shrub respectively while water has the lowest producer's accuracy and users 'accuracy (78.95%).

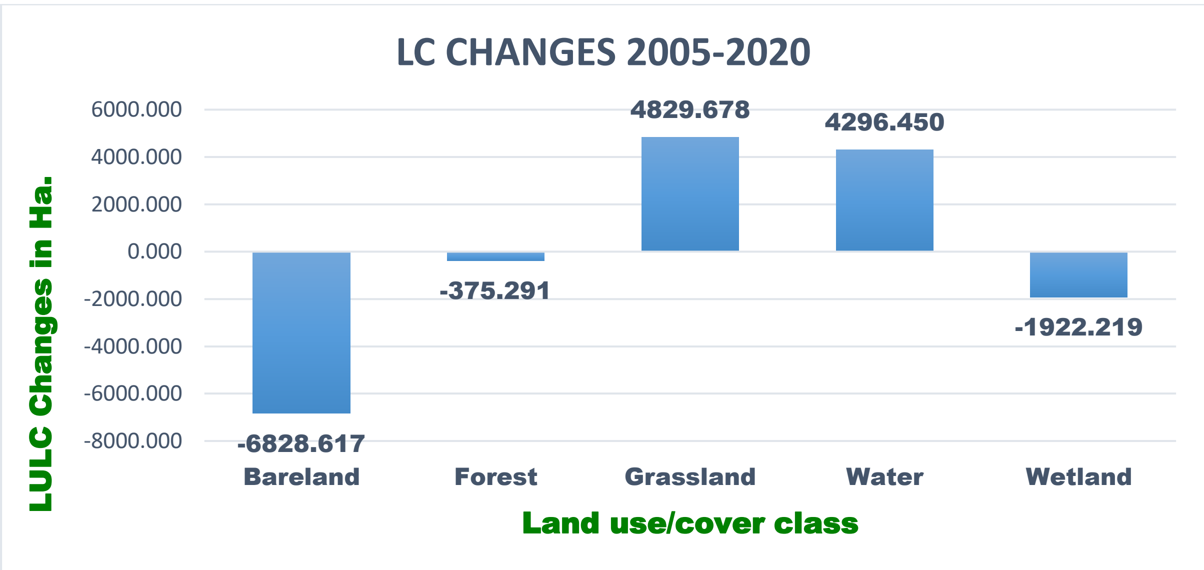
4.1.3.1. LC change between 1990 to 2005

Within 15 years i.e. from (1990-2005) in the ANP, grassland/savannah and wetland showed maximum changes. More specifically; grassland/savannah area, water and wetland decreased by -3561.98ha, -442.93ha and -2435.83ha respectively with a rate of change of -237.47ha/year, -29.53ha/year and -162.39ha/year respectively. Whereas bare land increased to 4582.190 ha with a rate of change of 305.48ha /yr. Forested land also shows significant changes with an increase of 1858.6 ha with a rate of change of 123.91ha/year.



4.1.3.2. LC change between 2005 to 2020

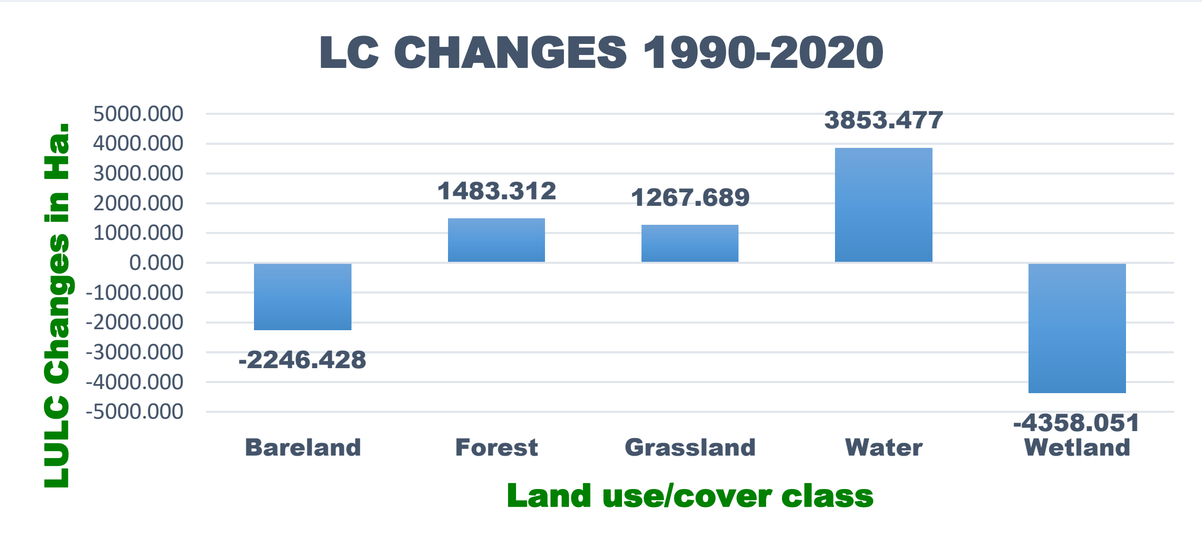
When comparing 2005 LU/LC classification with 2020 LC classification, there are changes that showed decrease or increase in particular land use land cover. The land use/cover categories that showed increase are only grassland/savannah and water area. In 2020, 57% of the study area covered by grassland area which was increased to 4829.678038 Ha in 2020 with 321.98ha/year while area occupied by water has increased to 4296.450 Ha with 286.43ha/year. On the other hand, the land use land cover categories like bare land, wetland and forested land and showed decreasing pattern with -455.24ha/year, -128.15ha/year and -25.02ha /year of average rate of changes respectively. This is mainly related to human induced factors on existing natural resource of the area.



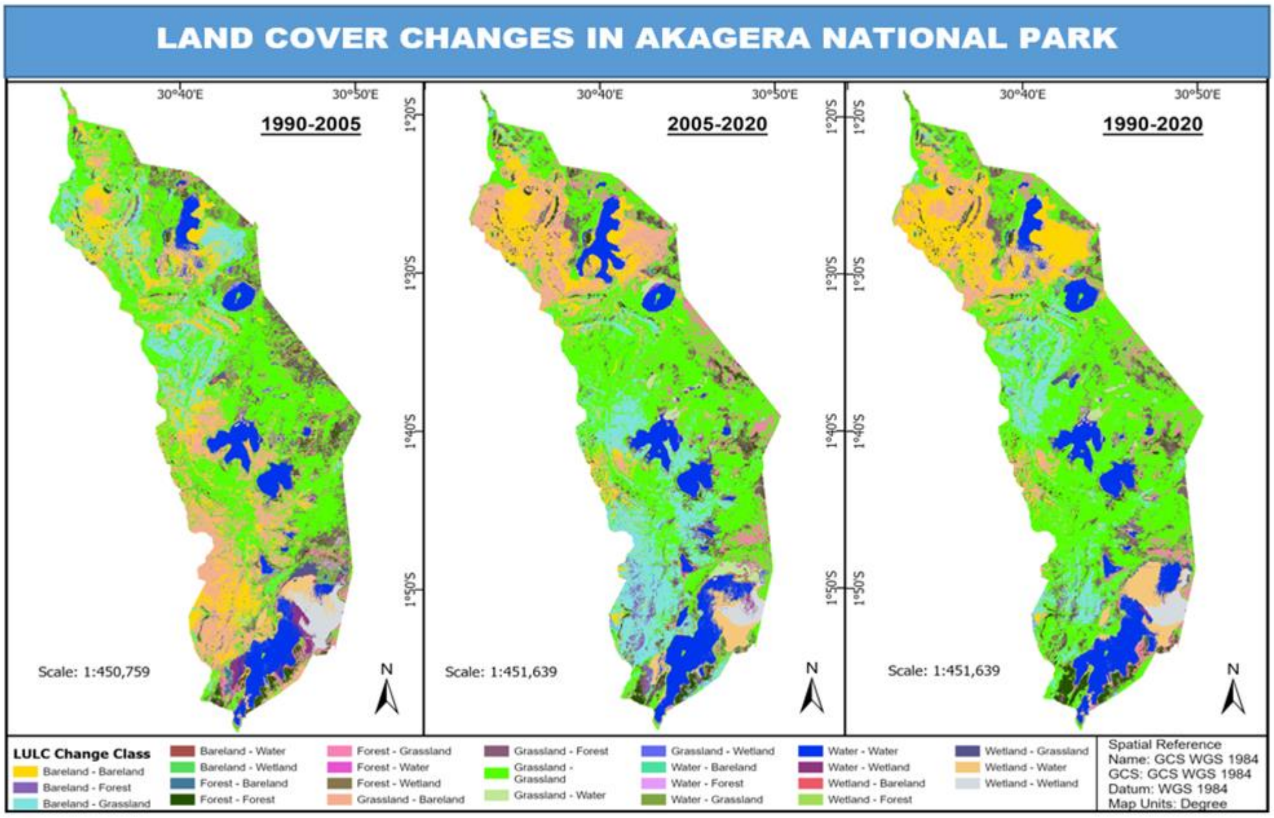
Grassland/savannah was radically increased in the period of 15 years due to the conservation efforts and Akagera National Park strong management. This was mainly related to the observed rapid population decrease and settlements demolition due to the expropriation to extend the buffer zone of the park.

4.1.3.3. LC change between 1990 to 2020

To drive LULC changes of the study area satellite images of 1990, 2005 and 2020 have been considered. The whole-time range has been segmented into two; 1990 to 2005 and 2005 to 2020 and finally the overall change (30years) has been assessed. The rate of change (difference in area from the final to the initial state of each land use/cover category over the specified time period or number of years in each period) across the study period has also been analyzed based on the statistical data derived from the images. Generally, the LULC types in the three study periods gradually changed with differing rates depending on the existing socio-economic, political, and environmental situation.



Considering the overall study period (30years), there was a remarkable increase in a real extent of grassland/savannah area of land from 60274.2ha (55.8 %) in 1990 to 61541.9ha (57%) in 2020. Wetland and bare land were diminished at a higher rate within these 30 years.



By considering the overall study period (30years) with focus on the land cover transition inside and outside the park; the results indicate that there was a remarkable increase in a real extent of grassland/savannah area of land from 60274.2ha (55.8 %) in 1990 to 61541.9ha (57%) in 2020. Consequently, wetland and bare land were diminished at a higher rate within the park.

4.1.4. Magnitude of Landscape fragmentation during the study period

In this study, the forest fragmentation was assessed using the Fragstat 4.0 software for different classes using specific metrics. Fragstats 4.0 spatial pattern analysis was applied for different land use classes that to be derived from LULC maps to be done from the Landsat 8 digital data. Class Area (CA), Percentage of Landscape (PLAND), Largest Patch Index (LPI), Number of Patches (Han *et al*., 2015), Patch Density (PD), Area Weighted Mean Shape Index (AWMSI) at the class level has been quantified in the study area. These spatial metrics are good, simple and helpful in quantification of patches dynamics and spatial processes and can be used as an effective means for monitoring Akagera NP Landscape. Landscape metrics (Tilman *et al.*, 2001) were derived with FRAGSTATS Version 2018, a spatial pattern. The landscape patterns were computed and analyzed at class, patches and landscape levels. Landscape indices in FRAGSTATS are quite effective for describing the landscape changes or fragmentation refer to both human activities and natural effect. Some metrics were generated for characterizing the study area's landscape evolution from 1990 to 2020. A landscape pattern index is an indicator of spatial landscape patterns, with reflects the characteristics of the landscape composition. Then 10 landscape indices were chosen to display the LULC of ANP. These indices include number of Patches (Han *et al., 2015*), largest patch index (LPI), patch richness (Lamprey & Reid), Total class Area (CA), Total core Area (TCA), Percentage of landscape (PLAND), Core area percentage of landscape (CPLAND), Shannon diversity index (SHDI), Shannon evenness index (SHEI).

In my study area, selected metrics are often used, and they are key for describing the landscape. The landscape configuration can be assessed by elucidating the TECI, CWED, LSI and AI given that these indices were judged suitably for characterizing spatial arrangement of landscape habitant types. Land use land cover dynamics are most of the time coupled with habitats fragmentation and conversion of existing LULC. The level of fragmentation is easily tracked by either counting the change in the number of patches in particular patch mosaic, and/or the change in the number of patches per unit area. Using the FRAGSTAT Software; metrics for classes, patches and landscapes were computed: Classes, Landscape and Patches

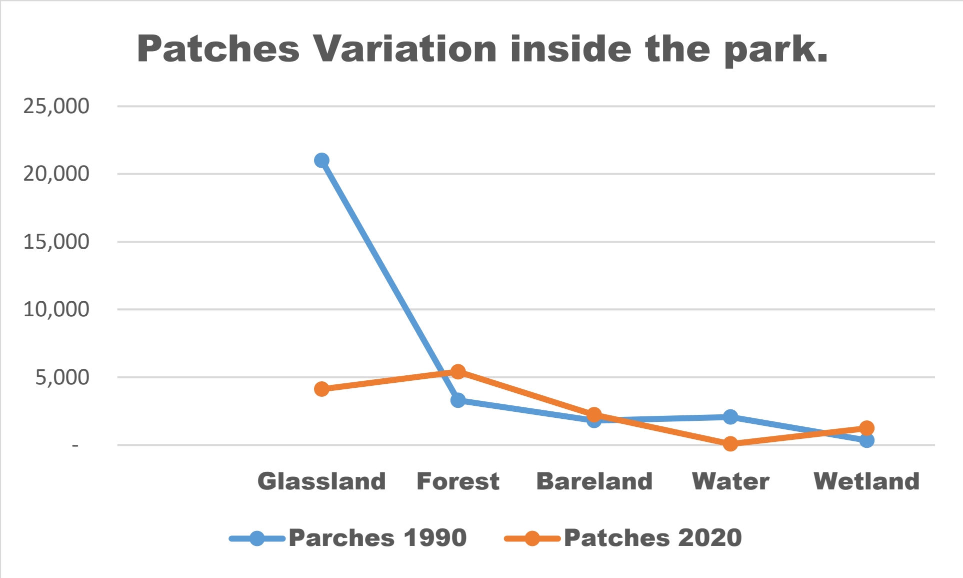
- **For classes**: Total class area (CA), Percentage of landscape (PLAND), Large patch index (LPI), Total core area (TCA), Percentage of Landscape (CPLAND)
- **For Landscape**: Total core Area (TCA), large patch index (LPI), Shannon's diversity index (SHDI) and Shannon's evenness index (SHEI)
- **For Patches**: Number of patches (Han *et al*., 2015) and patch richness (Lamprey & Reid, 2004)

Table 6: Metrics of landscape fragmentation

Classes										
LC Classes	1990					2020				
	CA	PLAND	LPI	TCA	CPLAND	CA	PLAND	LPI	TCA	CPLAND
Glassland	60,274.21	55.80	59.60	60,274.21	55.80	61,541.90	57.0%	62.09	61,541.90	57.0%
Forest	8,441.17	7.80	1.13	8,441.17	7.80	9,924.48	9.2%	1.25	9,924.48	9.2%
Bareland	21,915.10	20.00	22.08	21,915.10	20.00	19,668.67	18.2%	20.06	19,668.67	18.2%
Water	11,357.12	10.50	13.09	11,357.12	10.50	15,210.59	14.1%	16.45	15,210.59	14.1%
Wetland	6,000.31	5.90	4.10	6,000.31	5.90	1,642.26	1.5%	0.15	1,642.26	1.5%
Landscape	TA	LPI	TCA	PR	SHDI	SHEI				
LANDSCAPE 1990	107987.9	72.486	107987.907	5	0.8603	0.5345				
LANDSCAPE 2020	107987.9	72.486	107987.907	5	1.0085	0.6266				
Patches	LC Types	Parches 1990	Patches 2020							
	Glassland	20,999	4,110							
	Forest	3,305	5,409							
	Bareland	1,800	2,230							
	Water	2,060	75							
	Wetland	345	1,230							
	Total	28,509	13,054							

Source: Field survey, 2021

Results from table 6 indicate that, patches for grassland and water were reduced while the patches for forest, wetland and bare land increased. Due to landscape analysis at class level, landscape level and patches level, the results revealed that the values of overall patches decreased proportionally from 28,509 to 13,054.



Source: Field survey 2021

4.2 Discussion of the results

4.2.1 The LCU types of eastern savannah ecosystem

The only most important major LCU classes in the ANP was selected, and these classes are bare land, forest/shrub, grassland (savannah), water and wetland. Overall, LC classes distribution in ANP from 1990-2020 is presented in the table 4 obtained from the remote sensing based-classification. The table (4) shows the extent of each type of land use/ cover class at different study periods of the ANP whereby, the dominant land cover types of the study area within this period (1990-2020) is grassland/savannah land that account 56% of the total study area while the less prevalent land cover is wetland which varied 5.56% to 1.52%. Changes in the land-use reflect the history and, perhaps, the future of humankind. Such changes are influenced by a variety of factors related to human population growth, economic development, technology and environmental changes (Houghton, 1994). Changes in land cover can occur in response to human drivers. For example, the demand for new settlements often results in the permanent loss of natural and working lands, which can result in localized changes in weather patterns (Appiah Mensah, Akoto Sarfo and Partey, 2019). The reduction in some land cover classes indicates how people are using the land (Sajjad *et al.*, 2015b). By comparing land cover data and maps over a period of time, park managers can document land use trends and changes (Hashem and Balakrishnan, 2015). Land cover change (S. K. Robinson & Wilcove) is the study of land surface change. Land Cover (such as savannah, or grass and shrubs) describes human use of land, while land cover (such as forest or desert) describes the biophysical characteristics of the land surface so it was seen that some land cover classes reduced while other increased (Ogbole, 2013). With the understanding that driving forces of land cover change interact in complex ways; two key underlying drivers of change have been given particular attention population, which determines the demand and pressure on land resources and related activities in ANP.

4.2.2 Land cover changes and their impact on natural habitat fragmentation

To drive LC changes of the study area satellite images of 1990, 2005 and 2020 have been considered. The whole-time range has been segmented into two; 1990 to 2005 and 2005 to 2020 and finally the overall change (30years) has been assessed. The rate of change (difference in area from the final to the initial state of each land use/cover category over the specified time period or number of years in each period) across the study period has also been analyzed based on the statistical data derived from the images. Generally, the LCU types in the three study periods gradually changed with differing rates depending on the existing socio-economic, political, and environmental situation. Grassland/savannah was radically increased in the period of 15 years (2005 to 2020) due to the conservation efforts and Akagera National Park strong management. This was mainly related to the observed rapid population decrease and settlements demolition due to the expropriation to extend the buffer zone of the park. Obviously, the increase of bare land and decrease of grassland or savannah are associated with housing and agricultural activities by Rwandans returning from exile, which influence the land, cover change and integrity of the park in general. The whole period 30years clearly indicates how much dynamic the land use/land cover of the ANP. For instant, grassland/savannah area of land was the greatest land class of the final period were increased in a real extent, it got from bare land. Forested land and wetland that were converted to grassland. The bare land has increasingly decrease due to its conversion to grassland. There were different magnitudes of changes has been recognized over the study period. Some of the land categories increased and thus has positive mean rate of change but others were diminished and thus have negative rate of change the rate of change of grassland area of land indicates an ever expanding in positive direction. Wetland is the next showing decrement from year to year (Table4). In opposite

direction, both bare land and wetland have been diminished much more at a faster rate from year to year.
Analysis of land cover changes and landscape dynamics in Akagera National Park through time series as well as land cover mapping revealed that the transactions among the cover types were highly rendered by changes of land cover from 1990 to 2020. The results revealed a moderate degradation inside the park where bare land cover and wetland have been reducing approximately an annual loss of -74.88ha and -145.27ha respectively. This loss in forest cover inside the park has been converted into different classes among the land cover types found in ANP after classification especially “grassland”. This analysis highlighted those conversions among the land cover types basically triggered the reduction of forest cover size within the park. Given that, the major transitions mainly occurred among three classes during the entire study period (grassland, bare land and wetland).

Due to landscape analysis at class level, landscape level and patches level, the results revealed that the values of overall patches decreased proportionally from 28,509 to 13,054 (during 1990-2020 period a large decrease of the degree of fragmentation). The consequence of reducing the number of patches from 28,509 in 1990 to 13,054 in 2020 was the park management strategies set by the government. This fact determined increases in the mean patch area and in the largest patch index (LPI). Moreover, the reduction of fragmentation is proved by the Shannon’s evenness index (SHEI) of the landscape. This type of evolution given by the fact that patches became non-sparsed and the probability that two patches from the same class to be closer was high with reference to their spatial distribution. In the year 1990 study identified a high level of landscape fragmentation but they were reducing as the years go on until 2020. This evolution caused a decrease of the mean patch. The size of the patches registered large increases indicated a more uniformly configuration of the landscapes, because the patches were more regularly distributed across the study area. The analysis of patch and landscape metrics indicated that forest/shrub inside the park was slightly fragmented as reported by previous studies (Macpherson, 2013b; Gatali, Callixte Wallin, 2015; Kayiranga *et al.*, 2016b; Ndayisaba *et al.*, 2017). The two basic indices are used to quantify fragmentation are number of patches (Han et al.) and patch area (PA), usually measured as mean patch area (MPA). Similar investigations highlighted that the greater MPA the lower degradation (Dimobe *et al.*, 2017), conforming to the findings of this study especially the analysis of number of patches (table6). Normally due to the lowest change found in forest and wetland area without external incidents, the inner forest inside the park could have remained in its intact state. However, NP revealed that forest was affected and slightly patched. Despite the lowest level of forest fragmentation found inside the park; wetland in the park 's NP were represented by the highest values which indicated the high level of wetland fragmentation. Hence, in the whole, the forest was highly fragmented; following the assumption that the greater the number of patches the greater subdivision of forest cover may have incurred. Association between forest and other land cover types using change detection tool and fragstat software was suggested by Rajani (2017) as the most useful way to describe spatial association.

Akagera National Park is a protected natural reserve and the measures to preserve its rich biodiversity are initiated by Rwanda government (African Parks, 2016) and the park is registered as a protected area. However, the results of this study highlighted considerable forest losses (deforestation/habitat degradation) over the last few decades. Despite the entire protection protocol governing the park, several factors may have contributed to the losses observed including but not limited to the anthropogenic activities that have played a leading role throughout the degradation process. Those include paddy fields allowed within the park. As reported by APIO *et al.* (2015), the impacts of anthropogenic activities and the encroachment exerted the Rwandans returning from exile and did occupy the park and in turn affect the forest cover. The results discussed herein, land cover maps and statistical forest cover changes provided were yet assessed and presented so far. Therefore, there is a great task for forest and park managers to effectively halt the degradation processes through joint collaboration and timely responses while promoting sustained research and mapping. The findings should help and support the Rwanda's journey of biodiversity conservation and park management with regards to climatic conditions as park shirking, overgrazing, desertification and reintroduction of new species includes among factors influencing the forest fragmentation found inside the park.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Akagera National Park expanding with higher savannah/grass richness and it is the main land use/cover. The present study indicates that the forest areas is recovering from past processing varying magnitude. Altered physical processes and impacts of human land use has a profound influence on forest patches and their biota, particularly on fragment edges. Highly vulnerable to forest fragmentation in future. The study concluded that; anthropogenic pressure due to higher pace of tourism activities, agricultural expansion and over grazing, are the major provoking factors of forest fragmentation. LULC changes had the shadow feature, which is the negative impacts it has on the park. The researcher's participatory observation and documentary resources were tools to collect data in addition to the satellite's images collected from United States geological survey with the application of the landscape metrics approaches. Remotely sensed data are very useful in biodiversity studies. ''Spatio-Temporal evaluation of Akagera National Park land cover change & habitats fragmentation using Geospatial techniques and landscape metrics'' provided relevant results. This study showed that the LULC changes has negative impacts on park landscape and it directly and indirectly affects the habitat integrity. RS and GIS technologies were applied in this study to process and analysis the geographical data used, Fragstat software were used to derive landscape statistics. There has been rapid conversion of bare land and wetland to grassland cover; spatial expansion has occurred around the whole park.

The study results revealed that from 1990-2005, grassland/savannah area, water and wetland decreased by -3561.98ha, -442.93ha and -2435.83ha respectively with a rate of change of -237.47ha/year, -29.53ha/year and -162.39ha/year respectively. Whereas, bare land increased to 4582.190 ha with a rate of change of 305.48ha /yr. Forested land also shows significant changes with an increase of 1858.6 ha with a rate of change of 123.91ha/year. In 2020, 57% of the study area covered by grassland area which was increased to 4829.678038ha in 2020 with 321.98ha/year while area occupied by water has increased to 4296.450ha with 286.43ha/year. On the other hand, the land use land cover categories like bare land, wetland and forested land and showed decreasing pattern with -455.24ha/year, -128.15ha/year and -25.02ha /year of average rate of changes respectively. Generally, the LULC types in the three study periods gradually changed with differing rates depending on the existing socio-economic, political, and environmental situation. Considering the overall study period (30 years), there was a remarkable gain in some land cover class since 1990 to 2020 where the grassland/savannah area increased from 60274.2ha (55.8 %) to 61541.9ha (57%), forest/shrub area increased from 7.8% to 9.1%. water area increased from 10.5% to 14.1 %. Conversely, wetland and bare land were diminished at a higher rate within these 30 years, from 5.5% to 1.5% for wetland and 20.2% to 18.2% for bare land.

The results also revealed a moderate degradation inside the park where bare land cover and wetland have been reducing approximately an annual loss of -74.88ha and -145.27ha respectively. This loss in forest cover inside the park has been converted into different classes among the land cover types found in ANP after classification especially “grassland”. All those changes mainly related to human induced factors on park area. Due to landscape analysis at class level, landscape level and patches level, the results revealed that the values of overall patches decreased proportionally from 28509 to 13054. The findings should help and support the Rwanda’s journey of biodiversity conservation and park management with regards to climatic conditions as park shirking, overgrazing, desertification and reintroduction of new species includes among factors influencing the forest fragmentation found inside the park. The study suggests the continuous monitoring of LC changes using geospatial techniques and landscape metrics and analysis of their impacts on habit fragmentation and also the whole ecosystems.

5.2. Recommendations

From the results of this study, we recommend the following for:

- **<u>ANP Managers</u>**
  - Establishment of adequate strategies to mitigate the park degradation by implementing quick and effective solutions.
  - Continuous monitoring of LC changes using geospatial techniques and landscape metrics and analysis of their impacts on habit fragmentation.
  - ANP management should be enhanced in sustainable ways that consider the sustainable habitats.
- **Government and NGO’s**
  - Improvement of the implementation and planification of long-term conservation programs and effective eco-tourism.
- **<u>Researchers</u>**
  - There is need of continuous monitoring and assessment of impacts of LULC changes not only on habitant fragmentation but also to the whole ecosystems.

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APPENDICES

Appendix A: Ground Trothing Points table (GTP)

s/n	**Longitude**	**Latitude**	**LC Type**
1	30.566643	-1.445350	Bare land
2	30.568412	-1.474570	Forest/shrub
3	30.576101	-1.461440	Water
4	30.578190	-1.435400	Grassland
5	30.584791	-1.406580	Wetland
6	30.598096	-1.367760	Bare land
7	30.598411	-1.353900	Water
8	30.606964	-1.481740	Water
9	30.612570	-1.416130	Water
10	30.616884	-1.464450	Water
11	30.617225	-1.422690	Grassland
12	30.622020	-1.439320	Grassland
13	30.624031	-1.512510	Bare land
14	30.624568	-1.492130	Grassland
15	30.630507	-1.529640	Forest/shrub
16	30.634175	-1.440440	Grassland
17	30.640362	-1.440470	Grassland
18	30.642615	-1.507510	Bare land
19	30.645863	-1.630580	Water
20	30.646411	-1.678650	Forest/shrub
21	30.647626	-1.652230	Water
22	30.651333	-1.431340	Bare land
23	30.652957	-1.614240	Wetland
24	30.655601	-1.728930	Water
25	30.655679	-1.590550	Grassland
26	30.655957	-1.444140	Grassland
27	30.665046	-1.586830	Grassland
28	30.669079	-1.658670	Grassland
29	30.672540	-1.783870	Wetland

30	30.676469	-1.703710	Grassland
31	30.677497	-1.783990	Wetland
32	30.679771	-1.595890	Grassland
33	30.682999	-1.546280	Bare land
34	30.683377	-1.904900	Forest/shrub
35	30.684731	-1.699710	Bare land
36	30.684770	-1.501750	Forest
37	30.685558	-1.711220	Forest
38	30.687481	-1.918350	Grassland
39	30.687539	-1.770620	Grassland
40	30.696312	-1.791930	Bare land
41	30.696483	-1.885280	Grassland
42	30.696705	-1.523360	Grassland
43	30.697642	-1.500170	Grassland
44	30.698364	-1.609300	Grassland
45	30.699750	-1.591030	Wetland
46	30.701182	-1.537110	Grassland
47	30.701307	-1.890500	Grassland
48	30.703661	-1.514390	Bare land
49	30.704414	-1.951040	Grassland
50	30.704932	-1.449020	Bare land
51	30.709058	-1.688380	Wetland
52	30.710085	-1.698650	Grassland
53	30.715667	-1.698990	Bare land
54	30.716892	-1.836440	Water
55	30.718908	-1.439580	Grassland
56	30.719411	-1.803690	Wetland
57	30.720046	-1.464330	Wetland
58	30.721415	-1.813980	Grassland
59	30.724475	-1.834510	Forest/shrub
60	30.725009	-1.476650	Forest/shrub
61	30.728350	-1.567830	Forest/shrub

62	30.729396	-1.716180	Bare land
63	30.729426	-1.609930	Forest/shrub
64	30.729963	-1.718270	Grassland
65	30.730806	-1.840730	Grassland
66	30.731083	-1.743480	Grassland
67	30.731378	-1.900280	Forest/shrub
68	30.732936	-1.886410	Grassland
69	30.733910	-1.686480	Grassland
70	30.734448	-1.849030	Water
71	30.736168	-1.934500	Forest/shrub
72	30.736723	-1.722550	Grassland
73	30.737485	-1.526710	Grassland
74	30.738018	-1.862740	Wetland
75	30.740239	-1.860340	Grassland
76	30.752153	-1.799430	Grassland
77	30.755065	-1.703050	Forest/shrub
78	30.766556	-1.719260	Water
79	30.771021	-1.835860	Grassland
80	30.771643	-1.828160	Wetland
81	30.772368	-1.681150	Grassland
82	30.774184	-1.676490	Forest/shrub
83	30.776721	-1.677280	Forest/shrub
84	30.778474	-1.579650	Water
85	30.780732	-1.610750	Grassland
86	30.784355	-1.633770	Water
87	30.785207	-1.688990	Grassland
88	30.788161	-1.658080	Grassland
89	30.789830	-1.655380	Bare land
90	30.791917	-1.765750	Forest/shrub
91	30.793485	-1.614900	Forest/shrub
92	30.794293	-1.807460	Forest/shrub
93	30.799459	-1.640960	Grassland

94	30.800703	-1.807050	Grassland
95	30.805700	-1.814180	Water
96	30.806280	-1.744780	Grassland
97	30.810339	-1.662300	Bare land
98	30.813532	-1.621440	Grassland
99	30.817426	-1.744120	Forest/shrub
100	30.825423	-1.833410	Wetland

Appendix B: Field Pictures taken at ANP


Elephants in ANP (Photo taken October 2021)


View of ANP (Photo taken October 2021)

Author Site photo (Photo taken August 2021)

Giraffe in low land at ANP (Photo taken November 2021)