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The Impact of Land Use and Land Cover (LULC) Change on Water Resources and its Implication for Smallholder Farmers in Rwanda. A case study of Lake Cyohoha North

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DEDICATION

I dedicate my dissertation work to my family and my friends. A special feeling of gratitude to my loving mother whose words of encouragement and push for tenacity ring in my ears. I am grateful for the many hours of proofreading. My brother and sisters have never left my side and are very special.

I also dedicate this dissertation to my internship supervisor, who have supported me throughout the process. I will always appreciate all he has done. Finally, my sincere gratitude goes to Fatiha Zergui whose idea was developed to come up with my research topic.

DECLARATION

I, Patrick MUDAHEMUKA, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material, and results from other works presented here, have been fully cited and referenced following the academic rules and ethics.

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CERTIFICATION

This is to certify that the master's thesis entitled "**The Impact of Land Use and Land Cover (LULC) Change on Water Resources and Its Implication for Smallholder Farmers in Rwanda. A case study of Lake Cyohoha North**" is a record of the original bona fide work done by Patrick MUDAHEMUKA in partial fulfillment of the requirement for the award of Master of Science Degree in Water Policy track at Pan African University Institute of Water and Energy Sciences (including Climate Change)- PAUWES during the Academic Year 2018-2019.

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ABSTRACT

The catchment of Lake Cyohoha North is currently faced with climate change, increasing subsistence farming, increasing household numbers, urbanization, declining the quantity and the quality of water resources, population growth, and escalating development pressures. These factors have consequently triggered changes in LULC and incited issues such as land degradation, reduced crop production, excessive and prolonged droughts, limited public access to resources, increased illegal activities, food insecurity and hunger, deforestation, erosion, encroachment of Cyohoha Lake buffer zone and excessive growth of aquatic weeds. Furthermore, there have been past high levels of in-migration, leading to unsustainable land-use practices degrading Lake Cyohoha North. These issues pose a challenge to the government which strives to plan effectively to maintain ecosystem functions for a sustainable nation. To meet this challenge requires understanding drivers of LULC. A study of changes in LULC was conducted by integration of a remote sensing study of LULC maps using 2002, 2010 and 2018 Land Use/Land Cover Maps for Rwanda, opinion of experts in the form of face-to-face interviews, catchment's smallholder farmers survey and past literature analysis. An adapted DPSIR Framework was used to analyze the relationship between anthropogenic activities and land-use change and present LULC changes in the study area. The results of this study show that LULC changes in Lake Cyohoha catchment are driven by political, economic, environmental, demographic, technological and cultural factors. Socioeconomic benefits will result from effective future planning policies and strategies. The results from remote sensing reveal significant reduction in forests and open land and increase in agricultural land, -8.58%, -17.26% and 28.19% net change respectively which affected 61.04% and 29.37% decrease in wetland and the lake size. Finally, based on significant impact that agriculture sector has on Rwanda's economy whereby more than 80% of population depends on agriculture, 91% of food consumption and 34% GDP are from national agriculture; an investigation was conducted by surveying the impact LULC change and Lake Cyohoha degradation had on smallholder farmers. The results show reduction in crop and fish production, coupled with climate change, increased the number of local communities eating once a day to 80%. Therefore, knowledge from this study can be used by planners as a guide to effectively planning policies and other driving factors, ensuring achievement of SDG 2 and 6 in Lake Cyohoha catchment.

Key words

LULC Change, Catchment, Land degradation, DPSIR, Smallholder farmers, Water resources

RÉSUMÉ

Le secteur régional du lac Cyohoha Nord est actuellement dévoré par des changements climatiques continus. La cause majeure est la pratique ininterompue d'une agriculture de subsistence liée à une augmentation incontrolée du nombre de consommateurs. L' urbanisation qui s'avère du moment est aussi l'une des raisons provocantes de ces changements climatiques sans oublier la chaleur qui occasionne la diminution sensible tant de la quantité que de la qualité des eaux dans les sources disponibles. Les facteurs ci-hauts mentionnés ont eu pour conséquence la dégradation du sol et des LULC. Cette dégradation tire avec elle l'insuffisance de la production agricole, la pauvrété et le sentiment de marginalisation des habitants de la dite région. En effet la sécheresse menace la région et les périodes de manques de pluie se repètent et sont fréquentes. Vus ces difficultés de survie, la population s'adonne à des pratiques frauduleuses comme la déforestation illégale qui occasionne l'érosion et la destruction des bords du lac Cyohoha où croissent de mauvaises herbes. L'histoire de la dégradation des bords du lac Cyohoha remonte en outre du temps où une vague immigrants a afflué dans la zone entraînant des pratiques agricoles massives et désordonnées. La population faisait face à des famines répétées. Depuis lors, la dégradation de cette zone agricole du lac Cyohoha est un problème pour le gouvernement qui s'est vu obligé de chercher des solutions qui aideraient la population à survivre. L'une de ces solutions es tune bonne géstion des sources restantes. On a aussi pensé à la création de moyens modernes permettant l'accès aux services de maintien de l'écossystème fonctionnel de la dite région. C'est après avoir compris l'impact de changements climatiques qu'une étude a été menée successivement en 2002, 2010 et 2018 visant à améliorer l'exploitation agricole du pays en général et de la zone Cyohoha en particulier. Une ligne étendue de DPSIR a été utilisée pour analyser la relation qui existerait entre les activités anthropogéniques et les changements climatiques. La recherche présente est le cas des changements des LULC. Les résultats de cette étude montre que ces changements ont été occasionnés par des facteurs tant politiques que environmentaux, démographiques, technologiques et culturelles. Il est nécéssaire d'envisager des stratégies pour ambiguer les conséquences pouvanr gêner les bénéfices socioéconomiques. Un recensement isolé de la région du lac Cyohoha montre qu'il ya une réduction signicative de la forestation ainsi que celle de la production agricole respectivement de -8,58% et -17,26% et par conséquent une altération de 28,19%. Ces changements ont affecté la diminution de 61,04% et 29,37% de zone humide et superficie du lac. En fin de compte, les changements ci-haut mentionnés, ajouter à la diminution des revenus de la pêche ont augmenté le nombre de ceux qui n'ont qu'un seul repas par jour à 80%. Les données issues de cette étude pourraient server de base d'action aux décideurs nationnaux dans la lute contre la faim et la recherche d'un meilleur avenir de la population rwandaise.

Mots clés: Changement de LULC, bassin versant, dégradation du sol, DPSIR, ressources en eau

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ABBREVIATIONS AND ACRONYMS

AIC	Appraisal Institute of Canada
BDDP	Bugesera District Development Plan
CBA	Critical Biodiversity Area
CGIS	Canada Geographic Information System
DEMP	Decentralization and Environment Management Project
DEO	District Environment Officer
DPSIR	Drivers-Pressures-State-Impact-Response
EEA	European Economic Area
EICV	Enquête Intégrale sur les Conditions de Vie
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
EU	European Union
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GGGI	Global Green Growth Institute
GoR	Government of Rwanda
GWP	Global Water Partnership
HGS	Home Grown Solutions
HH	Household
IDP	Integrated Development Project
LDCF	Least Developed Countries Fund
LUC	Land Use Consolidation
LULC	Land Use and Land Cover
MINAGRI	Ministry of Agriculture and Animal Resources
MINECOFIN	Ministry of Finance and Economic Planning
MINIRENA	Ministry of Environment
MOH	Ministry of Health
NGO	Non-governmental Organization
NISR	National Institute of Statistics of Rwanda
NYEP	National Youth Environment Project

OECD	Organisation for Economic Co-operation and Development
PAUWES	Pan African University Institute of Water and Energy Sciences
RAB	Rwanda Agriculture Board
REMA	Rwanda Environment Management Authority
RGB	Rwanda Governance Board
RICA	Rwanda Institute for Conservation Agriculture
RWFA	Rwanda Water and Forestry Authority
SAR	Synthetic Aperture Radar
SAS	Seasonal Agricultural Survey
SERPG	Supporting Ecosystem Rehabilitation and Protection for Pro-poor Green Growth Programme
SPIU	Single Project Implementation Unit
SPSS	Statistical Package for Social Sciences
TVET	Technical and Vocational Education and Training
UN	United Nations
UNEP	United Nations Environment Programme
VERP	Vulnerable Ecosystem Recovery Programme
WASAC	Water and Sanitation Corporation

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CHAPTER ONE
INTRODUCTION

1.1 Background to the Problem

The world urban population has been growing at unprecedented rates over the past decades. According to the 2018 Revision of World Urbanization Prospects, 30% of the world's population was urban in 1950, today it is more than 55%, and it is estimated that in 2050, 68% of the world's population will be urban (United Nations, 2018). Further analysis indicates that by 2050, population growth and urbanization will increase the world's urban population by 2.5 billion people and 90% of this increase will be concentrated in Africa and Asia (United Nations, 2018). The prospect of living in urban areas is often associated with better infrastructure, access to jobs and better health, education, transport, and social services. Such perceptions lead to rapid rural to urban migration which contributes to urban population growth and increases the demand for housing, and other urban land uses.

United Nations shows that low income and lower-middle-income countries will face challenges to meet the population demand. If not managed and properly planned, urban growth can lead to severe issues such as inadequate infrastructure, environmental degradation, and housing and transport shortages which pose adverse effects on the environment and increase pressure on water resources. In Rwanda, the implementation of six secondary cities has increased the pace of urbanization rate to 9% posing economic pressure in the distribution of wealth and economic opportunities. Despite the effects on environment and water resources, the policy of Rwanda provides an opportunity for intervention to promote a more inclusive development approach (GGGI, 2015).

Bugesera District Development Plan (2013-2018) reveals that the District is experiencing significant population growth, limited access to socioeconomic infrastructures, increasing household numbers, high levels of migration, urbanization, infrastructure development, and agricultural expansion and intensification (BDDP, 2013). These trends have consequently triggered changes in LULC and incited issues such as urban extension, limited public access to resources, land degradation, and climate change. Furthermore, the issues surrounding LULC in the District emanate from past repeated drought coupled with unsustainable land-use practices resulted in degradation of water resources that left lake Cyohoha north likely to disappear (de Dieu *et al.*, 2013).

This poses a challenge to the government which strives for a sustainable nation that safeguards democracy by providing basic access to services, managing limited resources and advancing effective and efficient integrated planning whilst to maintain ecosystem functions (GGGI, 2015). Understanding drivers of LULC change and analyzing how various factors influence LULC is vital in meeting this challenge (Corner and Dewan, 2014).

Tools which integrate and evaluate diverse factors of LULC change can be used to guide planners in making more informed decisions and hence, achieve a balance between urban growth, intensive agriculture, and preservation of the natural environment. Some countries have created and adapted such tools as computer models which can assist in exploring the consequences of policies, human behavior and other drivers on LULC patterns (El-kawy *et al.,* 2011; Hegazy and Kaloop, 2015). Remote sensing and geographical information system offer essential tools which can assist humans in making more informed decisions. The rationale for using remote sensing is to manage large amounts of data from widely dispersed locations effectively at much shorter time intervals, significantly reduced costs, and what is more, getting simultaneous observations covering vast areas. This research uses this approach to study the impact LULC change has on Lake Cyohoha North to address a particularly suitable land-use system.

1.2 Problem Statement

Anthropogenic activities such as agricultural, mining and industrial activities have affected most of the lakes across Africa, mainly Lake Chad, Lake Victoria, Lake Tanganyika (Zhu *et al.,* 2019) since the mid-twentieth century. The study of LULC change impact on water resources corresponds in line with the aspiration of the Agenda 2063 to transform Africa in a way that natural resources will sustainably be managed and the integrity and diversity of Africa's ecosystem conserved (AUC, 2015). The study comes from a background of food insecurity, poor management of the catchment area. Thereby, it seeks to empower local community with knowledge and skills to manage their resources sustainably.

The problem has manifested itself through poor management of the catchment area by the community and the authorities which has promoted the extreme reduction in size and quality of water resources in Africa (Zhu *et al.,* 2019). An example is Lake Chad, which undergoes gradual degradation, extended dry periods and a decrease in lake water inflow. Those are severe challenges accelerating the surface water variability.

Lake Cyohoha has undergone gradual degradation that resulted in its eutrophication while it was the primary source of irrigation and domestic water and economic activities like fishing and exchange of goods between both Rwanda and Burundi. The Lake Cyohoha North catchment was mainly covered by forests and uncultivated lands, since then people started migrating to settle in those areas and changed it into mostly agricultural land. The forests were destroyed, and the land cover changed, which resulted in increased runoff directly into Lake Cyohoha, and the weather changed so dramatically that nowadays the region has low rainfall and most of the remaining parts of the year are dry.

The program of agriculture intensification provided fertilizers and pesticides that were washed away in eroding soils carried by runoff water from surrounding agricultural farms. It affected the quality of Lake Cyohoha water and promoted the growth of aquatic weeds inside the lake. Therefore, the challenging problem today is excessive growth of water hyacinth and other aquatic weeds that cover a wide surface of the Lake.

Despite water hyacinth problem, the buffer zone of the Lake is being cultivated by local communities who cut papyruses (*Cyperus papyrus*) that used to protect the lake from erosion and play the role of filtration and water reservoir. Consequently, erosion directly goes into the lake and this is leading to the diminution of the water quality and quantity and directly harm the fish production, biodiversity, and life of this ecosystem in general.

Bugesera region (comprising the study area), was the country's breadbasket concerning the vital food crops (beans, sorghum, cassava, etc.). However, prolonged and repeated drought occurred and made the region unproductive since 1998, resulting in food insecurity and massive population movements (UNEP, 2007). Although blessed with considerable water resources (lakes and rivers), the region has often recorded frequent famines due to poor harvest in the wake of drought and inadequate water control. On several occasions, the Government appealed for food aid for the region's malnourished people. This calls upon researchers, policy-makers, and decision-makers to find viable solutions.

1.3 Research Questions

The following research questions arise from the above problem statement.

- **i.** What are the driving factors of LULC development and change in the Lake Cyohoha catchment?
- **ii.** What is the relationship between land use, land cover, and changes on Lake Cyohoha between 2000 and 2018?
- **iii.** In which ways the economic and social activities of smallholder farmers using Lake Cyohoha from the period 2000 to 2018 have been affected?
- **iv.** In which ways can the community conserve and manage natural resources and what would be the options available to improve policies to manage the catchment area and improve the livelihood of the smallholder farmers?

1.4 Research Aim and Objectives

1.4.1 Research Aim

This study seeks to investigate the effects of land use and land cover change on Lake Cyohoha using remote sensing, in order to minimize unsustainable development practices and trigger better practices on the management of water resources.

1.4.2 Research Objectives

- **i.** To assess the relationship between land use and land cover changes on the Lake Cyohoha from 2000 to 2018,
- **ii.** To determine the driving factors of LULC change in the Lake Cyohoha catchment,
- **iii.** To conduct the socioeconomic impact of Smallholder Farmers'use of the Lake Cyohoha on the period 2000-2018,
- **iv.** To empower the community, through training in the future, on ways to conserve the catchment areas and the environment, and also, based on research findings, recommend strategies to decision-makers on ways to safeguard the impact of the LULC changes on the water resources and improve livelihood of the Smallholder Farmers.

1.5 Significance of the Research

The lack of regulation in the rural settlement has promoted scattered settlement and, in most cases, far from basic infrastructures. The reason behind the situation is the lack of appropriate institutional framework and tools to plan and manage the land in rural areas (MININFRA, 2009). This lack of specialized frameworks to manage rural settlement, combined with the ineffectiveness of firms and research consultancies in developing appropriate, economical and robust models of human settlement in rural areas, raised a gap in research on projects that attempt to evaluate past and simulate future LULC scenarios at regional scale in Rwanda.

A review of academic literature has revealed that no attempts have been made to implement LULC change models at a regional level in Rwanda. This is, however, a significant scale to analyze the factors which drive LULC change (e.g., governance) operating at this level. LULC changes operating at regional levels have significant impacts on catchment-scale issues such as climate change and food security. Furthermore, processes which contribute to LULC change do not operate in isolation, various factors operate at different scales, and there is a need to analyze higher-level processes which influence LULC change. This study will, therefore, fill the gap of LULC change at a catchment scale in a Rwandan context. This project will further help government for reinforcing policies governing agriculture for the protection and management of water resources to achieve the goals of economic development and poverty reduction strategy to foster and remain on the path to sustainable water resources management and achieve the aspirations of the 2020 vision (T. R. of Rwanda, 2011; The Republic of Rwanda, 2012).

The research will, therefore, contribute to building the capacity of farmers in Lake Cyohoha catchment on soil conservation and best water management practices to sustainably prevent the degradation of this water resource. The contribution of this study was of interest to planners and researchers because it will:

- Augment the existing practical and theoretical knowledge based on LULC development and change.
- Infuse more knowledge on drivers of LULC change.
- Fill the knowledge gap by recommending priorities in LULC change to a developing country at a regional scale.

1.6 Justification of the Study

This study is vital because it provides effective information to drive policies in Rwanda in line with promoting food security, empowering public engagement in the proper management of natural resources, through capacity building and map out ways to conserve and protect the environment. This has been achieved through application of mixed research design, which made the research inclusive, and achieve the goals of providing decision-makers with scientific knowledge to drive policies. Thus, the objective of this research was intended to study the gradual evolution of Lake Cyohoha degradation, the causes of its degradation and finally it provided measures to be taken by the government and communities living in the region as well as the policy priorities needed to enhance the protection and control of Lake Cyohoha. Furthermore, it has assisted farmers, herders, fishers, and other sectors working in the region to cope with climate change adaptation.

1.7 Justification of the Case Study

There are three primary reasons why this case study has been chosen.

- This area has a significant interest in water management and development of irrigation in this area due to the long-term duration of the dry season, intensive population growth and increase in food demand.
- Lake Cyohoha catchment comprises the Murago wetland of Akanyaru river which is on the list of proposed Ramsar convention sites in Rwanda. It is a wetland of international importance for which sustainability in protection and management is of high interest for the region. Murago wetland degradation does not have impact only on Lake Cyohoha but also on Lake Victoria, the biggest lake in the eastern region of Africa. However, droughts that occurred in the Bugesera region made local communities use it as an agricultural area, and this resulted in continual degradation of Lake Cyohoha North.
- Bugesera district must be protected from hunger by supporting rainfed by irrigated agriculture, and farmers must be helped to cope with prolonged dry periods.

1.8 Limitations

This study was aiming to assess the impacts of LULC change on Lake Cyohoha and drive factors that affect the Lake Cyohoha catchment. However, satellite images for the past 30 years were not available for the region, though research analyses are based on recent data available and the experience of people living within the catchment.

This study also involved the identification of significant social, economic and political factors which can drive significant changes in LULC and their implication on smallholder farmers. However, the incorporation of such factors into the management of Lake Cyohoha may be limited by the insufficiency of available data. According to (GWP, 2016), environmental legislation and enforcement, including water resources management, vary significantly in Rwanda and Burundi. Rwanda, on one hand, is bound to stringent environmental laws in order to protect freshwater resources in its boundaries, while Burundi on the other hand, is still at low levels in managing its environment. In the current situation of resource scarcity and environmental degradation, conflicts are likely to arise. Limited management efforts by Burundi to protect the Lake may compel Rwandans to take advantage of the lake's resources without considering issues of sustainability. Also, if the lake continues to shrink and wetlands to dry up, conflicts over access and use of resources could easily cause or aggravate social problems. Thus, in some cases, the data may not be available due to these challenges, and this may pose a difficulty in drawing accurate solutions.

1.9 Research Methods

This section explains the methods used to answer research questions and subsequently achieve the aim of the research.

1.9.1 LULC Drivers

What are the driving factors of LULC development and change in the lake Cyohoha catchment?

Answering this question involved determining the driving factors of LULC change by examining historical development patterns and exploring the current state of LULC change by reviewing literature on factors which influence land-use decisions in the Lake Cyohoha catchment. Policies such as The Water Law of 2008 that put in place regulations for the use, conservation, protection and management of water resources (G. of Rwanda, 2008; T. R. of Rwanda, 2011) and urbanization and rural settlement sector strategic plan 2012/13-2017/18 (MININFRA, 2009;

Ministry of Infrastructure, 2012) which determine future LULC change have been reviewed. Interviews have been conducted to further supplements of the secondary literature on historical and current drivers of LULC change and to determine important factors which will influence future change. The interview participants were catchment planners, and their responses were based on their past experiences and knowledge on current land issues in the region. The questions focused on why LULC change has been taking place in the region, what future changes are likely to occur and what is driving LULC change. The findings of driving factors of LULC change obtained from literature search and the interview were very significant in this study as they determine the data needs of the research.

1.9.2 LULC and Lake changes relationship

What is the relationship between land use, land cover, and changes on Lake Cyohoha between 2000 and 2018?

Answering this question required determining LULC changes occurred between 2000 and 2018 and according to the findings, the research highlighted the ones that have had more impacts on Lake Cyohoha.

1.9.3 Agricultural impact

In which ways the economic and social activities of smallholder farmers using Lake Cyohoha from the period 2000 to 2018 have been affected?

This question determined the impacts the observed changes have had on Lake Cyohoha and quantified how much those changes affected smallholder farmers doing agriculture within Lake Cyohoha catchment as well as the effect on socio-economic activities. To answer this question questionnaires were distributed to a sample of 100 farmers taken within the catchment to further supplement secondary literature reviewed on historical and current productivity of the region. The questions focused on why LULC change has been taking place in the region, what impact it had on Lake Cyohoha and how it affected smallholder farmers. The findings of the effects on socio-economic activities of smallholder farmers obtained from literature search, questionnaires and the interviews were significant in this study as they were useful for the future planning for the region.

1.9.4 LULC and Lake Cyohoha catchment management

In which ways can the community conserve and manage natural resources and what would be the options available to improve policies to manage the catchment area and improve the livelihood of the smallholder farmers?

To answer this question, suitable and comfortable management practices were described, recommendations on future trainings to provide to farmers were given and on how to implement them. The question about the options available to improve policies to manage the catchment were answered by the staff in charge of catchment management under Rwanda Water and Forestry Authority (RWFA) and Rwanda Environmental Management Authority (REMA). The outcomes will be used for the management of the Lake Cyohoha catchment, and farmers will not live with fear that the Lake will disappear.

1.10 Chapter Overview

This thesis is made up of seven chapters that focus on achieving the purpose of this research and answering research questions. A summary of the chapters is provided below.

Chapter one introduces the background of the problem, study area, problem statement, research questions, research aim and objectives, the significance of the research, justification of the study, justification of the case study, limitations, research methods, and chapter overview.

Chapter two forms the theory base of this research and provides a literature review on LULC change. This chapter covers the driving factors of land-use change, major concepts important in LULC and classification. Finally, it provides a review of the situation of agriculture sector in Rwanda.

Chapter three describes the methods used in achieving research objectives and provides an outline of data gathering and analysis processes.

Chapter four discusses the results of the impact LULC has had on Lake Cyohoha and driving factors identified from interviews, questionnaires, and reports analysis. It also underlines the main discussion points for the findings.

Finally, **chapter five** provides the study conclusions, recommendations, and possible future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This Chapter provides a literature review of LULC change modeling. The first section of the literature review explains the concepts land, land use, and land cover. LULC change and factors which influence or drive LULC change have been reviewed from both a local and international perspective. After that, a summary of the most popular land-use model classification techniques has been provided based on published literature. The last section of the literature review presents the current agricultural status of Rwanda.

2.2 Land Use and Land Cover

2.2.1 Land

The Food and Agriculture Organization (FAO) defines land as: "An area of the earth's surface, the characteristics of which embrace all that are reasonably stable, or predictably cyclic, the attributes of the biosphere vertically above and below this area, including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations, and the results of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of the land by humans." (Rossiter, 1996). The United Nations Convention to Combat Desertification documentation defines land as, "the terrestrial bio-productive system that comprises soil, vegetation, other biotas, and the ecological and hydrological processes that operate within the system" (Haber, 1981).

2.2.2 Land Use

The terms land use and land cover are often used interchangeably, though they have different meanings. Land use is the purpose for which land is used, whereas land cover refers to the physical characteristics of the surface of the land. A formal description by FAO states that land use is "the arrangements, activities, and inputs people undertake in a certain land cover type to produce, change or maintain it" (FAO and UNEP, 1999).

Chapter 1 of the Spatial Planning and Land Use Management Act No 16 of 2013 (SPLUMA) defines land use as "the purpose for which land is or may be used lawfully in terms of a land use scheme, existing scheme or in terms of any other authorization, permit or consent issued by a competent authority, and includes and conditions related to such land use purpose." (Republic of South Africa, 2013; Ogunronbi, 2014). This definition is however not entirely correct as people can take de facto control of land and use it for various purposes which may not align with any land use scheme or authorization (de Groot *et al.,* 2010). The use of land is therefore uncertain, does not end at political boundaries and can be both legal and illegal (AIC, 2009). Land-use systems exist when different land uses are systematically linked through temporal interactions, e.g. crop rotation or spatial relations and are linked with land ownership (Angeles, 2005). Land-use change is the result and cause of diverse interactions between society and environment that lead to global change and rural development (Verburg *et al.,* 2010).

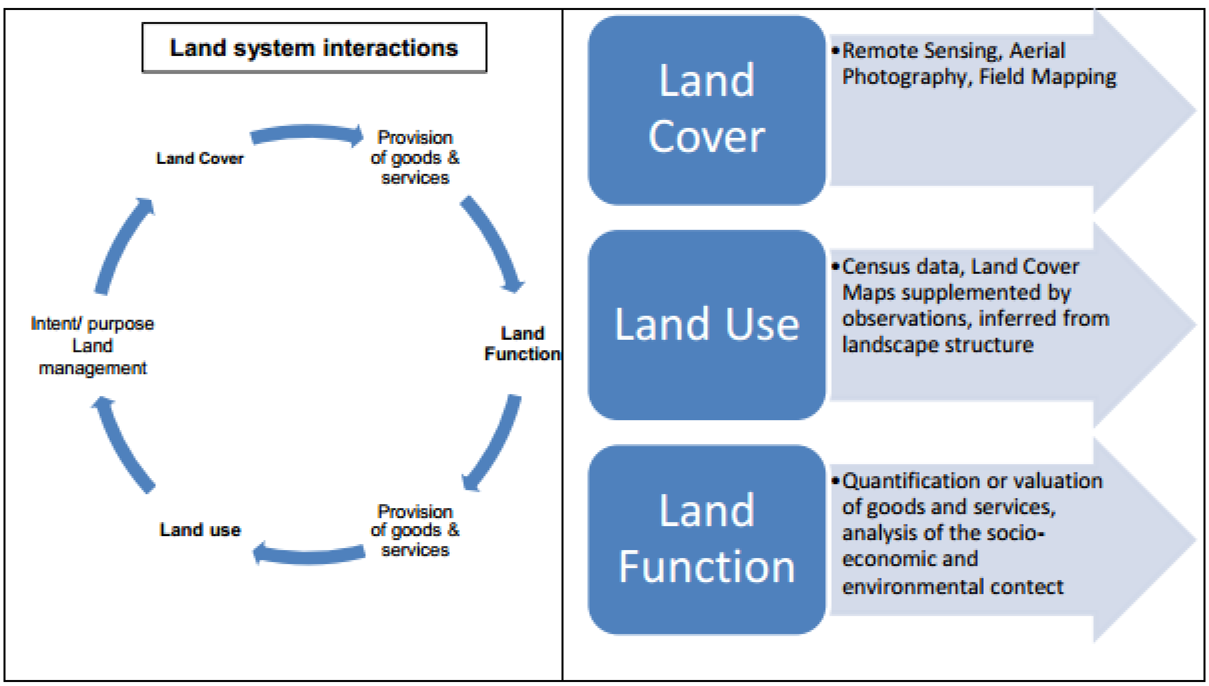


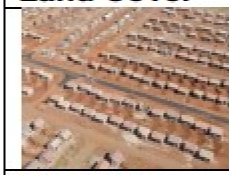
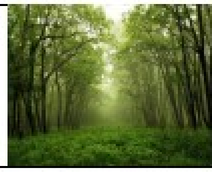
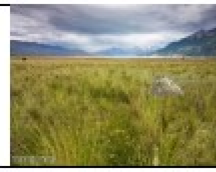
Figure 2-1: Land Use, Land Cover and land Function interactions with their data collection methods (Source: Verburg *et al.*, 2010)

2.2.3 Land Cover

Land cover is a fundamental variable that impacts on and links many parts of the human and physical environments (Chase *et al.,* 2000). Land cover change is therefore regarded as the single most crucial variable of global change affecting ecological systems with an impact on the environment that is at least as large as that associated with climate change (Niraula *et al.,* 2010). Drought vulnerability drives land cover changes in the rift valley of East Africa (Biazin and Sterk, 2013) and growing scientific evidence proves that changes in anthropogenic land cover (ALC) produces a significant impact on regional climate (Deo *et al.,* 2009; Corresponding and Wang, 2010). It is well established that land cover change has significant effects on basic processes including biogeochemical cycling and thereby on global warming (Feddema *et al.,* 2005), the erosion of soils and thereby on sustainable land use and for at least the next 100 years is likely to be the most significant variable impacting on biodiversity (Cebecauer and Hofierka, 2008; Mohammad and Adam, 2010; Verburg, 2006).

According to (Turner *et al.,* 2009), "Land cover is the biophysical state of the earth's surface and immediate subsurface." Land cover, therefore, includes quantity and types of all features over the earth such as vegetation, water, soil, artificial surfaces, etc. The difference between land use and land cover is demonstrated by (Turner *et al.,* 2009) as illustrated in Table 2-1. (Turner *et al.,* 2009) further add that land use involves the intent or purpose for which land is utilized. A different aspect, "biophysical manipulation" is also described as the manner which humans treat land to achieve intent, e.g. the planting of grass for pasture.

Table 2-1: Landcover and Land Use types

Land Cover				
				
Non biotic Construction	Forest	Grassland	Cropland	Wetland
Land Uses: Purpose				
				
Logging	Grazing	Agriculture	Wildlife Preserve	City/Town
Biophysical Manipulation				
Clear cutting	Grass Planting & Fertilising	Mounding	Culling for	Drain groundwater

Source: (Turner *et al.,* 2009)

Land use and land cover are linked; however, it should be noted that a single land cover can support multiple land uses and vice versa. For instance, a land cover, e.g. grassland can support many land uses such as grazing and recreation and a single land use may also take place on various land covers. Land cover can be determined by analyzing remotely sensed images such as satellite images or aerial photos whilst land use and land-use change will require additional socio-economic data and methods to determine the activities occurring on the landscape (Pan *et al.,* 2004). (Thenkabail *et al.,* 2007) agree with this and state that unlike land cover, land use is not directly observable though it can be inferred from activities such as grazing or structural landscape elements like logging roads. This study is conducted at a regional scale. The data will be used in analysis with a combination of data obtained from satellite imagery and socio-economic data. The term LULC will therefore be used to refer to land use and land cover in this study.

2.3 LULC Change and Drivers

2.3.1 International Review of Drivers of Land Use Change

LULC change involves a conversion from one LULC to another or intensification of the present or current LULC (Turner *et al.,* 1994). The changes in LULC are determined by how individual landowners, communities, businesses, and governments control land use and make decisions on how to use land. Such decisions are influenced by the interactions between socioeconomic factors such as population and environmental factors (e.g. topography and climate) which vary at different scales (Turner *et al.,* 2007). (Barbier and Burgess, 2008) confirms this and further clarifies that environmental drivers do not have a direct impact on land-use change but impacts land cover change which in turn influences land managers' decisions. LULC change can therefore be modeled as a function of socio-economic and environmental factors. These factors are often referred to as 'driving factors.' The driving factors of LULC change are also categorized as either proximate or underlying, where the former are direct modifications by individuals at a local scale such as individual farms, and the latter are indirect changes which occur at a regional scale (Turner *et al.,* 2007). Proximate driving factors are usually caused by human activities such as infrastructure and agriculture expansion whereas underlying factors are caused by complex interactions between social, political, demographic and environmental variables (Lele and Joshi, 2008). According to (Lele and Joshi, 2008), proximate causes can be categorized into three broad categories of agricultural expansion, wood extraction and infrastructure expansion whose activities or variables are demonstrated in Figure 2-2.

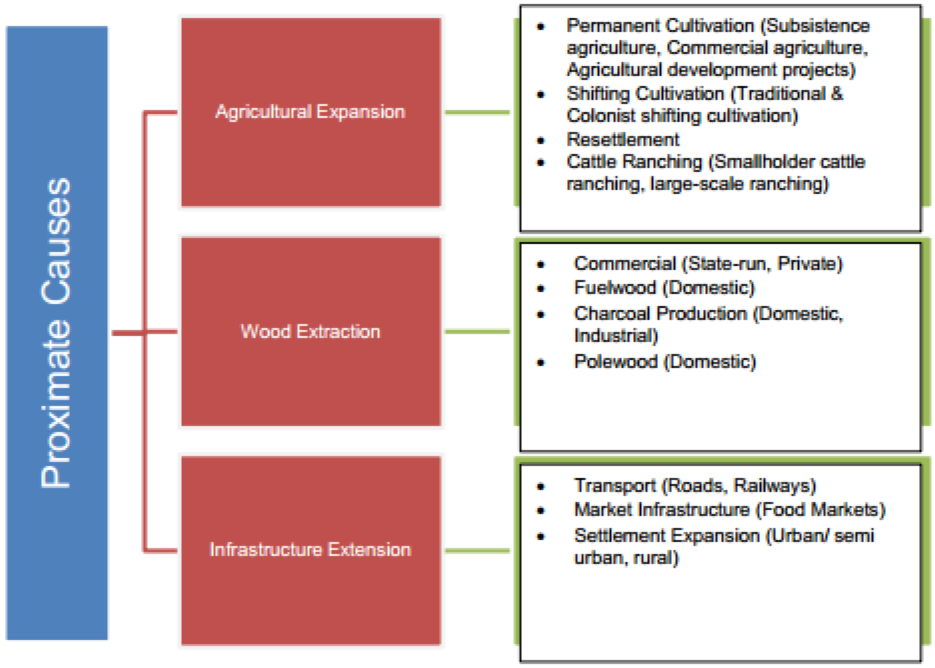


Figure 2-2: Proximate causes of LULC change and their variables (Source: (Caldas *et al.*, 2015)).

(Caldas *et al.,* 2015) describes underlying driving forces as socio-economic drivers, which comprise population change, infrastructure development, economic, market factors, institutional factors, technological and cultural or socio-political factors. The proximate causations are factors such as agricultural and cattle expansion. These components of underlying driving forces are further explained by (Lele and Joshi, 2008) and summarized in Figure 2-3 below.

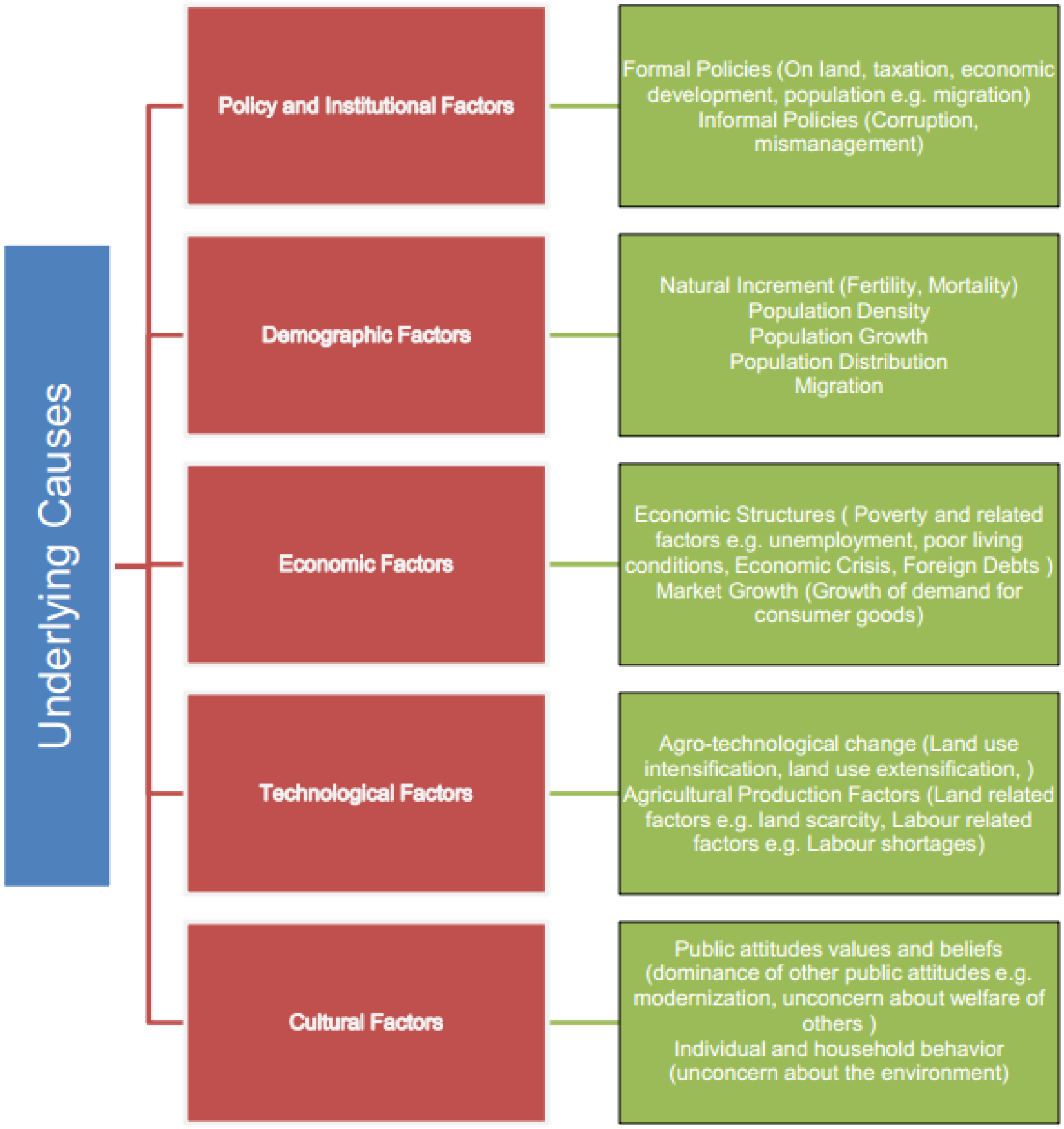


Figure 2-3: Underlying causes of LULC change and their variables (Source: (Lele and Joshi, 2008)).

2.3.2 Review of Drivers of LULC in Rwanda

This section of the literature review covers drivers of LULC change in Rwanda. Land-related problems in Rwanda are multiple and varied (GoR, 2004). The focus will be on underlying causes, which consist of political, demographic, economic, technological, cultural, and environmental variables. This is because unlike proximate factors, underlying factors operate at regional levels which coincide with the scale of this study.

2.3.2.1 Political factors

Various legislation and policies play a significant role in stirring LULC change in Rwanda. The land tenure system in pre-colonial Rwanda was characterized by the collective ownership of land, where there was complementarity between agriculture and livestock. This system promoted economic production and was a factor of stabilization and harmony in the production of social relationships. Families were grouped in lineages, and these were in turn grouped in clans. Each clan had a chief. Clans were spread all over the national territory: in different proportions according to regions. Land ownership relationships were thus based on free land use and the complementarity of the modes of production.

While political management in pre-colonial Rwanda was based on the control of the economic system which was founded on three pillars, namely land ownership for agricultural purposes, livestock and security in order to guarantee prosperity. Belgian colonization introduced profound changes in the management of the country which were later to destroy the traditional system. This traditional trilogy, which represented a system of national social balances, was therefore dismantled and transformed into a centralized administration. (GoR, 2004) states that the 1926 reform divided the country into chieftainships and abolished the system by which a chief could own several land properties in different parts of the country, which characterized his importance in the country's hierarchy. Yet, this form of the management of the country had been a factor of national unity and cohesion. The abolition of these traditional structures to exercise better control of the country and get colonial orders accepted caused many disturbances to the Rwandan society. Nonetheless, land management maintained aspects of traditional practices.

Belgian colonization also introduced the written law appearing in the "codes and laws of Rwanda," particularly in order to guarantee land tenure security for settlers and other foreigners wishing to invest in land in Rwanda.

Owing to the high population density and the need to exploit new areas, the colonial administration introduced the system of grouped homesteads called paysannats, which was similar to the traditional system of "Gukeba." This system was developed in those regions with grazing land and other land reserves and consisted of giving each household two hectares mainly for cultivating cash crops such as cotton in Bugarama and coffee in Mayaga. This practice was introduced after the abolition of the Ubuhake system and the distribution of cattle in grazing areas (Ibikingi), and it promoted the extension of cultivated land to the detriment of livestock.

A new aspect of national development was thus introduced, putting emphasis preferably on agriculture and disrupting ipso facto the balance that had always existed between agriculture and livestock. This development gave rise to conflicts: both latent and real. Even though in this system where agriculture dominated over livestock there were no open conflicts between the government and the local population, real tensions could nevertheless be felt at that time. Thus, large sections of the population among cattle breeders migrated to Umutara, Uganda, and the Democratic Republic of Congo.

From 1959 onwards, the land tenure system became a factor of real conflict among the population. It was during this period that, with the eruption of the political crisis, the first-ever wave of refugees went into exile, leaving behind both their lands and real estate properties.

- **Land situation after independence**

After independence, the government gave a vital role to the "communes" in the administration of land. Through the "Loi Communale" of 23/1/63, the protection of rights relating to registered land under the customary law became the responsibility of the commune. However, the provisions of this law were virtually nullified by Decree No. 09/76 concerning the purchase and sale of customary land rights or land use rights.

While at the beginning of the 60s the Government banked on abolishing the system of "Ibikingi" to put them under the authority of the "communes" and on recovering the land abandoned by the 1959 refugees to acquire new agricultural land, the 1970-1980 decade was characterized by intensive migration from the already densely populated regions of Gikongoro, Ruhengeri, Gisenyi and Kibuye to the semi-arid savannas of the East (Umutara, Kibungo and Bugesera) in search for vacant land. It is during this period that the Government attempted to transform the existing human settlement system into one of the grouped homesteads, known as the "paysannat." The purpose was to make more rational the occupation and use of land which was becoming more and more scarce (Oshodi, 2014).

In 1976, Decree No. 09/76 of 04/03/76 concerning the purchase and sale of customary land rights, or the right of soil use, authorized individuals to purchase and sell customary land after applying to the competent authorities. They were subject to retaining at least 2 ha of land. The buyer also had to justify that he did not have land property equal to at least 2 ha. Ever since, the Government recognized only the right of ownership based on land registration and became, therefore, the eminent landowner.

At the beginning of the 80s, there were no more new lands, and problems began to emerge bluntly: reduction of soil fertility and reduction of the size of land for cultivation, family conflicts stemming from land ownership, food shortages, etc. From 2 ha in 1960, the average area of a family's cultivation plot was reduced to 1.2 ha in 1984, according to the agricultural survey carried out at the time (GoR, 2004).

Since the beginning of the 90s, the country found itself in a land-related deadlock. Problems appeared including insufficient agricultural production, the increase of population pressure on natural resources, a growing number of landless peasants, and conflict between agriculture, livestock and natural reserves. Through agricultural projects, particularly forestry and grazing land projects, the government strengthened its role as the owner of vast stretches of land. Reforestation became an essential factor in land accumulation by the State and private individuals. Forests extended even in lands fit for crops as well as marshlands. Reforestation became thus a simple form of long-term land ownership. However, despite actions, problems such as excessive parceling out plots, deforestation and the gradual soil impoverishment arose (MININFRA, 2009; MOH, 2009; Karadaş, 2011).

2.3.2.2 Demographic factors

Various literature has pointed out that it is not the number of people that leads to pressure on land use, but rather aspects of population composition and distribution such as household size, migration, and urbanization (Gennaio *et al.,* 2009; Smith, 2013; Ecology, 2014). These factors are explained in the following sections, including their implications (particularly in housing) and interactions with the government policies.

- **Migration and Urbanization in Rwanda**

Migration is a concern in most developing countries. Even though the reasons for migrating vary from country to country, the most common for internal migration in Rwanda is the problem of food security and security issue for international migration. A combination of political, social, economic, and demographic factors drives internal and international migration in Rwanda. International migration involves movement across national boundaries, whereas internal migration involves movements within the same country.

- **Internal Migration**

Internal migration in Rwanda is mostly characterized by temporary circular migration and permanent migration to urban areas (Lawrence and Uwimbabazi, 2011). Circular migration involves movement to places of work, mostly business or education, while permanent residence remains in the rural or peri-urban setting in settlements and some parts of the cities (Urbanizationrwanda, 2017). In rural areas, a large percentage of employment relies on agriculture. However, poverty, unproductive land, and the need to survive often lead to the breakup of rural communities, impelling migration to urban locations. In Rwanda, migration to urban cities is extensive and this can be attributed to three main factors. The first is limited land and high level of poverty in Rwandan's rural regions, the second is the pattern of migration to urban areas that is not adequately managed and the third is that due to the scarcity of land, the government of Rwanda is promoting grouped settlements namely "imidugudu" so that people can use their small piece of land for strategic farming to combat food insecurity affecting most of rural areas in Rwanda. These grouped habitats intend to improve aspects of basic service delivery such as water, electricity, schools, and hospitals and to afford security. Despite this positive-sounding strategy, people fail to cope with the new living conditions found in grouped settlements and then choose to move once again towards major cities, especially to the capital, Kigali (Lawrence and Uwimbabazi, 2011).

Table 2-2: Distribution of the resident population by lifetime migration status, sex and area of residence

Area of residence and Sex	**Lifetime-migration status**			**Percentage of Migrants**
	Number of Migrants	**Number of non-migrants**	**Not stated**	
Rwanda				
Male	1,013,922	4,045,357	5,589	20.00%
Female	1,079,727	4,365,517	5,861	19.80%
Total	2,093,649	8,410,874	11,450	19.90%
Urban				
Male	438,317	451,625	1,864	49.10%
Female	387,868	456,144	1,866	45.90%
Total	826,185	907,769	3,730	47.50%

Area of residence and Sex	Lifetime-migration status			Percentage of Migrants
	Number of Migrants	Number of non-migrants	Not stated	
Rural				
Male	575,605	3,593,732	3,725	13.80%
Female	691,859	3,593,732	3,995	15.00%
Total	1,267,464	7,503,105	7,720	14.40%

Source: (NISR, 2014a)

The distribution of lifetime migrants by province and area of residence shows that only two Provinces (Kigali City and the Eastern Province) exhibit a relatively higher percentage of migrants than the national average (about 20%). In Kigali City about 54% of the resident population are lifetime migrants, while lifetime migrants represent about 34% of the resident population in the Eastern Province (Table 2). Table 2 also shows that more males (about 326,000) than females (285,000) moved to Kigali City and slightly fewer men (about 416,000) than women (453,000) moved to the Eastern Province. For Kigali City, this may be explained by the supply of employment opportunities in various sectors: this pushes people to leave their district of birth and migrate to the capital. For the Eastern Province, this migration may be explained through the recent availability of land or as the result of family or employment reasons. According to the Integrated Household Living Conditions Surveys (EICV2 and EICV3), the main reasons to migrate to the Eastern Province were family, employment and a lack of land in the 'sending' province, accounting for 71% of migrants to the east in EICV2 and 86% in EICV3 (NISR 2012, Main Indicators Report EICV3). Except the Eastern Province, where the percentage of migrants in rural and urban areas is similar (about 46% in urban and about 33% in rural areas), the difference between urban and rural areas are substantial, reinforcing the idea that migration is more an urban phenomenon than a rural one. (Table 2-3).

Table 2-3: Number and Percentage of the population which has experienced a lifetime migration by sex, province, and area of residence (Source: (NISR, 2014a))

Province and Area of Residence	Male		Female		Both Sexes	
	Number of Migrants	% of Migrants	Number of Migrants	% of Migrants	Number of Migrants	% of Migrants
Rwanda						
Urban	438,317	49.1%	387,868	45.9%	826,185	47.5%
Rural	575,605	13.8%	691,859	15.0%	1,267,464	14.4%
Total	1,013,922	20.0%	1,079,727	19.8%	2,093,649	19.9%
Kigali City						
Urban	291,572	64.6%	249,446	61.2%	541,018	63.0%
Rural	34,517	25.7%	35,378	25.5%	69,895	25.6%
Total	326,089	55.6%	284,824	52.1%	610,913	53.9%
South						
Urban	42,122	35.3%	34,906	31.6%	77,028	33.5%
Rural	95,574	8.6%	132,086	10.6%	227,660	9.6%
Total	137,696	11.2%	166,992	12.3%	304,688	11.8%
West						
Urban	42,675	28.5%	40,517	26.7%	83,192	27.6%
Rural	49,923	4.9%	69,043	6.0%	118,966	5.5%
Total	92,598	7.9%	109,560	8.4%	202,158	8.2%
North						
Urban	18,541	24.0%	21,014	25.2%	39,555	24.6%
Rural	22,928	3.1%	44,018	5.3%	66,946	4.3%
Total	41,469	5.1%	65,032	7.2%	106,501	6.2%
East						
Urban	43,407	46.2%	41,985	45.4%	85,392	45.8%
Rural	372,663	32.0%	411,334	33.0%	783,997	32.5%
Total	416,070	33.1%	453,319	33.9%	869,389	33.5%

Figure 2-4, presenting the distribution of the lifetime migrant population by the province of birth and the current province of residence, offers an idea of the importance of in-migration related to the size of the lifetime migrant population at the current province of residence. It is important to remember that lifetime migration is measured across district boundaries, so some lifetime migrants might have migrated to a different district from their place of birth, but they still live in the same province. This is emphasized by the figure above. First, it shows that the lowest lifetime migrants currently still living in the province in which they were born found in Kigali City, while the highest (about 58%) was found in the Southern Province. This means that Kigali City is the province with the highest percentage of lifetime in-migrants that was born in a different province or abroad (about 89%), followed by the Eastern Province (about 82%). Secondly, most of the lifetime migrants in Kigali City come from the Southern Province (about 31%), the Western Province (about 18%) and from abroad (about 18%), whereas most of the lifetime migrants in the Eastern Province come from the Northern Province (about 31%), the Southern Province (about 16%) and from abroad (about 16%).

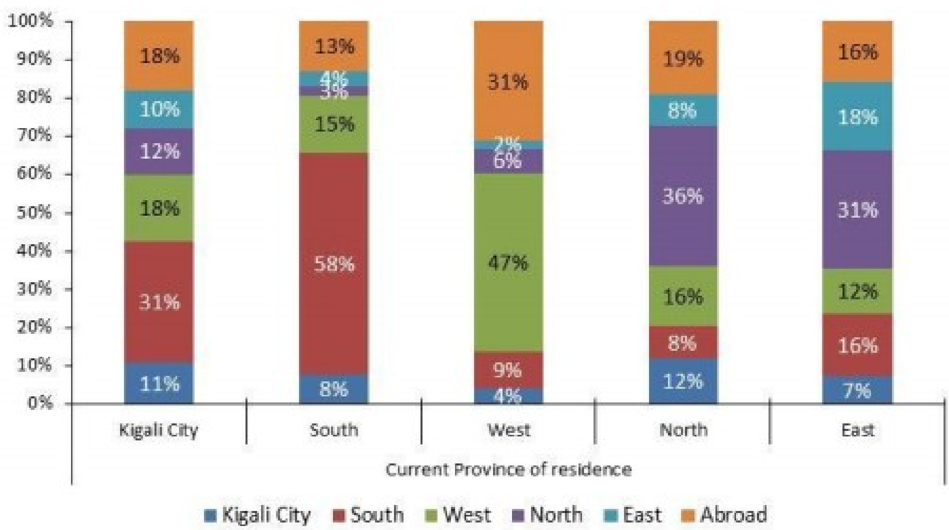


Figure 2-4: Distribution of the lifetime migrant population by the province of birth and current province of residence (%)

Figure 2-5, presenting the distribution of the lifetime migrant population by the province of current residence and place of birth, provides an overview of the out-migration movements from the place of birth. It shows that most of the out-migrants from the Northern Province have moved to the Eastern Province (about 67%) and Kigali City (about 18%), while those from the Western Province have mainly moved to Kigali City (about 30%) and the Eastern Province (about 28%).

Figure 2-5: Distribution of the lifetime migrant population by the current province of residence and place of birth (%)

Figure 2-5 also shows the main destinations of lifetime migrants that were born abroad. They are located mostly in the Eastern Province (about 37%), Kigali City (about 29%) and the Western Province (about 17%).

- **International Migration**

International migration into Rwanda is currently triggered by poverty, deteriorating economic conditions, and political instability in neighboring countries (Boswell, 2002; Since & Icpd, 2004). (NISR, 2014a) defines international lifetime immigrant as a resident individual whose place of birth is abroad. In Table 2-4, the distribution of the international lifetime immigrant population by sex and area of residence shows that foreign-born residents are a rather small group, representing about 4% of the resident population. The percentage of foreign-born residents is about five times higher in urban areas (about 10%) than in rural areas (about 2%).

According to a report by National Institute of Statistics of Rwanda (NISR), 48% of recent international immigrants living in Kigali City were previously living in Burundi, and 37% were previously in the DRC. 88% of international immigrants living in the Southern Province were previously living in the DRC. The high percentage of Congolese now residing in the Southern Province is partly the result of the Congolese refugees there in the Kigeme refugee camp, estimated at around 19,500 in 2018 (Since & Icpd, 2004; UNHCR, 2018), 46% of recent international migrants in the Western Province had their previous residence in the DRC and 35% in Uganda. Those living in the Northern Province were previously residing in various neighboring countries: 32% in Uganda, 31% in Burundi and 22% in Tanzania (National Institute for Statistics (NISR), 2015).

Table 2-4: Distribution (number and percentage) of the resident population by international lifetime migration status, sex and area of residence

Area of residence and Sex	International Life Migration Status (Count)			Percentage of Foreign-Born Migrants
	Number of Foreign-Born Migrants	Number of non-migrants	Not stated	
Rwanda				
Male	188,841	4,870,438	5,589	3.70%
Female	181,390	5,263,854	5,861	3.30%
Total	370,231	10,134,292	11,450	3.50%
Urban				
Male	95,770	794,172	1,864	10.70%
Female	84,459	759,553	1,866	10.00%
Total	180,229	1,553,725	3,730	10.40%
Rural				
Male	93,071	4,076,266	3,725	2.20%
Female	96,931	4,504,301	3,995	2.10%
Total	190,002	8,580,567	7,720	2.20%

Source: (NISR, 2014a)

Figure 2-6 with percentages, illustrates that the percentage of foreign-born females is slightly high in all provinces except in Kigali City, where 55% are males, and in the Eastern Province, where the percentage of females is equal to the percentage of males.

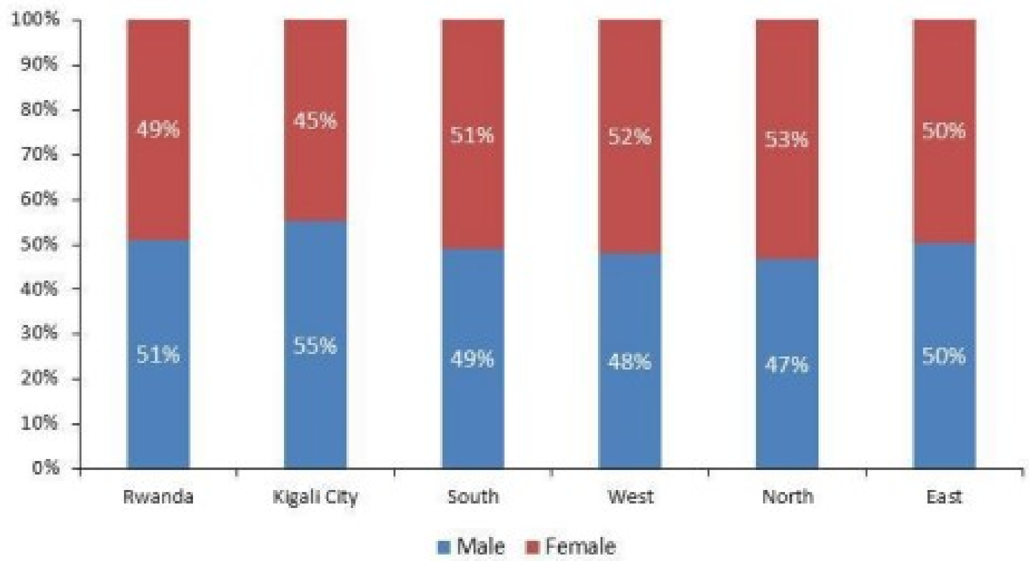


Figure 2-6: Distribution of international lifetime migration status by sex and province (%) (Source: (NISR, 2014a)**).**

- **Effects of Population Growth and urbanization**

The principal economic activity in rural areas of Rwanda is Agriculture. The size of plots for households is insufficient considering the population density that is high (IPAR, 2009; Report, 2014). Population growth exerts positive pressure on urbanization growth while the impacts of population density in agricultural areas is negative. Productive areas are covering increasing pressure on land with increasing runoff and in turn enhance water resources degradation. An increase in population and urbanization leads to pressure on these natural resources resulting in serious issues such as landscape change (Antrop, 2004), poverty, under-serviced informal housing and land degradation (Dao, 2002).

Increased effects of urbanization are evident in Rwanda's housing and transport sectors where the demand for housing in urban areas is continuously increasing yet there is no affordable land close to places of business and work, thus resulting in shacks in peri-urban areas and expensive transport costs (Poumanyvong *et al.,* 2012).

2.3.2.3 Economic and Technological factors

Economic factors can be in the form of taxes, investments, access to capital, markets, cost of production and transportation, technology, and subsidies (Barbier, 1997). Land managers are stimulated by these economic factors. Besides, they are also motivated by profitability and feasibility of particular land-use. Economic factors, combined with institutional and technological factors play a significant role in land-use change. For example, giving farmers access to capital and markets and agricultural technology can encourage agriculture expansion and conversion of land (Hussein, 2001).

- **Land Markets**

"Land Markets are mechanisms by which rights in land and housing, either separately or together, are voluntarily traded through transactions such as sales and leases. These transactions may take place on the formal land market, or may happen through informal channels such as informal land developers". In a land market, a developer searches and scrambles for land. When demand for a particular piece of land increases, its value also increases, leading to demand and supply where demand is triggered by increase in population, household development projects, and availability and access to credit funds (Wallace and Williamson, 2006).

Heavy competition for land exists between the private and public sectors, where the main objective of the private sector is to accumulate as much profit from the land as they can generate, but is reluctant to participate in the delivery of affordable housing projects. Therefore, if land is accessed by the private sector, they will allocate it mostly to office parks, shopping malls, high income generating development projects, etc. However, for the government side the land is used for building housing settlements to meet what the population can afford for rent. In grouped settlements, the government provides facilities similar to those offered in cities (Habiyaremye *et al.,* 2011).

2.3.2.4 Environmental Factors

Environmental factors are biophysical factors which "define the natural capacity or predisposing environmental conditions for land-use change, with the set of abiotic and biotic factors – climate, soils, lithology, topography, relief, hydrology and vegetation" (Linard *et al.,* 2007; Wohlfahrt *et al.,* 2008).

The interactions between environmental variables and human activities influence land-use change, e.g. relief determines the extent to which machinery can be used and the rates of erosion. Steep slopes are difficult for operating modern farm machinery and are subject to erosion thus limiting exploitation. Changes in land-use such as agriculture are influenced by environmental factors, e.g. climate (rainfall, wind, temperature) and soil conditions (Matson *et al.,* 1997; Buck *et al.,* 2004; Dale *et al.,* 2011).

- **Soil**

Fischer *et al.* (2007) identified constraints for physical and chemical properties of soil which are essential for land exploitation as terrain-slope, soil depth, soil fertility, soil chemical, soil texture, soil drainage. Soil loss, compaction, poor drainage, salinization, and acidity are classified as soil degradation,which is common in Rwanda and contributes to low productivity of the soil (Kagabo *et al.,* 2013). High population density and steep slopes make it difficult for the peasant farmers to control erosion. Fragmentation and small farm sizes are characterized by overstocking, soil erosion, excessive wood harvesting, and high population and are generally perceived as degraded (Clay and Lewis, 1990). Land degradation is one of Rwanda's critical environmental issues which is linked to food security, urbanization and climate change (Byiringiro, 2002; Hategekimana and Twarabamenya, 2007).

- **Water availability**

The availability of water resources influences land uses such as agriculture and activities associated with it (Kannan *et al.,* 2010; Munyaneza *et al.,* 2014). Agriculture and crop irrigation are the dominant users of water in Rwanda but still face challenges of water scarcity, and uneven and unreliable rainfall with abundant rainfall in the Northern Province whether in the East rainfall is insufficient. Although about 79% of the country's land is classified as agricultural, only 11% of the land represents permanent cropland. The remaining agricultural lands are covered with forests, marshlands and marginal lands in the hillsides where permanent and routine cultivation of crops are not tenable. Of a total arable land of 2,294,380 ha, 1,735,025 ha is cultivated with food and cash crops and the remaining represents pastures and bushes (Muhinda and Dusengemungu, 2011) but faces competition from other land uses such as residential, industrial developments and mining and this is further exacerbated by other factors such as water availability and climate change.

All the factors which have been discussed above require an understanding of how individuals and governments make land-use decisions and how the various factors interact in specific contexts to influence land-use change. These factors will be further explored in the catchment of Lake Cyohoha and verified using experts in land use planning. The following section of the literature review will focus on theory on status of agriculture in Rwanda.

2.4 Agriculture status in Rwanda

2.4.1 Introduction

Rwanda's economy is mostly agrarian (Hoyweghen, 1999). More than 80% of Rwanda's projected population of 12 million depend on farming (NISR, 2016). The total land area of the country measures 24,700 square kilometers. Although about 79% of the country's land is classified as agricultural, only 11% of the land represents permanent cropland. The remaining agricultural lands are covered with forests, marshlands and marginal lands in the hillsides where permanent and routine cultivation of crops are not tenable.

Over 80% of the population live in rural areas and subsist on smallholder farming. With an average of 407 persons per square Km, Rwanda represents the most densely populated nation in the continent. Hence, land distribution is highly fragmented and skewed in Rwanda. Land in Rwanda is the most valuable, productive and contested asset. Proper management of land is therefore a must. However, most of the laws governing land administration and management in the country had been formulated by the colonialists and have remained the same until the 90s. (Daley *et al.,* 2010) enunciated that several reforms and policies are under implementation in Rwanda, among these, the Land Use Consolidation policy is a key for agricultural transformation (Musahara and Huggins, 2004; Muhinda & Dusengemungu, 2011).

The overarching strategies of economic development and poverty reduction in Rwanda that envisioned social transformation through agriculture require shifting from such subsistence farming to commercially oriented agriculture. It has been followed by National Strategy for Transformation that will accelerate inclusive economic growth and development founded on the private sector, knowledge and natural resources (MINECOFIN, 2017). In Rwanda, the growing demographic pressure on land and continued fragmentation of households' plots by inheritance forced the land-use patterns to be inevitably re-organized. The volume of food crop production is function of physical land area and the productivity of land under cultivation.

Crop productivity, often measured as the ratio of farm outputs to inputs, reflects the efficiency of usage of inputs. However, the efficiency of the inputs depends on the size of the farmland (Byiringiro, 2002; Cantore, 2011; Cioffo *et al.,* 2016). Land fragmentation thus affects productivity and competitiveness of smallholder farms (Bizimana *et al.,* 2004). Furthermore, the inherent difficulties in mechanizing farm chores in small farms also impede public and private investments.

2.4.2 Agriculture Intensification

Agriculture is a significant component of Rwanda's national economy (MFEP, 2000). The favorable climatic conditions and the generally fertile soils allow cultivation of a wide range of crops in Rwanda. Major food crops include maize, rice, banana (cooking, beer, and fruit), Irish potato, sweet potato, cassava, sorghum, and beans. Vegetables such as onions, cabbages, dodo, gourds, and eggplants are also widely grown. Cash crops such as coffee, tea, and sugarcane are grown on commercial scales for exports and domestic consumption in Rwanda. Cultivation of food crops, on the other hand, has long been predominantly grown by smallholder farmers for subsistence living. As a result, the on-farm productivity levels have been deficient in Rwanda (Kathiresan, 2011).

The low productivity is attributed to the use of low inputs. As a consequence, many smallholder farmers produce the quantity which is neither enough for their consumption nor the market and therefore have no income with which they may invest in buying inputs. Increasing agricultural productivity and food security in Rwanda therefore requires replication of such adoption of modern inputs by the smallholder farmers. Setting this as the goal, the Ministry of Agriculture and Animal Resources (MINAGRI) developed Crop Intensification Program (CIP) in 2008 (Nahayo *et al.,* 2017). Since most of the inputs have to be imported, the cost of transportation to remote areas combined with the inherent reduced demand for inputs keep the prices of the inputs high. The government with the help of development partners overcame this hurdle through bulk procurement of improved seeds and fertilizers from neighboring countries and distributed the inputs to farmers through a network of public and private partnerships (Cantore, 2011; Nahayo *et al.,* 2017). The following Figure 2-7 highlights the impacts that CIP has had during the first three years of its implementation.

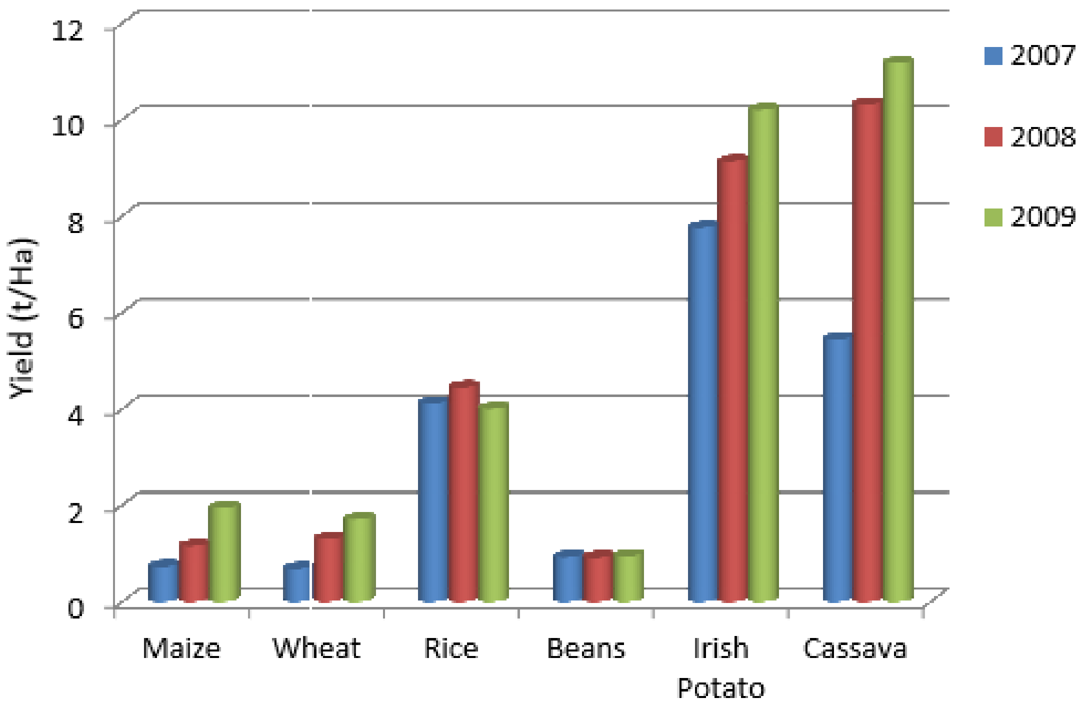


Figure 2-7: Changes in on-farm productivity of selected crops in response to the use of distributed inputs (Source: (Rudel *et al.,* 2009)**).**

From 2007 when CIP was implemented, the program has taken several approaches to increase the production and benefit farmers. During the first three years, the production of the beans has doubled, and the production of rice and Irish potatoes has increased by 3O%. The figure 2-7 above shows that the total production improved mainly because of the increase in productivity per unit land area. Such outputs have transformed Rwanda from a list of food-insecure countries to a country with improved food security. The CIP has provided the much-needed foundation for a positive change in Rwanda's agriculture development. The program has also revealed the massive potential that exists in the country in increasing the smallholder agricultural productivity which is the last objective of this research in the catchment of Lake Cyohoha. It has also testified that the cost of achieving food security is fiscally manageable and responsible. It demonstrates that land-use patterns can define the growth in productivity and development of the agriculture sector and shows that a program of national scale is feasible (Thomas and Christopher, 2005).

2.4.3 Land Use Consolidation

The Land Use Consolidation Policy was enunciated in 2004 by the Government after the presidential visit in Malawi where real benefits of consolidated lands were seen. LUC policy was implemented for the first time in 2008 by the Government of Rwanda, through the Ministry of Agriculture, as part of the Crop Intensification Program (CIP). The CIP was initiated by the same Ministry in September 2007 to increase agricultural productivity of high-potential food crops and to provide Rwanda with greater food security and self-sufficiency. The implementation of this program involves various components, including Land Use Consolidation as the central pillar, the proximity advisory services to farmers, inputs (seeds and fertilizers) distribution and post-harvest technologies (e.g. driers and storage facilities). The program is also supported by other initiatives like land-husbandry, irrigation and mechanization infrastructure development to bring more land under production, avoid dependency on rainfed farming system and use of farm power in the context of market-oriented agriculture (Nilsson, 2018).

The LUC policy is in line with Rwandan Government efforts to mitigate hunger and poverty. It correlates not only with CIP but also with the "Villagization" known as new resettlement program "Imidugudu" which started earlier in 2004. Therefore, its implementation process involves various stakeholders (e.g., Ministries, NGOs, Civil Society Organizations, and the Private Sector) (Rubanje, 2016). Figure 2-8 highlights the participatory approach of LUC under CIP implementation.

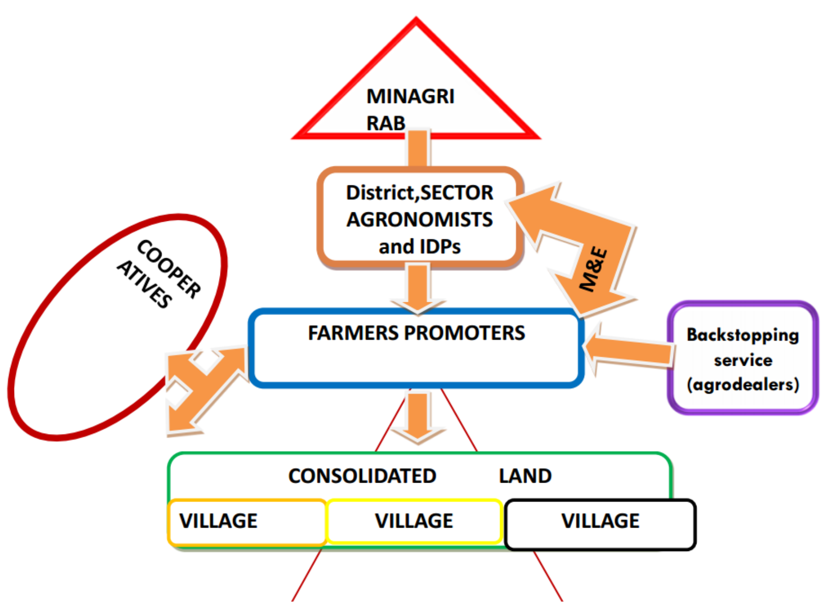


Figure 2-8: Farm LUC Implementation Process

2.4.3.1 Priority food crops under LUC

Eight priority crops (Irish potato, cassava, beans, maize, wheat, rice, banana, and soybean) have been selected for promotion under land use consolidation policy. The rotation system is based on comparative advantage, crop suitability in a specific agro-ecological zone and its contribution to the overall food security. Crops like Irish potato, cassava, beans, and maize have shown a competitive advantage with a positive trade balance, according to the recent cross-border trade study. To address both marketing and post-harvest challenges, the Government of Rwanda (GOR) has decided to establish driers and food storages facilities where land has been consolidated (Isaacs, Snapp, Chung, & Waldman, 2016). Consolidated use of lands allows farmers to benefit from the various services under CIP such as: (i) efficient delivery of inputs (improved seeds, fertilizers), (ii) proximity extension services, (iii) post-harvest handling and storage facilities, (iv) irrigation and mechanization by public- and private stakeholders, and (v) concentrated markets for inputs and outputs.

Since its introduction in 2008, the total area under land use consolidation has increased by 18- fold from 28,016 ha in 2008 to 602,000 ha in 2012. The figure below illustrates the increment in LUC under priority crops over the years, the target being to reach over 700,000 ha fully consolidated by 2017 (Muhinda and Dusengemungu, 2011).

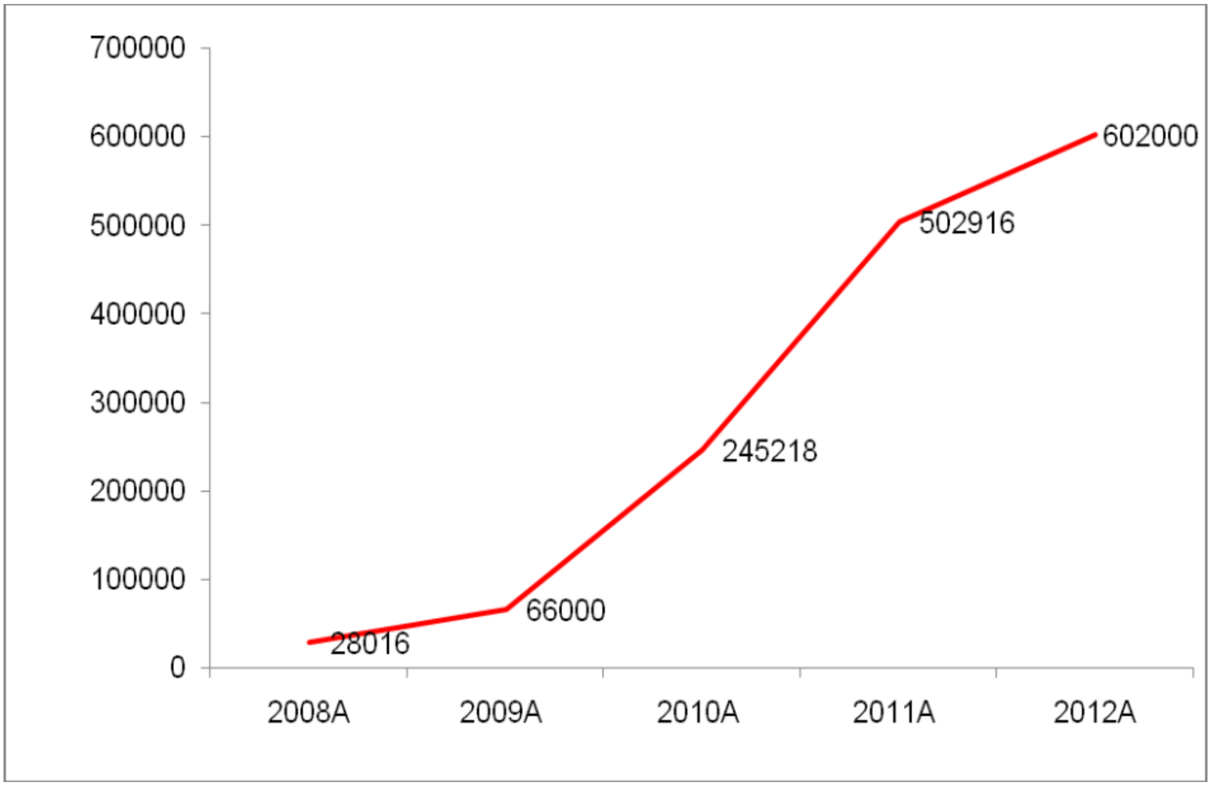


Figure 2-9: Increase in LUC under priority crops (2008-2012)

2.4.3.2 LUC worldwide

The process of land consolidation, "the method of reversing the action of land fragmentation," is not new in the World countries. In Britain, land consolidation took place so long ago, that many writers and even experts tend to forget that it took place at all (Pašakarnis & Maliene, 2010). Some of the earliest attempts at land consolidation, as a method of land reform, took place in Scandinavia, particularly in Finland (Hartvigsen, 2013), Sweden (Huang *et al.,* 2011), Cyprus (Demetriou *et al.,* 2012) and Denmark (Abubakari *et al.,* 2016) in the 18th and 19th centuries. According to (Bouma *et al.,* 1998), at least half of Western Europe's farmland was considered to need consolidation in the 1950s, a time when Europe had pressing needs of reconstruction after the Second World War.

Land use consolidation had also been implemented in Central and Western European (Pašakarnis and Maliene, 2010) countries since 1989 as part of an overall strategy of transition from centrally planned agriculture to privatization and market development in order to increase farmers revenues. It was also implemented in Latin America (Teubal, 2009), Asia (Niroula and Thapa, 2005) and Southern Africa (Asiama *et al.,* 2017) to mitigate land fragmentation.

In Kenya, the customary land tenure failed to meet the needs of an expanding population which then resulted in low subsistence levels and influenced land reforms needing land consolidation to stop further fragmentation in Kikuyu, Kiambu and Maranga Districts (Coldham, 1978).

2.4.4 Land degradation in Rwanda

Land degradation, as defined by the United Nations Convention to Combat Desertification, is the reduction or loss of the land's biological or economic productivity caused by human-induced land-use processes (UN Ecosoc, 2007). Land degradation in Rwanda is characterized by soil erosion (i.e. loss of topsoil) and declining soil fertility. Although a widespread problem in east and central Africa, soil erosion reaches an extreme in Rwanda due to its steep topography, natural soil susceptibility to erosion and leaching and climatic conditions (Karamage *et al.,* 2016). Land degradation manifests itself through soil erosion, water scarcity, reduced agricultural productivity, loss of vegetation cover and biodiversity, drought and poverty (UN Ecosoc, 2007).

Soil erosion results in a significant decline in soil fertility, which is the primary cause of low agricultural productivity in Rwanda. Heavily degraded soils are incapable of supporting large plant biomass because of low or depleted soil nutrients and soil organic matter (SOM). Organic matter is essential for maintaining soil structure and maximizing nutrient retention. It is the glue that holds soil nutrients, namely nitrogen and phosphorus in place until they are accessed by cultivated crops (Gordon *et al.,* 2008). Frequent, continuous cultivation has accelerated the rate of SOM depletion in the country.

Moreover, soil erosion has substantial downstream impacts. High sediment loads reduce the size of river channels and water-holding capacities of lakes, choke water harvesting and storage systems, and exacerbate flooding (Gran *et al.,* 2011). In addition, erosion is a major cause of progressive eutrophication in many of the country's lakes (Daniel *et al.,* 1998; Ekholm and Lehtoranta, 2012), promoting the proliferation of algal blooms and water hyacinth (*Eichhornia crassipes*), which reduce the amount of dissolved oxygen in water as it can be seen in the figure 2-10 below of Lake Cyohoha North.

Figure 2-10: Water hyacinth (*Eichhornia crassipes*) growth on Lake Cyohoha North

Several problems have been identified to be the route of soil degradation in Rwanda, which in turn has affected the depletion of the quality and quantity reduction of water resources. Lake Cyohoha (Figure 2-10) has been largely degraded, the causes of land degradation in Rwanda to be inadequate soil erosion control and unsustainable land-use practices (RADA, 2007).

2.4.5 Soil Conservation

In Rwanda, the initiative to prevent land degradation date back to the early twentieth century, when planting trees and constructing trench ditches were already being promoted to prevent erosion. Colonialists set warnings over over-grazing and over-cultivation threatening erosion and soil degradation (Olson, 1994). Today, the state encourages the construction of terraces to control soil erosion and reduce the loss of valuable top-soil (Mupenzi *et al.,* 2012).

Historically, Rwandan farmers settled along the upper ridges of hillsides, where soils were fertile, and cultivation was a more straightforward task than it was farther down, on the steeper slopes and in the marshy valleys. Rapid population growth has in recent decades brought several changes in the traditional agricultural system: (1) farm holdings have become smaller due to constraints on land availability; (2) holdings are more fragmented; (3) cultivation has pushed onto bottomlands and fragile margins on steep slopes previously held in pasture and woodlot; (4) many households now rent land, particularly households owning little land or those with large families; (5) and fallow periods have become shorter, and cultivation periods have grown longer. These factors have put pressure on soil, resulting in increased soil erosion and the government has taken measures to combat and control soil erosion (Berry *et al.,* 2003; RADA, 2007).

The emphasis on bench-terrace policies as an effective way to combat soil erosion and to maintain water and soil nutrients is supported by experts. If well maintained, they can also improve land management and increase crop yields (Posthumus and Stroosnijder, 2010; Rushemuka *et al.,* 2014). However, terracing on its own does not ensure increased production. It requires additional investments in inputs such as fertilizers, which farmers often find challenging to secure. Farmers also complain about the high labor input that is required to build and maintain the terraces (Bizoza and de Graaff, 2012). At present, farmers are encouraged to combine both mechanical and biological measures: terracing, contour bunds, trenches, and water retention systems at field level, fallows (although limited), hedgerows, intercropping, mulching and tree planting. Additions to the array of conservation techniques include hedgerows planted with agroforestry species (e.g. *Pennisetum purpureum*), which are highly appreciated because they protect the soil and provide fodder for livestock. Zero grazing has been promoted because of its combined effects such as soil protection and integrated nutrient management through manuring, thus strengthening the (re)integration of cultivation and livestock production (Nabahungu and Visser, 2011; Shapiro *et al.,* 2017).

2.4.6 The economic relevance of agriculture

Agriculture accounts for a third with 35% of the country's gross domestic product (GDP) (2009-2013) (FAO, 2015). Over the last 25 years, the agriculture sector has played a tremendous role in improving livelihoods of Rwandans and sustaining the country's economy. Recent statistics from the ministry of agriculture show that agriculture contributes 31% to the national GDP. It also covers 90% of food needs, generates 50% of the country's export revenues and employs around 70% of the population (MINAGRI, 2019). National economic growth projections are expected to depend heavily on the performance of the agriculture sector, which employs more than 80% of the country's population (Muhinda, 2013).

The agriculture sector also plays a vital role in national food production where more than 90% of the food produced nationally is consumed in the country. Although agriculture contributes significantly to the country's export revenues, Rwanda is still a net agricultural importer. Generally, tea and coffee are leading export commodities concentrating more than 90% of the export crops value. The main crops grown in the country are beans, banana, cassava, and maize, accounting for 18.1%, 17.3%, 9.2%, and 9.5% of total harvested area (2008– 2012). However, production of rice, maize, and beans do not meet the national demand, and therefore imports of these agricultural products are significantly higher (FAOSTAT, 2016).

There is an inclination for agricultural reinforcement due to heavy demographic pressure, resulting in a large amount of tiny and scattered farms. Small-Scale farmers (less than 1 ha) account for 72.4% of total farmers in the country. Since more than 70% of agricultural land is on hills or the side of hills and commercial agriculture is more difficult (NISR, 2017b).

Currently, Rwanda is finding a way to transform its traditional agriculture sector to a modern method in order to have sustainable management of natural resources, water, and soil conservation. The strategies are being made to achieve the target including crop diversification and intensification and irrigation development (USAID, 2010; MINAGRI, 2017). In Rwanda, there are three agriculture seasons and each season has its specific crops grown in a particular portion as shown in table below.

Table 2-5: Rwanda agricultural seasons and main crops grown

Season	Crop	Percentage (%)
Season A: Starts in September of one year and ends in February of the following year	Beans	27
	Bananas	19.7
	Cassava	12.6
	Maize	11.9
Season B: Starts in March and ends in July of the same year	Bananas	17.9
	Beans	17.4
	Cassava	15.9
	Sorghum	14.6
Season C: Starts in August and ends in September of the same year	Irish potatoes	71
	Beans	14
	Vegetables	12

Source: (NISR, 2014b)

2.4.7 Agricultural production systems and greenhouse gas emissions

Rwanda has a diversity of agriculture production systems spread throughout its various agro-ecological zones. The northern and western highlands are predominantly dedicated to mono-crop cultivation, such as potatoes, tea, maize, wheat, climbing beans, and pyrethrum. The eastern lowlands are famous for banana, maize, bush bean, sorghum, and cassava production. In the central and southern regions, farmers cultivate sweet potatoes, bush beans, tea, coffee, cassava and wheat (Mutware and Mugabo, 2009).

Livestock farming is both small- and large-scale and includes cattle, sheep, goats, rabbits, pigs, chicken, etc., usually reared under zero-grazing systems. The farmers with relatively large land endowments (above 5 ha per farm) are located in the eastern savannah (Nyagatare, Gatsibo, and Kayonza districts). Sugar cane is grown in Nyabugogo, Akagera, and Nyabarongo swamps located in Gasabo, Gicumbi, Kamonyi, and Bugesera districts (Mutabazi, 2010). Irrigated rice is grown throughout the country in swamps and extension of rice areas is ongoing. Agriculture industries include tea, coffee, pyrethrum, sugar processing plants and industries producing maize flour, soybean oil, packed milk, and its sub-products are developing (WorldBank, 2018).

Total greenhouse gas (GHG) emissions in Rwanda are relatively low compared to regional and global averages, but trends show a slight increase since 2010. However, the agricultural sector contributes significantly (39.5%) to the country's total GHG emissions (USAID, 2018).

2.4.8 Rwanda Agriculture and Climate Change

The Rwandan agricultural sector is highly vulnerable to climate and weather-related risks, including prolonged droughts (especially in the eastern and Southeastern regions), mudslides (especially in the northern and western regions), unpredictable rains, floods, and hailstorms. The variable rainfall in 2008 caused maize yield losses of 37% in the eastern province and 26% in the southern province. Milk production losses were estimated at 60% in times of drought (Herve, 2019). Research indicates that rainfall patterns are becoming more irregular and unpredictable with shorter rainy seasons negatively affecting Rwandan agricultural production (Kabirigi *et al.,* 2015). Moreover, estimates from the fourth IPCC assessment report indicate that average surface temperature in Africa has increased by 0.2 to 2.0 °C in the last four decades (1970–2004), expecting an overall increase in annual temperatures (by 1.0° C–2.0° C) over the next century (2010–2100) in Rwanda (IPCC, 2007). For that reason, Rwanda has taken a proactive approach in mainstreaming climate change into its development policies and strategies. Primary national development documents, such as Vision 2020, the Economic Development and Poverty Reduction Strategy (EDPRS), the Strategic Plan for the Transformation of Agriculture in Rwanda (SPTAR), and the Irrigation Master Plan (IMP), recognize climate change and variability as the most significant challenge and threat to the development agenda (CIAT, 2015).

2.5 Water pumping systems for agricultural irrigation

Water pumping system has a long history, and many methods have been developed to pump water to use for different purposes like irrigation, domestic use, industries with a minimum of effort (Mehrotra, 2013). The irrigation systems have the role of taking water from source, conveying it to individual fields within the farm and distribute it to each field in a controlled manner. Depending on elevation and location of water resources, two methods of irrigation can be used. When water surface is situated on higher slope, the gravity method is used while when source of water is underground or at low slop, the pumping system which is also known as pressure method is required to take water to the point of use (Basalike, 2015).

About 85% of African water withdrawals are used for irrigation (Fischer, Tubiello, Velthuizen, & Wiberg, 2007).

In Rwanda, many projects are being studied on how to improve agriculture productivity by combating the effects of climate change such as droughts, irregular rainfalls, and landslides. One of the measures taken to deal with these problems is to put much effort into providing irrigation to hillside farms (Branca and Tinlot, 2012). There are some considerations such as land slope, soil permeability, and type, plot size and crops, water availability, required labor inputs and economic costs/benefit have to be analyzed before carrying out irrigation (Bidogeza *et al.,* 2009). The most Rwandan cropped areas are irrigated using surface water resources by method of gravity, mainly for marshland areas.

However, some regions of the country showed to have a higher slope, and so it is impossible to apply gravity method of irrigation. Those areas include Bugesera district with an altitude varying between 1,100 m and 1,780 m. Bugesera is a hot district and is at the 17th position in the country to have a percentage of Households involved in agriculture and livestock activities. Crop farming and livestock are essential in the Bugesera district's economy where 77.8% of the population depends on agriculture, against 72% for national average (BDDP, 2013). Compared to other regions of the country, Bugesera district has dry climate with a temperature varying between 20°C and 30°C with an average ranging between 26°C and 29°C. In the past the district was turning into a dessert zone due to the extended drought period, that is why sustainable agriculture needs to enhance the irrigation system. This district has abundant water resources (rivers and lakes) and suitable average solar irradiation of 5.6 kWh/m2/day which may be used for irrigation (Walraevens *et al.,* 2018).

2.6 Agriculture water resources

The available water resource is an essential criterion for choosing the kind of energy sources for any given water pumping application. Water can come either from groundwater or surface water. Surface water includes lakes, rivers, seawater, and rainwater whereas groundwater is found in underground aquifers, including springs. Spring and underground water do not commonly require treatment, except when it contains chemical substances such as salt and fluoride (Savci, 2012). Generally, the water treatment is not the main issue for irrigation purposes as long as it does not contain chemicals harmful to the soil and the crops (Ahmed *et al.,* 2010).

According to Chang *et al.* (2001), the quality of the water is another crucial factor in identifying water resources. If the water is used as a domestic water supply, treatment may be needed. Nevertheless, water quality may be less critical for irrigation and livestock watering, except if it contains harmful chemicals. For example, Saltwater can burn some crops and damage soils (Francoisz, 1975).

Usually, agriculture requires the use of freshwater to irrigate crops. The primary water resources used for Rwanda irrigation system are runoff for small reservoirs, runoff for dams, direct river and floodwater, lake water resources, groundwater resources and marshlands (IPAR, 2009). Water is a fundamental asset for improving the livelihoods of smallholders and family farmers in Rwanda (Murugani and Thamaga-chitja, 2017). Sufficient availability and reliable access to water is crucial, not only to food production but also to social and economic development and sustainability. While investments in agricultural water management are a key to the increase of productivity of poor farmers and reduce rural poverty (Kamara *et al.,* 2019), they often neglect considering the real needs and capacities of the local population or their market potential.

2.6.1 Agriculture water resources in achieving SDGs

Agricultural water management is an enabler and entry point for equitable and sustainable socio-economic development in Rwanda. Enhancing access to water for agricultural production is to be strongly emphasized to ensure ecological sustainability. “Promote sustainable agriculture” is tacked onto the proposed Goal 2, “end hunger, achieve food security and improved nutrition” (Burchi & Holzapfel, 2015; UNICEF, 2016). The access to water for agriculture will play a crucial role, and the importance of improving agricultural productivity is to reduce poverty and hence, end hunger in Rwanda. A recent inventory of marshlands in Rwanda conducted in 2008 showed that Rwanda had got 962 water bodies and 860 marshlands, which has the potential for achieving water sustainability for smallholder farmers (REMA, 2008).

2.7 Summary of the Literature Review

In summary, based on the literature review, water resources are the sources of water that are useful for humans, as only a small portion (0.8%) of fresh water is available for use (Farinotti *et al.,* 2019). Water is used for many different purposes, irrigation, domestic use, industrial use, and other human daily activities.

This research has focused on how changes in land use and land cover affect water resources. Lake Cyohoha serves the population for many functions, the main focus of this research is agriculture, this to ensure sustainable availability of water to smallholder farmers for irrigation in the future. Today the demand and consumption of water, food, and energy are increasing in the day to day life as the population growth increased. Several types of research have been done for studying the impacts of LULC change on environment in urban areas but failed to show its effect on water resources in rural areas where production is based on agriculture.

The research is built from a bank of knowledge which exists in this area. The research has associated land use, agriculture activities and the growth of population, leading to depletion of water resources, an example of Lake Chad. According to Niane *et al.* (2014), River Gambia has also experienced a reduction in size as a result of agricultural and mining activities along the river banks**.** The other study in Southern Africa has associated depletion of Zambezi water basin as a result of hydroelectricity projects and fishing according to (Pleasant, 1984; Kling *et al.,* 2014). Also many studies in the Nile basin have shown the existence of poor catchment management from riparian countries, causing severe water shortages and pollution (Pacini and Harper, 2016). So, the research addresses the knowledge gap which exists on Cyohoha Lake, its management, environmental sustainability, livelihood of communities and the influence of land use, land cover, and human activities. Also, this research tries to conceptualize the applicability of solutions which were posed from other studies such as creation of environmental community clubs, to monitor the protection and conservation of the catchment area in order to complement the Environmental Agency of Rwanda. This research is unique in Rwanda, Bugesera region, because there is no research which was done so far upon this problem, which has affected the local economic development of the area.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

This chapter covers all the techniques and methods that have been used for conducting this research. This section describes the methodology that was followed in the study to answer the research questions. This study was conducted using a mixed-method, research methodology, which integrated a quantitative and qualitative approach to better understanding of LULC changes and their drivers. Detection and analysis of drivers of LULC changes were conducted through a desktop study of LULC maps using Geographical Information Systems (GIS), interviewing catchments managers from both REMA and RWFA and Land Managers of the sectors within the catchment, document analysis and adapting the DPSIR framework. The desktop study of LULC maps was used to analyze LULC changes, and this addressed the objective of quantifying changes in LULC in the catchment of Lake Cyohoha. Interviews with catchments managers (Appendix 2) accompanied by reviews of documents were the methods used to determine driving factors and their impacts. An adapted Driver-Pressure-State-Impact-Response (DPSIR) framework was used to report and organize findings of the interviews into grouped themes presented as components of the framework. The sections below describe the sources of data, data analysis, population sample, research instrument and ethical considerations relating to this study.

3.2 Study area

The study area of this research is Lake Cyohoha North catchment, which lies in the Eastern Province of Rwanda. Due to poor management and repeated drought that occurred in 1999/2000, the Lake was about to dry up completely, which made the government and other institutions to start activities for the restoration of Lake Cyohoha North. The Lake Cyohoha catchment falls within the Akagera sub-basin of the more extensive Lake Victoria basin which is part of the Nile basin. The catchment covers watersheds that extend to an area of 508 km^2. It has an extensive wetland which is considered as a critical area under Ramsar Convention. Lake Cyohoha is 27 km long, and 5 to 2 km wide and is separated into two transboundary lakes, the southern and the northern Lake Cyohoha (GWP, 2016). The northern is estimated to 25km long and 0.30-1 km wide. Series of swamps up to 9 km separate the lake and the river Akanyaru, which is a tributary of the Akagera River, the biggest among 23 rivers that drain into Lake Victoria (Wali, 2011).

Lake Cyohoha is located in Bugesera Region. The dominant vegetation is dry savanna with short grasses, shrubs, and short trees; a characteristic of arid and semi-arid areas. The shrubs and short trees also surround the undulating hills, valleys and along the rivers and wetlands. The extensive savannas and their drought-resistant shrubs have historically provided grazing lands. The main types of ecosystems found in Bugesera are wetlands, water bodies, agricultural landscapes, savanna woodlands, and conserved rangelands. These ecosystems provide a variety of services for the people living in the surroundings of the lake. Lake Cyohoha and its wetlands, as well as the rivers, are the principal source of water for humans, livestock and wildlife. However, as previously mentioned, the lake and its wetland systems have been severely degraded due to agricultural expansion and settlement.

Consequently, with increasing population, most of the natural vegetation was converted into agricultural lands and over a time it disappeared. In terms of climate, the region is a low rainfall zone receiving an annual average of around 900 mm. Currently, the region is periodically faced with a persistent drought.

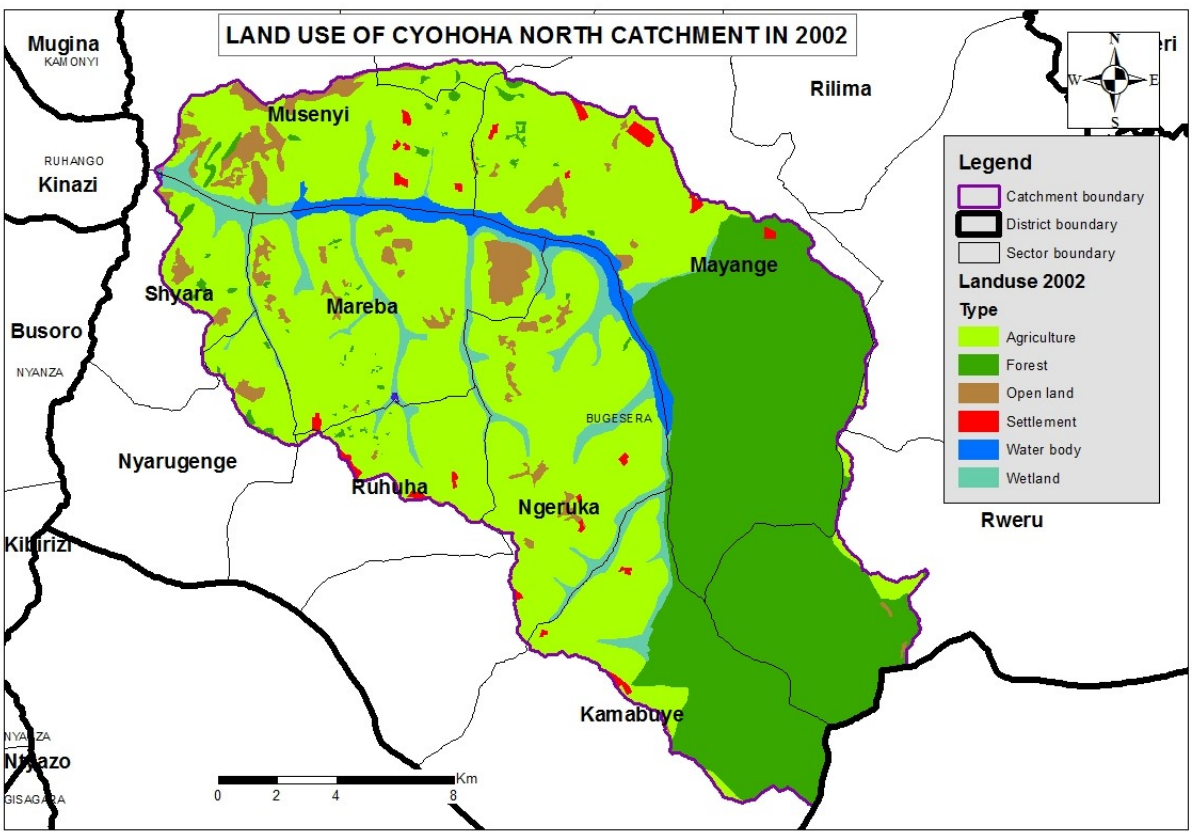


Figure 3-1: Lake Cyohoha South Catchment

According to General population census 2012, Bugesera is one of the seven districts of the Eastern Province in Rwanda. It covers a total surface area of 1337 km² of which arable land is estimated to 91,930.34 ha. The average size of land cultivated per HH is 0.59 ha. The district is composed of 15 Sectors, in which 10 compose the catchment of Lake Cyohoha North (Figure 1.1); 72 Cells and 581 Villages with a total Population of 363,339 people precisely 177,404 males and 185,935 females (BDDP, 2013).

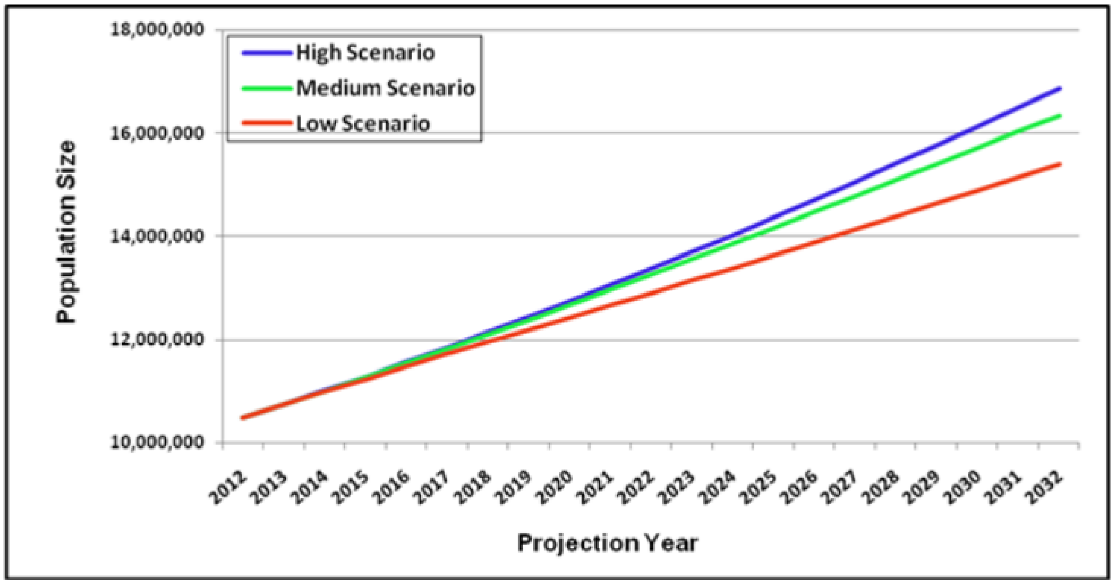


Figure 3-2: Evolution of the projected total population Source: (NISR, 2014a)

Agriculture Development in the Lake Cyohoha catchment region is very high and expected to increase in future. However, since 1960, the region has experienced inflow of more People from within and outside Rwanda, which has progressively changed the demographic structure of the region. Most immigrants to Bugesera mentioned search for better agricultural lands as the main reason for migrating (UNEP, 2007). Population increase in the region with subsistence agriculture coupled with hunger caused by repeated droughts occurred in the region and low rainfall are significant issues in the Province. Such increase, coupled with continued in-migration, results in the growth of informal dwellings with characteristics of poor living conditions such as lack of access to essential services. Furthermore, informal dwellings are located in unsuitable places which are often close to natural features such as wetlands and natural open space and hence, contribute to environmental degradation.

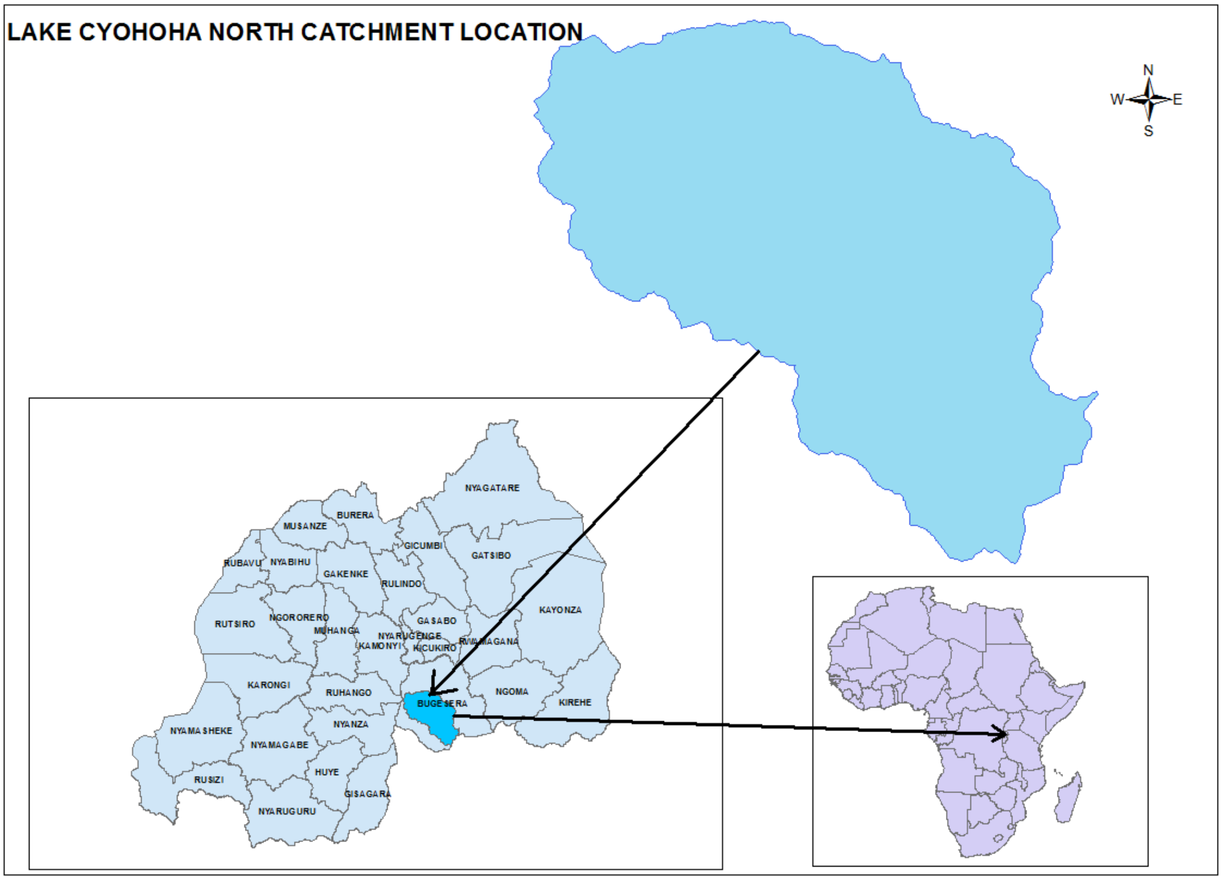


Figure 3-3: Lake Cyohoha south location in relation to Rwanda

Besides the issues associated with urbanization, population growth in the Lake Cyohoha catchment also contributes to an increase in pressure on natural resources such as land and water resources. The agricultural sector is a significant contributor to the economy of the region and is a crucial employment generator. However, expansion of agricultural activities harms the environment if it occurs at the expense of Critical Biodiversity Areas (CBA's). An analysis by the National Institute of Statistics of Rwanda (NISR) showed that a near-total conversion of wetlands, forests, and savanna woodlands into agricultural farms has occurred (NISR, 2017a). The Lake Cyohoha catchment is, therefore, faced with a challenge of weighing settlement development against agricultural expansion and protection of biodiversity areas to ensure better management of Lake Cyohoha.

3.2 Research Design

This study used both a qualitative and quantitative research design. Qualitative, as well as quantitative approaches, were employed to collect data. It has used both qualitative and quantitative approaches during sampling, data collection, and analysis. At data collection stage, Qualitative approach was used to collect ideas and opinions from farmers in an open-ended interview to the respondents where people provided their experiences in agriculture, while quantitative approach was used to collect responses from government institutions and nongovernment organizations in a closed-ended interview. A questionnaire has been used to collect numerical data and also observation method was used onsite to evaluate what was being done.

3.3 Population and Sample Size

This study was conducted in the catchment of Lake Cyohoha, Bugesera District, which was selected depending on increased degradation of the Lake while it sustains life of this region's people. Despite the availability of Lake Cyohoha, this region has recorded a problem of hunger and a significant number of families that are under a malnourished status. This study used sampling in order to obtain data from the field. A sample of 100 farmers in the catchment helped to simplify the work of the researcher by concentrating on a few respondents instead of covering many respondents. Further, two officers selected from RWFA and REMA, ten land managers and one reserve force were selected for interview. Sampling also helped to make generalizations due to the limited time of the research.

3.3.1 Sampling procedure and data collection

The study was conducted based on the survey in Bugesera district, Eastern Rwanda. The sample farmers were selected by utilizing a purposive sampling technique. From the total number of farmers that are using agriculture as their primary income source in the selected study areas, 100 respondents were taken from all Sectors which have their water flow to Lake Cyohoha: Musenyi, Nyamata, Rweru, Kamabuye, Ruhuha, Ngeruka, Mareba, Shyara, Nyarugenge and Mayange sectors. The summary of the number of respondents selected from study area is presented in Table 3-1.

Table 3-1: Sample size and sampling technique

Category of respondents	Sample Size	Sampling Technique
Farmers	100 (10 each Sector)	Purposive sampling
Sector Land Managers	10	Taken from each Sector
Agronomists	2	Purposive sampling
NGO	1	Purposive sampling
Catchment management experts	2	Purposive sampling
Total	**115**	

To carry out this study, both primary and secondary data sources were employed. The primary data were collected by employing methods such as critical informant interview using semi-structured checklist, expert interview; focus group discussion, semi-structured household questionnaire and observation of events. Secondary data that could supplement the primary data were collected from published and unpublished documents obtained from different sources. These included country policy statements, strategies regulations, reports, papers and journal on LULC and water resources. Items covered during the data collection were socio-economic situation of sampled farmers, land use and land cover change, land degradation, opportunities and barriers of using Lake Cyohoha for irrigation, demographic features, and the livelihood impact of irrigation activities. Discussions were also held with catchments management experts at the Rwanda Environmental Management Authority (REMA) and Rwanda Water and Forestry Authority (RWFA) and agronomists within the catchment.

3.3.2 Sampling techniques used

Simple random and purposive sampling techniques were used to ensure that each member of the target population has an equal and independent chance of being involved in the sample. Simple random sampling was used to select farmers in districts of the catchment. This technique was chosen because the category of farmers has a large population size and as such warranted simple random sampling to minimize sampling bias. Purposive sampling employed to select agronomists, experts, and administrative staff. This technique was used because sampling has to be done from smaller groups of informants and therefore, the researcher needs to choose one by one purposively.

3.4 Remote Sensing derived LULC data

3.4.1 Available LULC data

Analysis of LULC change in the study area was based on directly comparable LULC datasets of 2002, 2010, and 2018 obtained from Rwanda Water and Forestry Authority (RWFA). These datasets cover the whole country at a 30m spatial resolution. The 2002 datasets were created by digitizing orthophotos taken in 2000 while the ones from 2010 and 2018 were done by SARMAP, a very experienced company in remote sensing based in Switzerland subcontracted by Esri Rwanda Ltd.

The 2010 and 2018 datasets were generated from optical satellite imagery (Landsat 8) and Synthetic Aperture Radar (SAR) data (Sentinel 1) taken at regular time intervals over all seasons by automatic classification and incorporate both land-cover and land-use data which were validated and improved by field surveys.

3.4.2 Data processing and software

The 2002 datasets were classified into eight classes, 2015 into 13 classes and the 2018 LULC datasets into eight classes. All datasets were reclassified or grouped into six classes for easy analysis and assessment of LULC changes. The classes are summarized below.

Table 3-2: LULC Classification of the datasets

LULC Class	LULC included	Description
Forest	Dense forest, Sparse forest and Other tree covers (if appropriate)	Mainly natural forest, including some plantations with similar appearance and including unlogged or lightly selectively logged areas
Open areas	Open areas	Including parkland or savanna with detached trees, bushland or similar ecosystems, including areas

		of natural regeneration and young planted areas, and areas that have been heavily selectively logged but not clear-felled, or with scattered trees and shrubs
Agriculture	Banana plantation, Tea plantation, Coffee plantation, Hill-side perennial cropland, Hill-side seasonal/annual cropland without agroforestry, Hill-side seasonal/annual cropland with agroforestry, Valley irrigation/ drainage schemes: rice, Valley irrigation/ drainage schemes: other crops, Valley non-irrigated agricultural perennial cropland, Valley non-irrigated agricultural seasonal cropland, Open grassland, Grassland with scattered trees/savanna, Bush or shrubland, Other	Agriculture, grassland, clearings, including cropland, pasture, vineyards, nurseries, and natural grasslands or low herbaceous and shrubby vegetation. This class can be eventually disaggregated in terms of seasonality vs perennial
Bare Soil	Rock outcrops, Landslides, Quarries, and related degraded land	Barren land. This also includes bare soil associated with agricultural systems and other areas of bare soil, rocks, sediment deposits or landslides. It also included areas affected by clear-felling or bush burning with

		little or no vegetation cover
Settlement and buildings	Urban/dense settlements, Urban/houses in individual gardens, Informal settlements, Industry, Semi-urban dense/Sparse settlements, Scattered buildings	Built-up areas, residential, commercial or industrial of all kinds
Water bodies	Rivers/streams (running water bodies), Lakes/ponds/reservoirs (standing water bodies)	Rivers/streams (running water bodies), Lakes/ponds/reservoirs (standing water bodies)
Mines	Mines	Areas with mining activities
Unclassified	Unclassified	This category includes areas where data does not give a good image of the land cover or where the signal is unclear

Reclassification was done in ArcMap 10.5 using spatial analyst tools. It was performed to remain with inputs of LULC maps with matching classes, legend and characteristics. LULC change detection, quantification, and analysis were performed using Microsoft Excel that computed the changes and used to plot graphs. ArcMap 10.5 was therefore used to process the LULC datasets prior to analysis of the change detected. A Clip function in ArcMap was performed to create a new feature class of the Lake Cyohoha North catchment case study. This was followed by a copy of raster function to set resolution, and the Dissolve function was used to remove unnecessary boundaries between polygons. The workflow of reclassification in data processing in ArcMap is illustrated in the flowchart below.

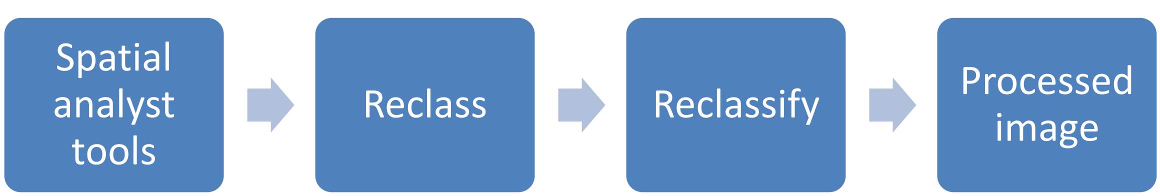


Figure 3-4: Flowchart illustrating data processing in ArcMap 10.5

3.4.3 LULC Change Qualitative Analysis

3.4.3.1 Population Sample

The research population for this study comprised of catchments management officers from two institutions in charge of environmental management and water and forestry management in Rwanda and participants were selected from each sector within the catchment, and they had to be aware of land use issues within their sector.

3.4.3.2 Research Instruments

Research instruments are tools used in the collection of data, such as interviews, questionnaires, observations and document readings. Whenever research instruments are used, the researcher needs to be sure that they provide accurate results on the topic of interest (Fagarasanu & Kumar, 2002).

- **Interview guide**

An interview guide was prepared in order to conduct interviews with respondents. This instrument was used as a being method of asking questions; the researcher utilized it for interviewing individuals as well as groups of key informants. The interview guide is a more flexible method of interviewing useful areas where the researcher has little knowledge of the situation under investigation.

- **Interview Structure**

Semi-structured interviews were conducted to gain knowledge of LULC issues in the study area and to collect primary data from interaction with planners. This method was selected to allow an exploration of issues relevant to the concerned catchment. The interviews were both face-to-face and telephonic, and data were collected by transcribing and digital audio recording. Participants were informed of the nature of the research, and a consent form was emailed and explained to them prior to the interviews. An interview guide (refer to Appendix 2: Interview guide) consisting of key themes was constructed. However, there was no strict adherence to the interview guide, and probing was used to explore new paths emanating from the respondent's answers and to obtain detailed information on a subject of discussion on which the researcher had no prior knowledge.

Data collected from the interview was validated and supplemented by relevant LULC change documentation and questionnaire. Land Administration Developments in Rwanda, Rwanda National Land Use Planning Guidelines, National Land Policy, and National Environment and Climate Change Policy were obtained from the internet and examined to retrieve relevant LULC information.

- **Questionnaire**

The questionnaires have been used to enable the researcher to balance the quantity and quality of data collected and also to enable respondents to provide information about particular questions with freedom by writing their opinions, views, perceptions, feelings, and experiences. This research could not achieve its intended objectives if the researcher had not approached farmers and heard from them to know the implications LULC change has on them and their concerns about the management of Lake Cyohoha.

3.5 Ethical Considerations

Identifying drivers of land-use change in the catchment of Lake Cyohoha required interaction with municipality catchments planners to understand how land-use decisions are made and how socio-economic, political, and environmental factors interact to influence these decisions. (Munhall, 1988) stated that various ethical issues regarding information collection, seeking consent, providing incentives, sensitive information, harm and confidentiality must be considered in relation to participants. The following section addresses how ethical issues were handled in the research.

3.5.1 Informed Consent

The participants were informed before the interviews, of the purpose of the research, how they had to participate, why the information was necessary and why they were selected. A consent form was sent to all participants, and the researcher also read out and explained contents of the consent form before undertaking the interviews. Written consent was, therefore obtained from participants.

3.5.2 Privacy, Confidentiality, and Anonymity

The researcher acknowledges that sharing information about participants for purposes other than the research is unethical. Furthermore, confidentiality and anonymity are maintained by ensuring that participant names or any identifying information is excluded in documentations.

3.5.3 Voluntary Participation

Participants were informed of the purpose and nature of the research as a master's research project, and they were not forced to engage in the interviews. The informed consent letter also included a section where the participants were informed of their right to withdraw their contributions during the interview.

3.6 Data processing and analysis

Data were analyzed both quantitatively and qualitatively. The Answers/responses were grouped and analyzed using SPSS software and Excel programs. The information grouped under excel micro-software has been interpreted both quantitatively and qualitatively.

3.6.1 Qualitative data analysis

Qualitative data analysis was done during data collection by assigning different categories to different information. Content analysis was carried out by checking questions to ensure the validity and authenticity of the given answers. All the information was analyzed according to the research question and the information available. The responses from interviews were analyzed using DPSIR Framework.

3.6.2 Quantitative data analysis

After the collection of data, the following methods were used to analyze and present data.

i) **ArcGIS**: ArcGIS 10.5 software was used to extract useful information for the case study area and compute the statistics.

ii) **Microsoft Excel:** Ms Excel was used for data entry of collected data after field survey and to make graphs.

iii) **SPSS:** SPSS software was used for statistical analysis of qualitative and quantitative data.

iv) **Simple tables**: The simple tables have been used to present collected quantitative data.

v) **Graphs:** The graphs were also used to present data.

3.7 Driver-Pressure-State-Impact-Response (DPSIR) Framework

The DPSIR is an analytical framework which can be used to organize, report, and illustrate the effects of human activities on the environment. This framework was developed by the European Environmental Agency in the 1990s and has been used for assessing interactions between different sectoral environment, demographic and social development (Patrício, Elliott, Mazik, Papadopoulou, & Smith, 2016). Today, DPSIR has been applied by international organizations (e.g., OECD, EU, EPA, EEA) in environmental research projects to support planning decisions (Levrel, Kerbiriou, Couvet, & Weber, 2009). The DPSIR framework was adapted in assessing LULC changes in the study area in order to present various aspects and issues which emerged from interviews and document readings.

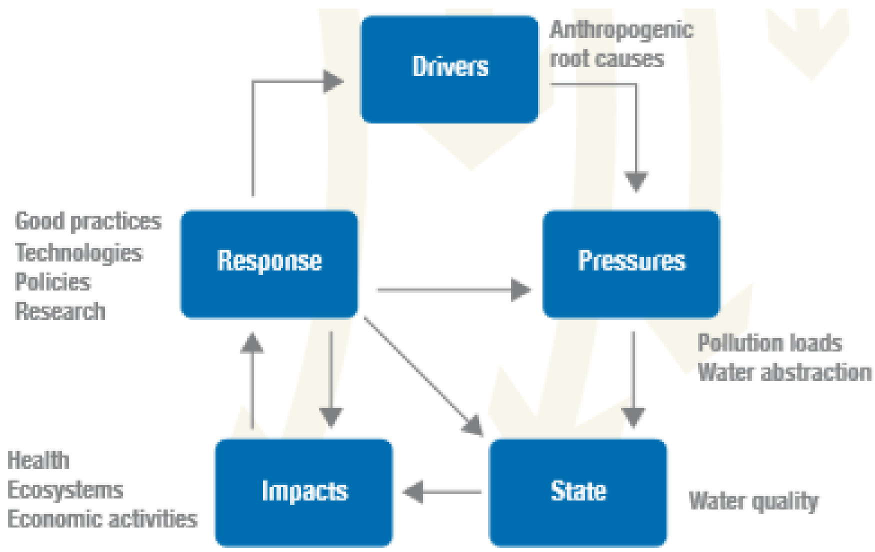


Figure 3-5: DPSIR Framework and Water Quality (Javier *et al.*, 2018).

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This Chapter presents the history of LULC changes which were observed in the Catchment of Lake Cyohoha North between 2000 and 2018. It consists of three Sections which provide qualitative and quantitative results obtained from the desktop study, questionnaire, interviews with Sector land managers and catchments management officers, and document analysis. The engagement of local communities in the management of Lake Cyohoha north through capacity building and their reflection. The Chapter concludes with an adapted DPSIR LULC change framework for the Lake Cyohoha north catchment.

4.1 Land Use and Land Cover changes of the Catchment

This section presents the results of desktop quantitative analysis of reclassified maps of 2002, 2010 and 2018. These maps indicate LULC changes in the Lake Cyohoha North catchment.

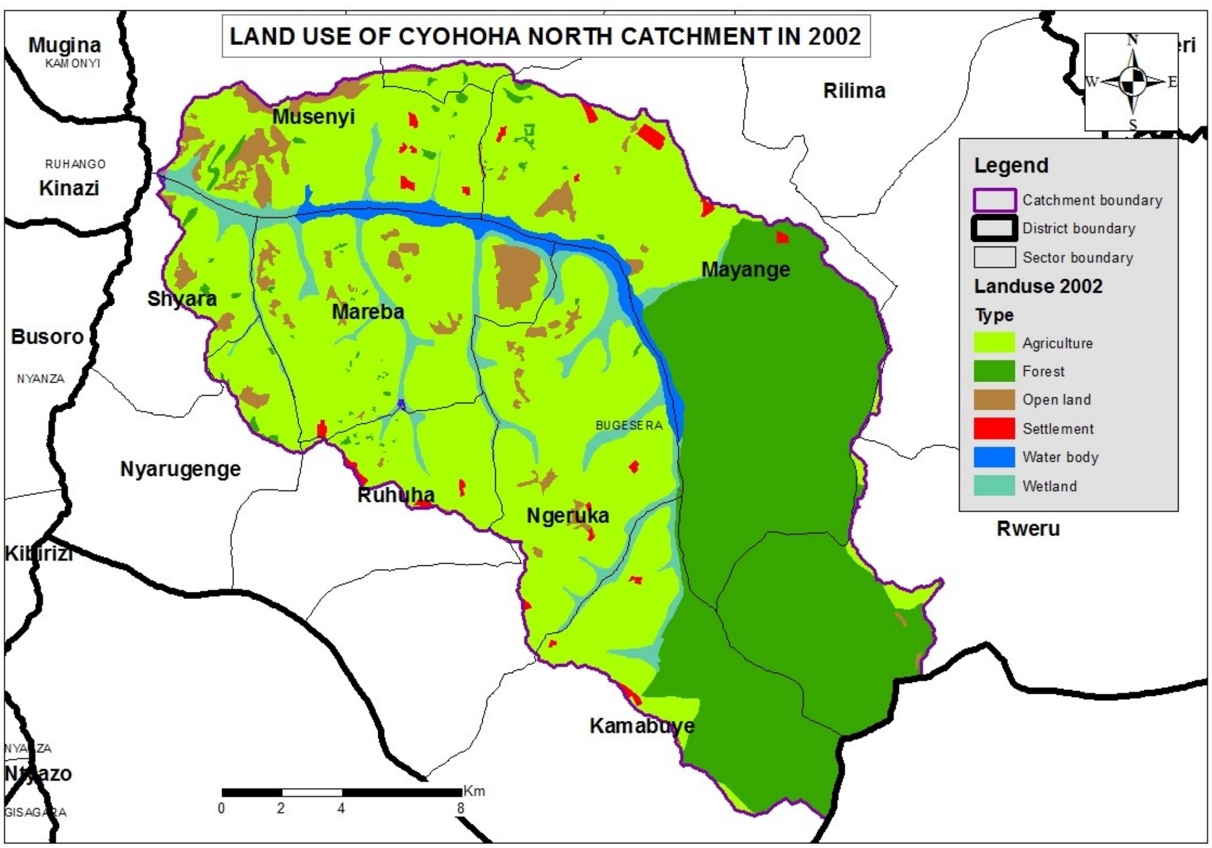


Figure 4-1: LULC map of Lake Cyohoha catchment for the year 2002

The Cyohoha north catchment (Figure 4-1) was dominated by coverage of forest, wetlands, agriculture, open lands and scattered settlements which were surrounding Lake Cyohoha North. In the 1990s this catchment was properly managed as it can be seen on the map (Figure 4-1) exerting limited pressure on water resources. However, the changes in land use coupled with climate change increased pressure that resulted in degradation. The degradation of Lake Cyohoha can be noticed on the next LULC maps of the catchment for the years 2010 and 2018. Additionally, the area and percentage covered by each class are presented in Table 4-1.

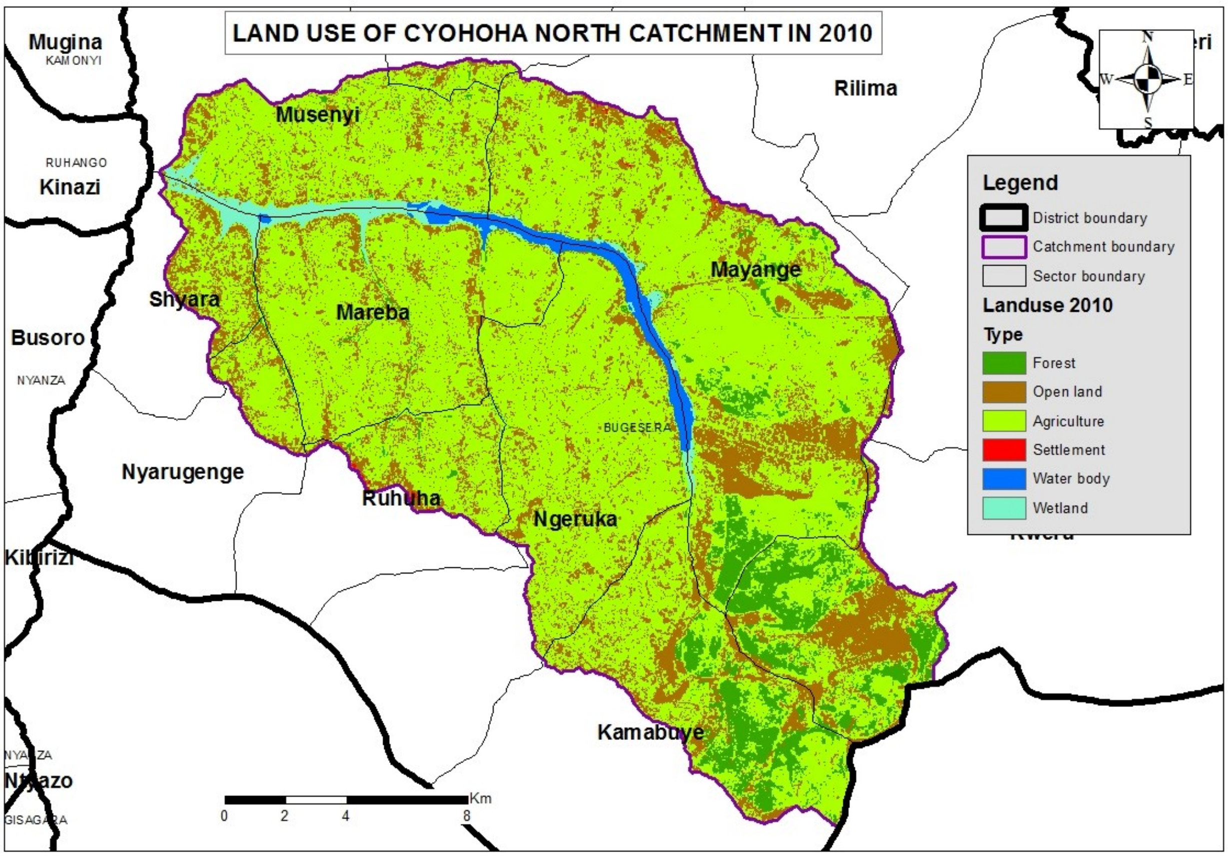


Figure 4-2: LULC map of Lake Cyohoha catchment for the year 2010

The LULC map of 2010 shows a reduction in a forested area in which some of its parts were converted into agricultural land and others into open land. The catchment like many places in the country has suffered from widespread deforestation because local populations rely on forests for firewood and construction materials. Large areas of land were also cleared for agriculture. Though, the 2010 LULC map also reveals a high increase in agriculture within the catchment which promoted the reduction of catchments wetlands.

The reason will be further discussed in below chapters where the prolonged and repeated droughts occurred in this catchment and made local communities mostly formed by smallholder farmers to cultivate some of the wetlands seeking for where they can grow crops because the remaining areas were dry. These factors contributed to the reduction of Lake Cyohoha north water quantity and accelerated the water quality depletion that resulted in Lake Cyohoha north eutrophication (Figure 2-10).

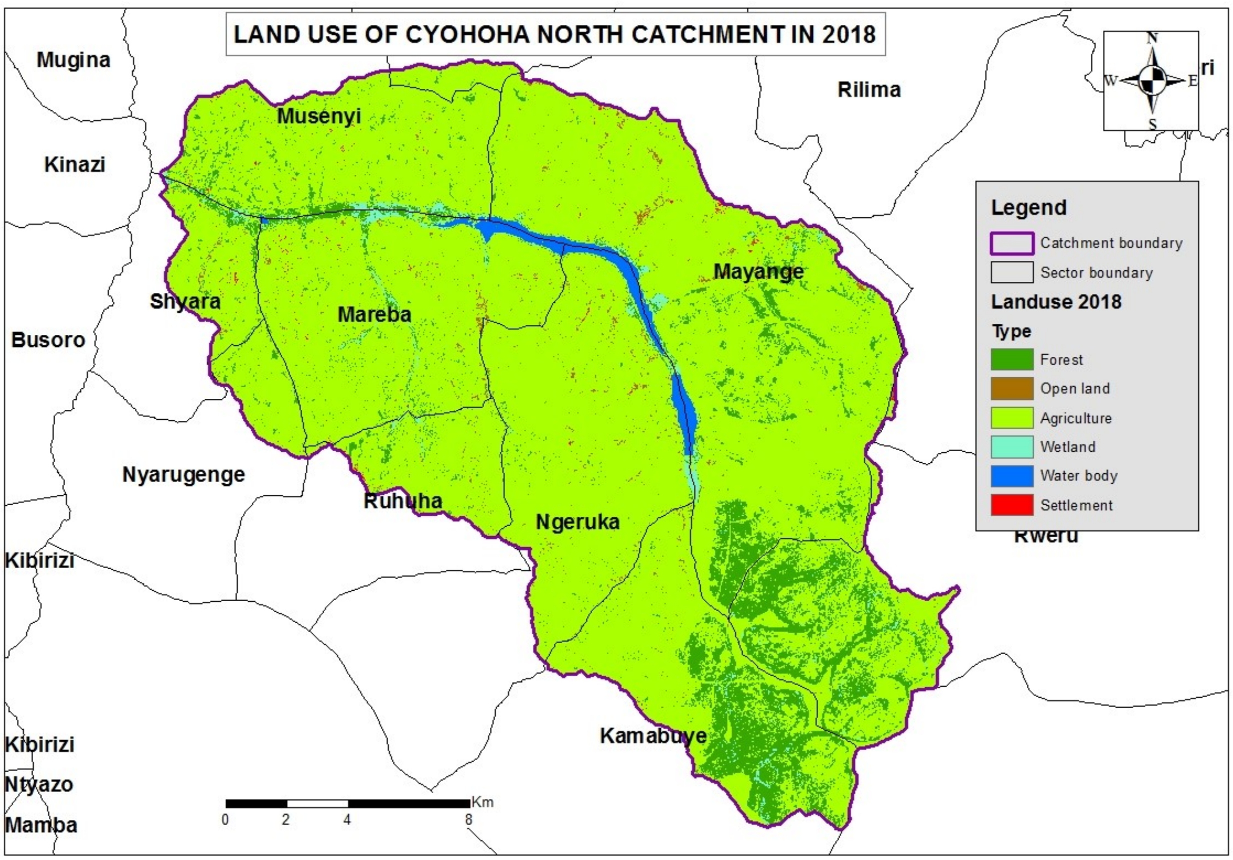


Figure 4-3: LULC map of Lake Cyohoha catchment for the year 2018

Different policies of environment protection were formulated and implemented by the government. With the conservation effort, Rwanda has set a target to increase its forests cover to 30% of the total country land area through afforestation and reforestation by 2020. The efforts to halt forest loss and increase forest cover have been underway since 2007 (MINIRENA, 2018). The other policy applied in this period was agroforestry to combat the effect of desertification in the Cyohoha north catchment.

However, despite these efforts made the quantity and quality of Lake Cyohoha north remained under ambiguity due to continued excessive growth of aquatic weeds and buffer zone deterioration by local farmers. Comparing 2002, 2010 and 2018 LULC maps above, it is clear that different LULC change occurred enhanced the reduction in size of Lake Cyohoha North which increased the pressure of water scarcity to local communities living in this catchment. LULC change within the catchment is presented in Table 4-1 and the percentage for each LULC category.

Table 4-1: LULC change of Lake Cyohoha north catchment and percentages

Year		**2002**		**2010**		**2018**	
LULC Class	**LULC Type**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
1	Settlement	42	0.11	28	0.07	12	0.03
2	Agriculture	14507	38.64	18620	49.80	25160	66.83
3	Forest	12549	33.43	7103	19	9357	24.85
4	Wetland	965	2.57	460	1.23	376	1
5	Water body	875	2.33	671	1.79	618	1.64
6	Open land	8602	22.91	10505	28.10	2127	5.65

Table 4-1 shows the change in LULC in hectares and percentage for individual LULC class between 2002 and 2010 and between 2010 and 2018 in the catchment of Lake Cyohoha north. The quantified results indicate that the Cyohoha north catchment has experienced considerable changes in LULC. Based on the datasets used, there has been an increase in open land and cultivated land between 2002 and 2010. Contrary to these increases, there have been decreases in forest plantations and woodlands, wetlands, settlements and the size of the Lake as shown in Figure 4-4.

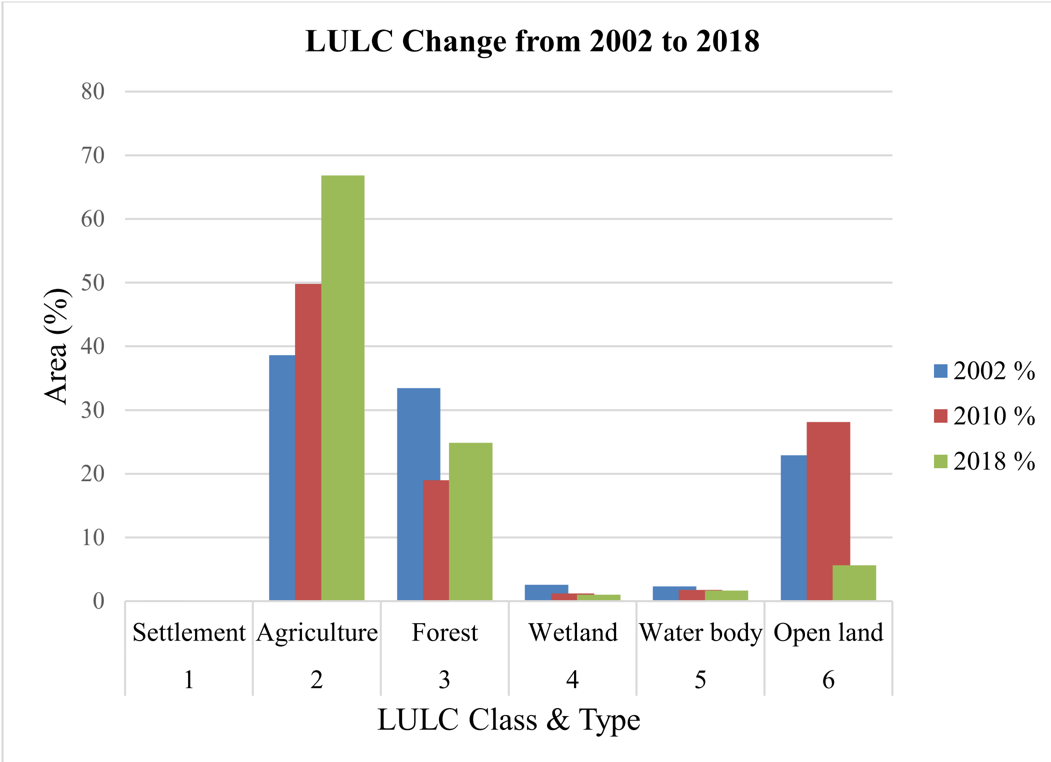


Figure 4-4: LULC change of Lake Cyohoha catchment over the past 20 years

Figure 4.4 shows significant changes in settlement where there has been a decrease between 2002 and 2010, also between 2010 and 2018. After noticing a remarkable decrease in size and quality of Lake Cyohoha north, the government appeared in, finding a solution to the local population living in Lake Cyohoha catchment and one of the applied solutions was to relocate and settle those who were living in high-risk zones into grouped settlements built in areas planned for settlements. This decision has reduced the area coverage of settlements within the catchment, which explains the decrease in settlements area between 2002 and 2018. The LULC change, net change and percentage of change over the past 20 years for Lake Cyohoha north catchment as presented in Figure 4-5.

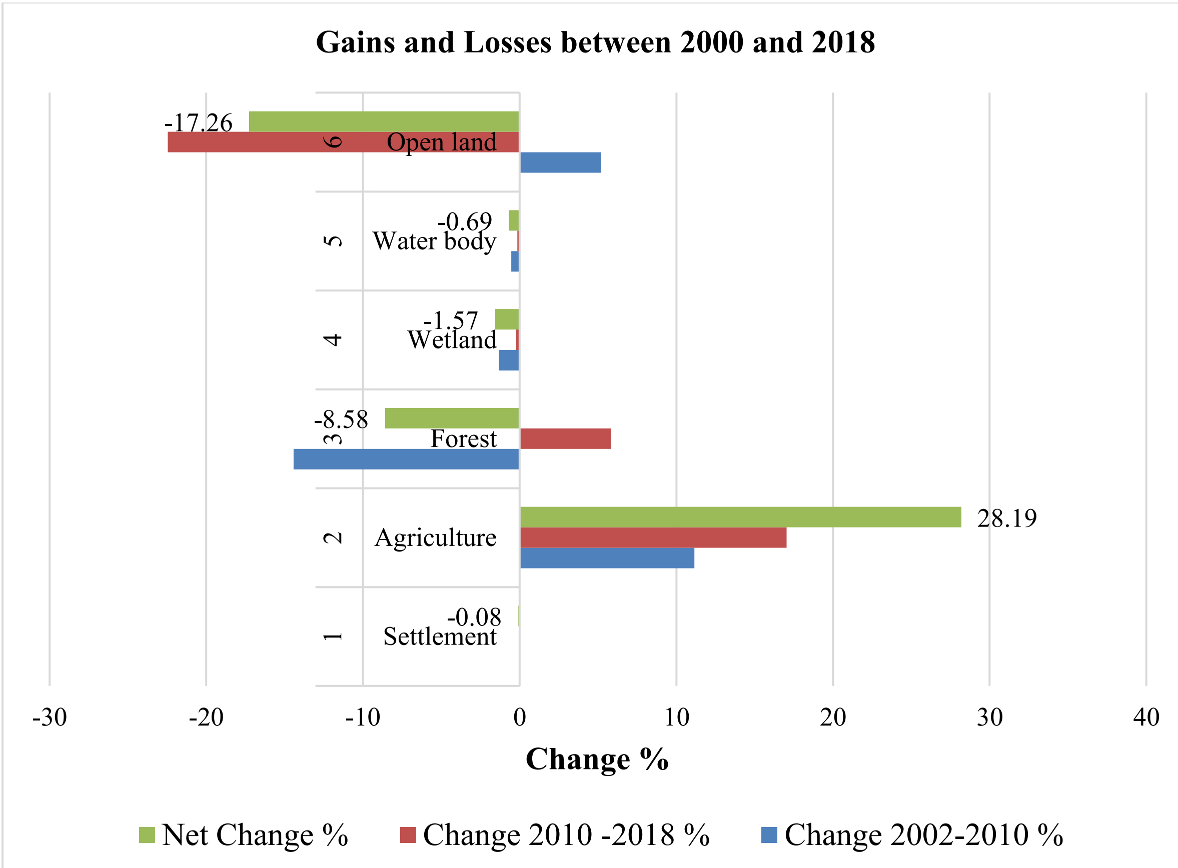


Figure 4-5: Lake Cyohoha north catchment gains and losses in each LULC type between 2000 and 2018

The highest percentage gain is in the cultivated area since a significant percentage of people of Lake Cyohoha North catchment are rural-based and practice agriculture, with farming activities mostly concentrated in this catchment to benefit from the Lake for irrigation. Although the Lake Cyohoha catchment agriculture is for subsistence, agriculture has a high contribution to the District's GDP and the District's plan is to transform the lives of local communities economically by modernizing agriculture to increase productivity and revenues (BDDP, 2013). Another gain was in open lands between 2002 and 2010 as a result of occurred prolonged and repeated droughts from 1998 that resulted in population migration to the neighboring countries mostly Uganda and Tanzania due to lack of food and unfavorable weather conditions. The migration, coupled with Government's policy of grouped settlements to protect and conserve the natural resources, have resulted in a significant loss of settlements in the catchment until today.

Figure 4-6: Constructed model village for relocating people from high-risk zones

The highest net percent loss is in open lands followed by forest plantations class, indicating that there has been a decrease in forest plantations over the past 20 years within the catchment. The decrease in open lands and forests in the Lake Cyohoha North catchment was mostly due to the conversion of forested and free lands into agricultural farms by local communities. The rationale behind this was that the forests were not economically viable and hunger at that time, therefore, forest plantations were cut down to cultivate food crops.

The conversion of most forested land to agriculture and cultivation of open areas that had varieties of bushes to prevent erosion have increased erodibility hazard of the catchment which increased transport of sediments containing fertilizers from agricultural farms and promoted excessive growth of water hyacinth (*Eichhornia crassipes*) into Lake Cyohoha North, hence the lake was eutrophicated. Consequently, the lake was no longer productive to make local communities survive. Despite the implementation of Rwanda's National Forest Policy in 2004 (Knox, 2014), there has been no significant increase in forests since the catchment has had low rainfall for a prolonged period. The local population benefits from promoted agroforestry through improved food security and poverty alleviation. This is due to the role that agroforestry plays in the prevention of land degradation, restoration of soil fertility and protection of catchments. Much emphasis was given to carbon fixing and fruit tree species.

An indication of the actual losses of LULC classes to agriculture between 2002 and 2018 is illustrated in Figure 4-7.

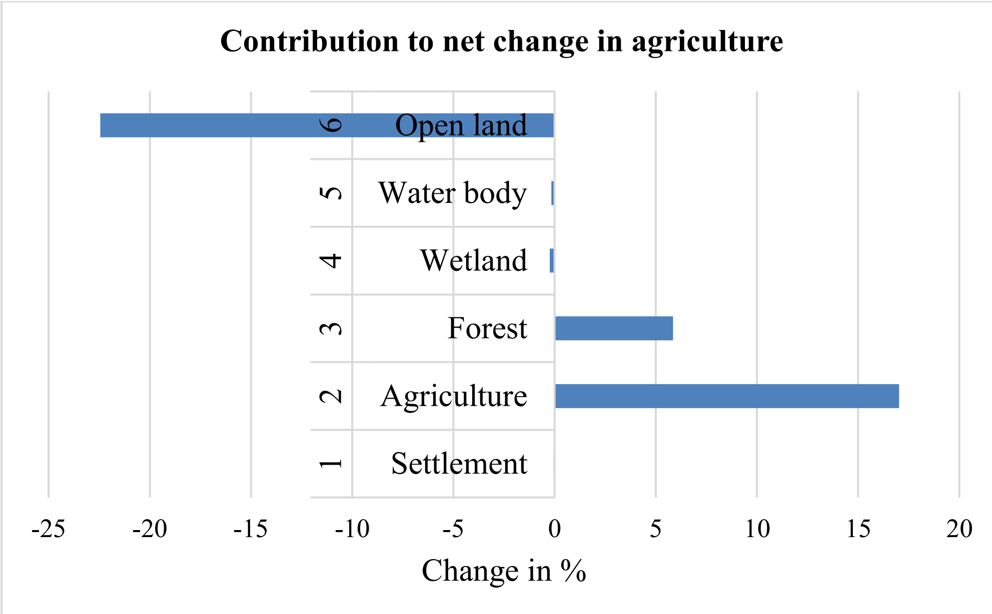


Figure 4-7: Contributions to a net change in agriculture by other LULC classes

The LULC change results also indicate that there has been an increase in cultivation of about 10,653 ha in the Lake Cyohoha North catchment. An assessment of the datasets, however, provides a clear picture of the actual LULC change and shows that the increase in agricultural lands in the past 20 years is concentrated along the Lake Cyohoha. The reason behind that is to benefit from subsidized irrigation equipment and free offer for cooperatives of farmers by the government through RAB to fight against malnutrition and hunger in the eastern region. The study reveals continuity in decrease of settlements because the government has put more emphasis on resettling families living in high-risk zones in the planned lands for grouped settlements to ease the access on basic services. Moreover, 3192 ha of forest plantations, 6475 ha of open land covered by grasses and shrubs, 589 ha of wetland and 257 ha that were covered by water have been converted into agricultural farms. Consequently, all of the changes that occurred had impacted the environment and moreover had slowly affected the degradation of Lake Cyohoha North both quantitatively and qualitatively. Figure 4-8 shows clearly how the size of Lake Cyohoha North had reduced in almost the past 20 years.

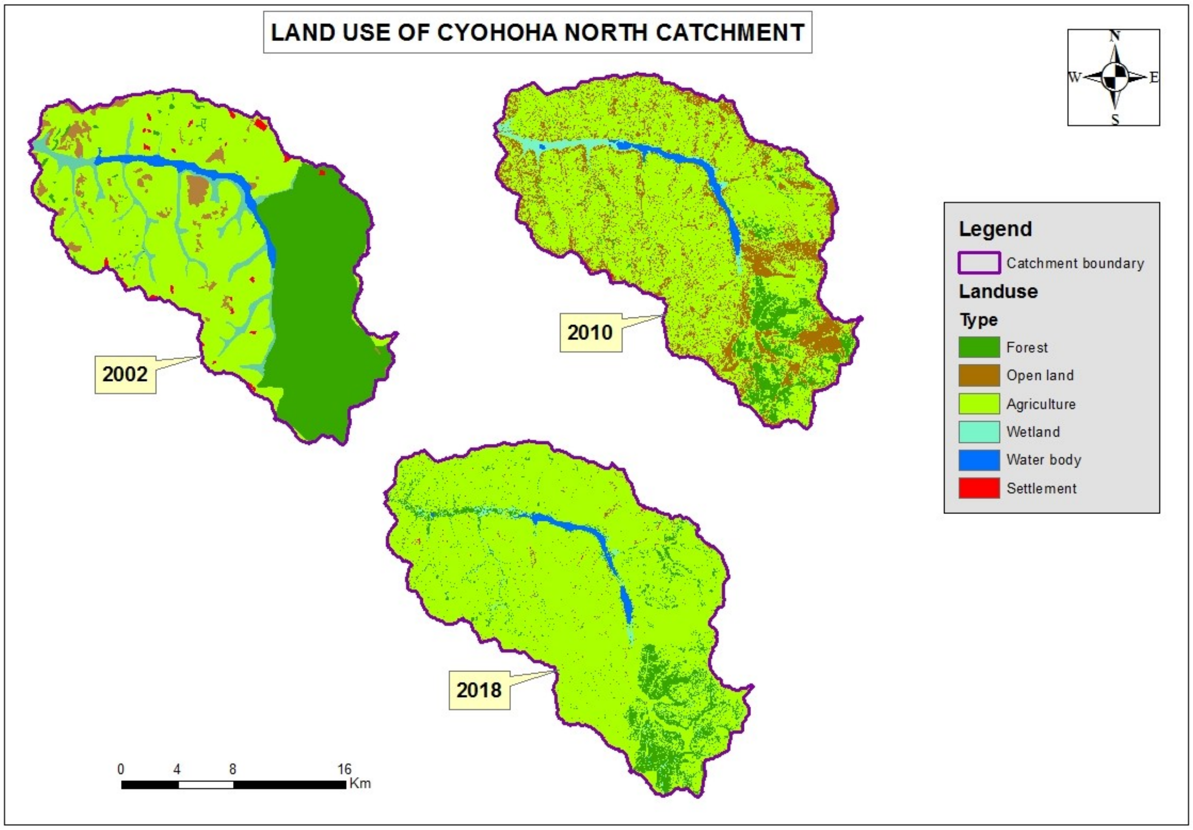


Figure 4-8: Cyohoha North Catchment LULC maps for years 2002, 2010 & 2018

4.2 Socioeconomic analysis of LULC change Impact on Smallholder Farmers

The following section provides LULC change quantitative results on socioeconomic impact obtained from farmers within the catchment of Lake Cyohoha North. The findings from the questionnaires were analyzed in SPSS, organized in tables, and presented using graphs highlighting the results.

4.2.1 Gender of Respondents

The respondents that have been selected to provide information for this research were equally distributed based on their gender (Table 4-2).

Table 4-2: The gender of farmers

Gender	Frequency	Percent	Cumulative Percent
MALE	50	50.0	50.0
FEMALE	50	50.0	100.0
Total	100	100.0	

4.2.2 Marital Status

Table 4-3: Marital Status of Respondents

Marital Status	Frequency	Percent	Cumulative Percent
Married	66	66.0	66.0
Widow	31	31.0	97.0
Divorced	3	3.0	100.0
Total	100	100.0	

Figure 4-9 shows that 66 percent of respondents are married, 31 percent are widowers, and only 3 percent have separated from their partners.

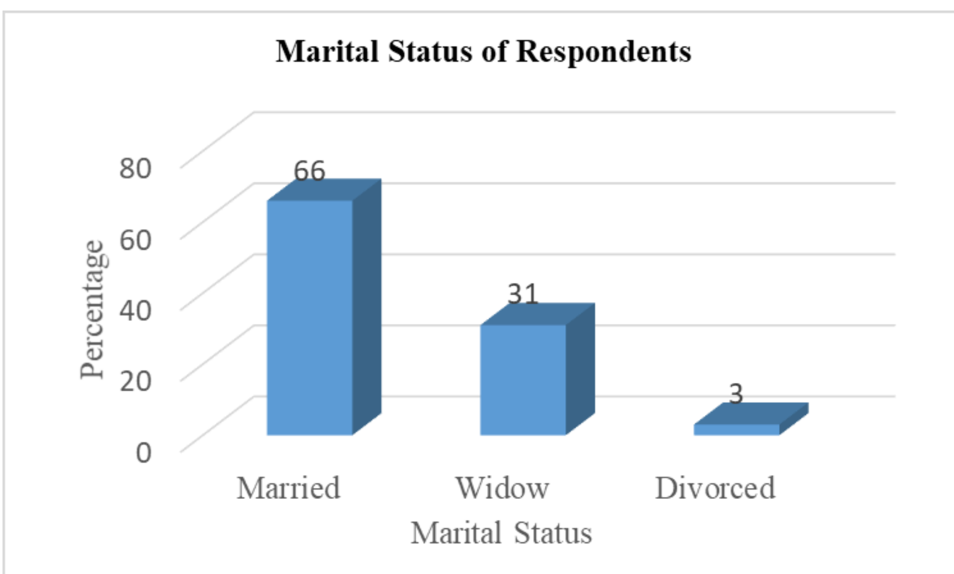


Figure 4-9: Marital Status of Respondents

4.2.2 Number of Children

Table 4-4: Number of Children per family

Number	Frequency	Percent	Cumulative Percent
1	4	4.0	4.0
2	3	3.0	7.0
3	7	7.0	14.0
4	16	16.0	30.0
5	15	15.0	45.0
6	23	23.0	68.0
7	15	15.0	83.0
8	8	8.0	91.0
9	9	9.0	100.0
Total	100	100.0	

The size of each family has been assessed in the following Figure 4-10 to analyze the average demographic growth status within the Lake Cyohoha North catchment.

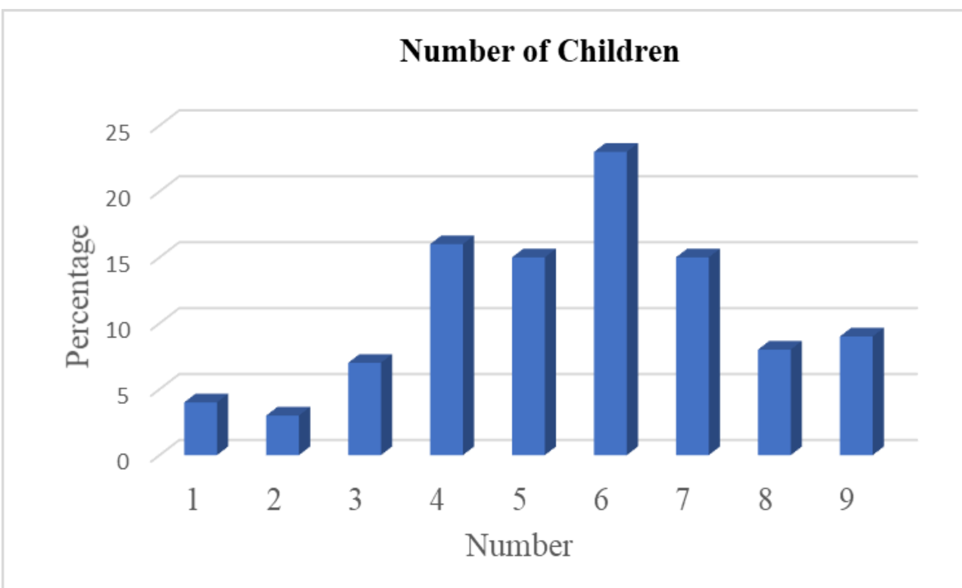


Figure 4-10: Family size of respondents

The above Figure 4-10 shows that the average size of farmers families in the catchment of Lake Cyohoha is estimated to 6 children per family. This size explains the effect of the population on increased agricultural land to sufficiently find food for their families. These forces lead to human activities and processes which exert pressure on land resources resulting in various states of the environment. The change in state of the environment results in increased erosion and pressure on Lake Cyohoha. Additionally, environmental degradation has consequences in seasons pattern resulting in low rainfall for a short period and drought for the rest of the year.

4.2.3 Crop production before and after 2000

Table 4.5 shows the results from a comparative analysis which was used to assess the farmers' crop production before and after the year 2000.

Table 4-5: Productivity before and after 2000

Quantity	Percentage before 2000	Percentage after 2000
1-2 tones	27	79
2-3 tones	62	20
>3 tones	11	1
Total	100	100

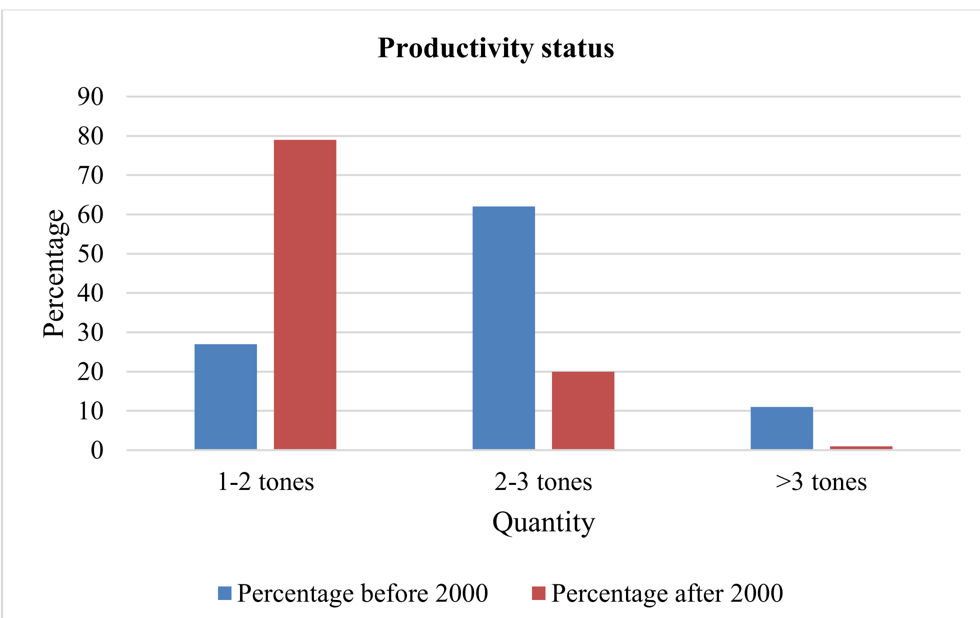


Figure 4-11: Quantity of Production per year before and after 2000

Figure 4-11 above illustrates that farmers production before 2000 was mostly ranging between 2-3 tones (62%). Despite the increase in agricultural land, crop production has been affected by land degradation and climate change. Rwanda has put effort in agriculture transformation, but it is still facing challenges that limit the achievement of the desired production. Lake Cyohoha North catchment has experienced repeated and prolonged dry periods that have been regarded as the effects of climate change due to the degradation of ecosystem. These effects have lowered the land productivity of the catchment, which promoted illegal agricultural activities by local communities. To protect the Lake from being degraded and disappear at a given time, REMA has established the buffer zone for the Lake. Unfortunately, most of the buffer zone of Lake Cyohoha North is being cultivated (Table 4-6) by local communities around the Lake because the land that is far from the Lake is dry. Farmers are cutting papyruses (*Cyperus papyrus)* that used to protect the lake from erosion and play a role of filtration and water reservoir. Consequently, the erosion goes directly into the lake and this is leading to the diminution of the water quality and quantity and also affect fish production, biodiversity and the life of the ecosystem in general.

Table 4-6: Illegal agricultural activities in the buffer zone of the Lake Cyohoha North

Agricultural activities arrive in the water

Figure 4-11 highlights the implication of low productivity to smallholder farmers living situation before and after 2000 in terms of the number of meals per day.

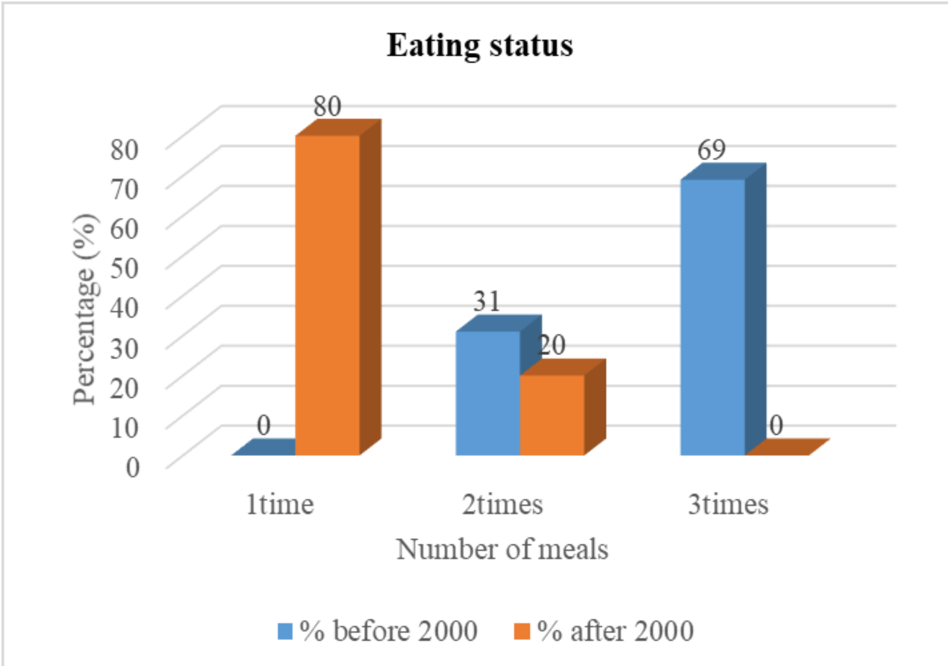


Figure 4-12: Number of meals status for smallholder farmers

From the figure above, it is clear that eating frequency has changed due to the availability and self-sufficiency in food that has been affected by droughts and low production of food crops. It shows that 69 percent of respondents used to eat three times a day when weather conditions were normal, and 31 percent eat twice a day. However, as it can be seen above, the highlighted factors, coupled with increased land degradation and depletion of soil fertility increased the number of local populations who eat only once a day to 80%, and 20% who eat twice a day to 35.48% change. Consequently, none of the smallholder farmers within the Lake Cyohoha North catchment eat three times a day.

4.2.4 Fishing and Animal husbandry Status

The production of fishes in the Lake Cyohoha North remains low despite the undertaken projects by REMA and Bugesera District for removal of water hyacinth and other aquatic weeds. NYEP/DEMP, SERPG, VERP, and LDCF II projects have been implemented to restore the lake and facilitate its valorization through the ecosystem services that the lake could offer like fish production and farming, transport, irrigation, research, etc.

Figure 4-13 shows the percentage change in fishing by smallholder farmers and illustrates the effect that Lake Cyohoha degradation has had on fish production.

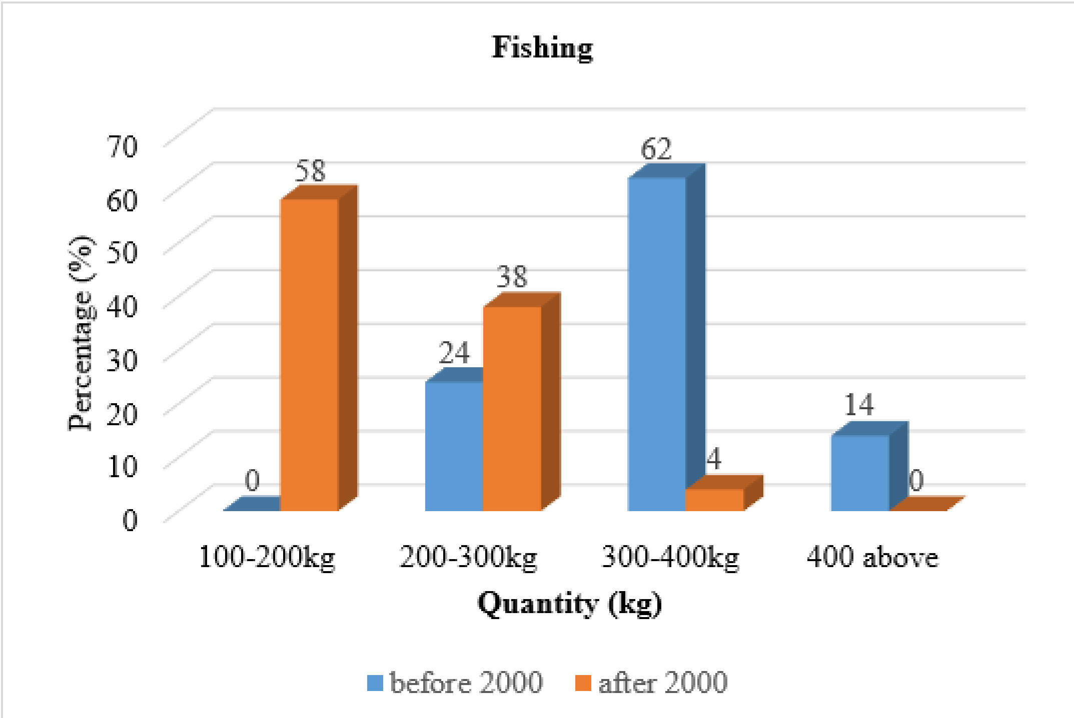


Figure 4-13: Fishing comparison before and after 2000

The fish production, as evidenced in the figure 4-13 above has reduced. Before 2000, 62% of respondent fishers were getting an estimated 300-400 kg, 200-300 kg (24%) and more than 400 kg (14%) whereas, after 2000, the situation slowly changed. 58% gets estimated 100-200 kg of fishes, 38% (200-300 kg) and only around 4% gets between 300 and 400 kg thus, 58.33% and 93.55% change respectively.

The many challenges seen in local communities include poverty and particularly malnutrition. This made the Government of Rwanda (GoR) develop a Home-Grown Solution (HGS), which is an initiative introduced in 2006 and geared to improve health and wellbeing of vulnerable citizens and reducing child malnutrition. “One Cow per Poor Family Program (Girinka). In this program, a farmer is given an in-calf heifer and is obliged to pass on to the first female offspring to another program beneficiary who is selected by local administration authorities and validated by MINAGRI/RAB (RAB, 2006; RGB, 2018). Since its implementation in 2006, 35% of respondents have received cows through this program. The Figure 4-14 highlights in numbers the state of animal husbandry among smallholder farmers in the Lake Cyohoha North catchment.

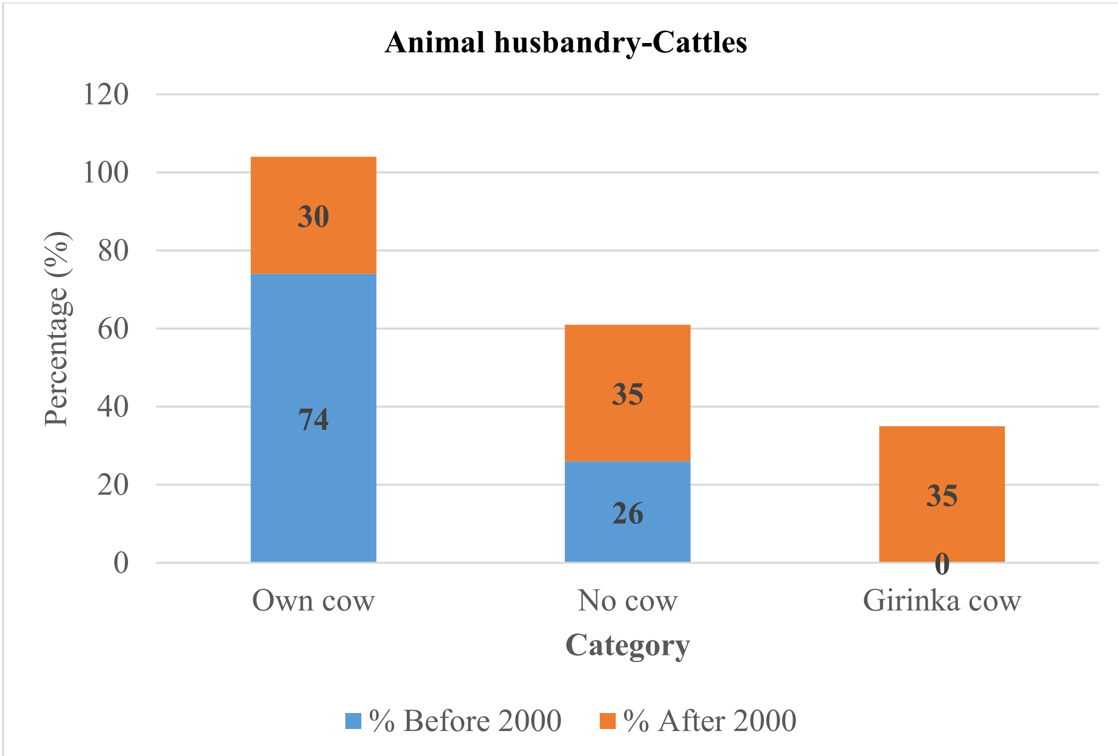


Figure 4-14: Animal husbandry for smallholder farmers in the Lake Cyohoha North catchment

In the past two decades, the number of families owning cows has dropped down due to unavailability of pastures, most of them have been cultivated, and the remaining have been given to big herders. Climate change, coupled with zero grazing makes it challenging to find grasses for feeding animals when it is dry all over the catchment.

4.2.5 Capacity building of smallholder farmers

In the course of projects that are being implemented in the catchment, farmers, as the beneficiaries of the projects, are supposed to receive training on the intended outcomes and sustainability safeguard. Different projects for the restoration of the catchment and lake have been implemented in the catchment, which were intended at protecting the Lake Cyohoha North and conserving it for the future generation as well as providing jobs to local communities living within the catchment. The following Figures 4-15 & 4-16 show a picture of farmers who received training and the interventions.

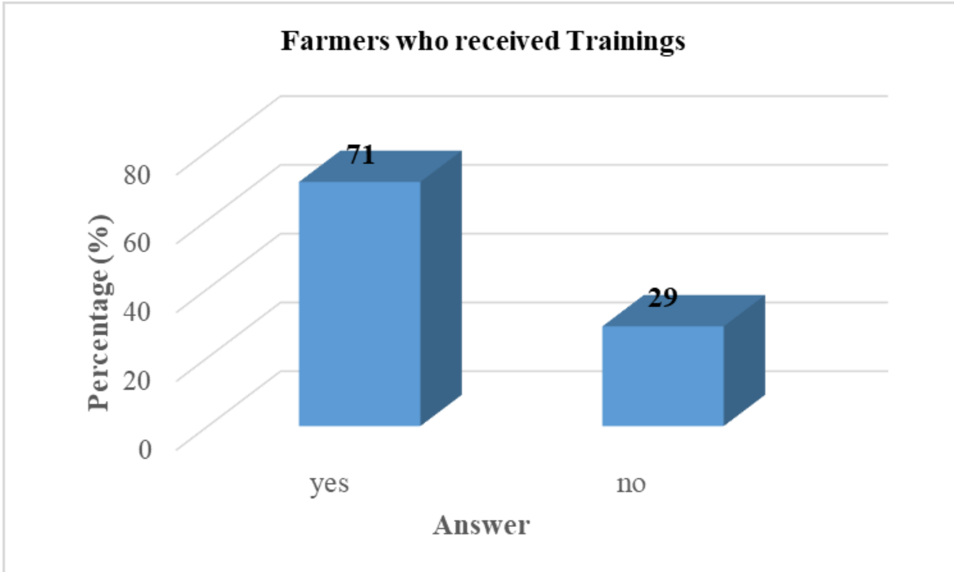


Figure 4-15: Smallholder farmers who received training

Figure 4-15 above shows that most of the smallholder farmers within the Lake Cyohoha catchment (71%) have received training and Figure 4-16 illustrates the types and frequencies of training received.

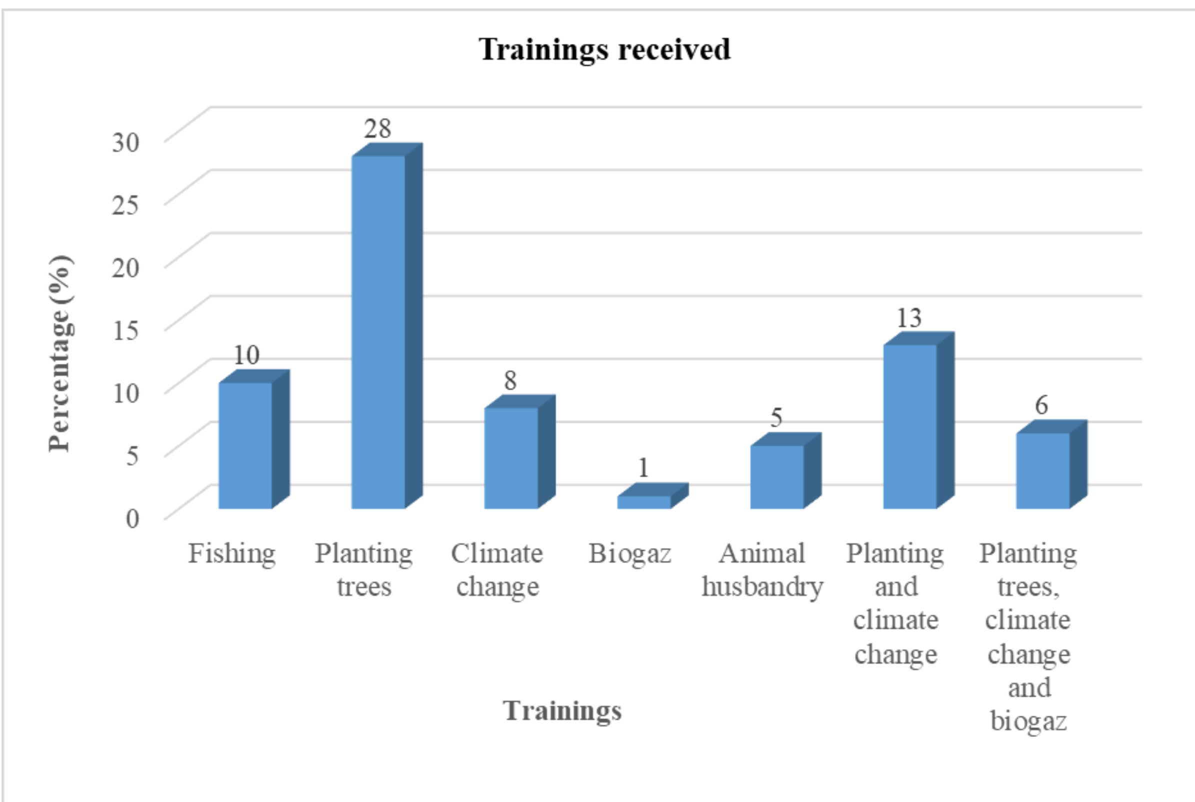


Figure 4-16: Types of training received by smallholder farmers

4.2.6 Causes of Lake Cyohoha degradation and Challenges faced by smallholder farmers

Lake Cyohoha North degradation has occurred slowly due to a combination of factors like deforestation of the catchment, inappropriate agricultural systems without soil erosion control practices, climate change that made the catchment drought-prone with repeated and prolonged dry periods. The encroachment of Lake Cyohoha buffer zone by local population who remove papyruses and imiberanya in buffer zone and expose the ecosystem to high evaporation. This leads to the destruction of the buffer zone and decreases water level. These native species (ibifunzo, imiberanya) play an essential role in the protection and maintenance of the ecosystem, including protection of buffer zone, erosion control, maintenance of fish reproduction area, reduction of lake evaporation, water filtration, removal of heavy metals, etc. The remaining open land where papyruses and imiberanya are removed become agricultural land for local communities. Thus, considering the ecosystem fragility, this may lead to the destruction of the ecosystem if there is no action taken on this issue. Table 4-7 shows how those native species are being cleared by local communities.

Table 4-7: Encroachment of the Lake Cyohoha North buffer zone by local communities

	
Open land where papyruses and imiberanya were removed and became agricultural land for local communities	

Among the challenges that smallholder farmers are facing on the ground, the most challenging the researcher noticed is climate change. The following table (Table 4-8) reflects the thoughts and views of smallholder farmers within the Lake Cyohoha North catchment on climate change issue.

Table 4-8: Smallholder farmers reflection on climate change as the cause of Lake Cyohoha degradation

Reflection	Frequency	Percent	Cumulative Percent
Yes	99	99	99
No	1	1	100
Total	100	100	

The contents in Table 4-8 above illustrate the thoughts of smallholder farmers in the lake Cyohoha catchment if they see climate change ahead of other existing factors that lead Lake Cyohoha North to being degraded. Ninety-nine percent of the respondents are positive on climate change being the other cause of Lake Cyohoha diminution of water quality and quantity.

Another challenge among the listed was poverty. For smallholder farmers that found cultivating inside the buffer zone say that their farms are dry and far from the lake so that they cannot afford the means of pumping water to their farms then due to that fact they use the buffer zone land as an alternative solution to survive from hunger. The same thoughts to those farmers whose farms have boundaries with buffer zone, they extend their fields inside the buffer zone because they see it as a waste of resources. Among the respondents, 62% have farms connected to the buffer zone and 38% with farms that are far from the boundaries of the buffer zone (Figure 4-17).

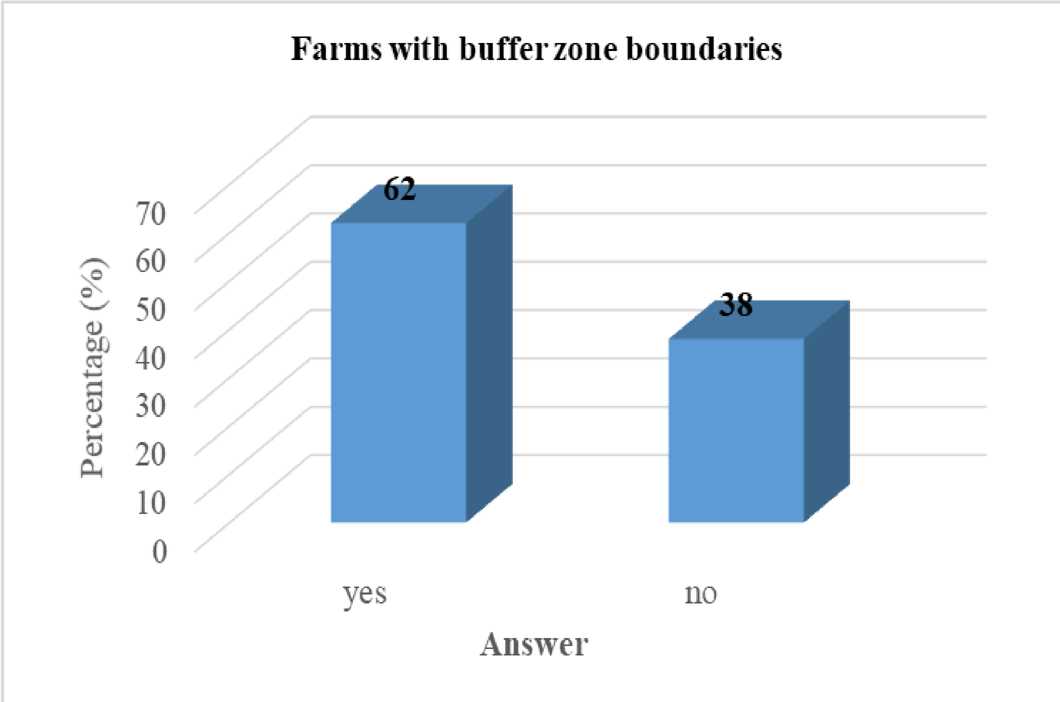


Figure 4-17: Respondents with farms connected with the buffer zone

4.2.7 Soil conservation practices in the Lake Cyohoha catchment

Soil conservation practices are techniques the farmer can use to prevent soil loss from erosion and build organic matter (Baumhardt, 2018). The excessive growth of water hyacinth and other aquatic weeds proves the transport of detached soil containing fertilizers into the lake. Along with other challenges seen in this catchment, soil erosion is also to be considered. Among the respondents visited during this research, only 34% practice at least one of the soil conservation techniques, and 66% do not control erosion. The techniques used in the Lake Cyohoha catchment to control erosion are agroforestry (57.1%), crop rotation (19.1%), cover cropping and mulching (15.2%), progressive terraces (2.9%) and others (Figure 4-18).

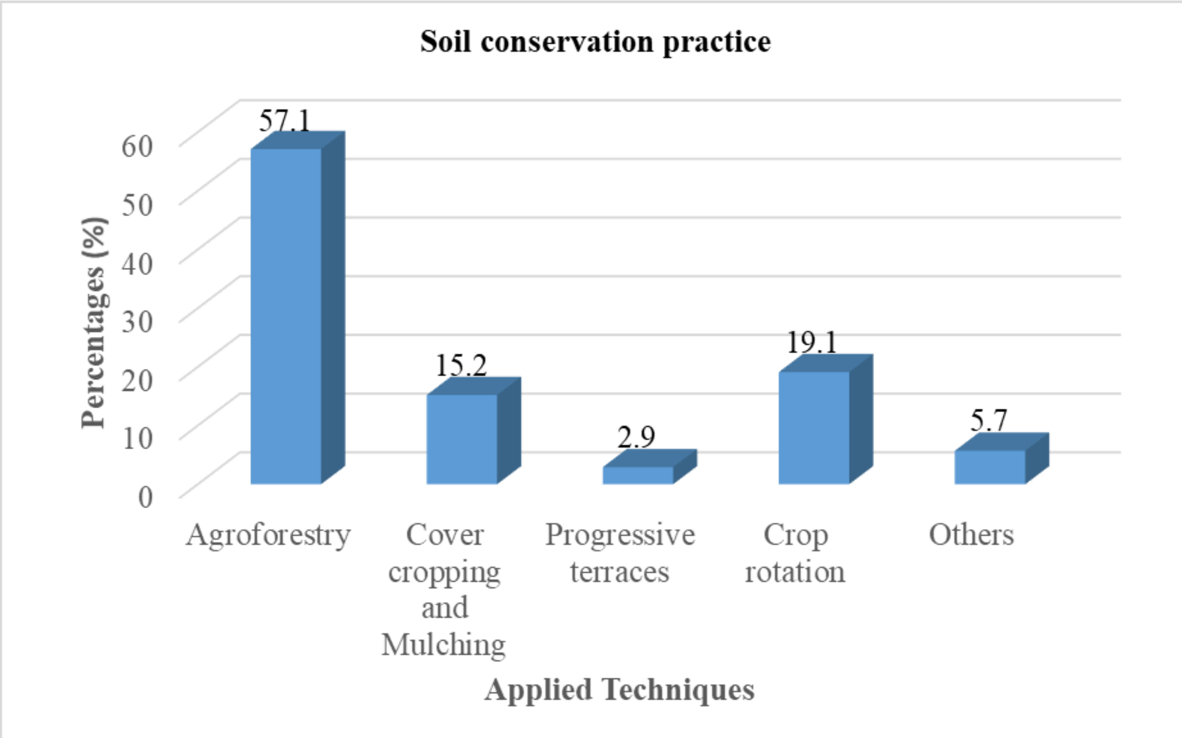


Figure 4-18: Soil conservation in the Lake Cyohoha North catchment

4.3 QUALITATIVE ANALYSIS USING THE DPSIR FRAMEWORK

The following sections provide a summary of LULC change, qualitative results obtained from interviews with catchments officers and land managers of the sector. The findings from the interviews are organized into themes which are presented using components of the DPSIR framework illustrated in Figure 4-19. The DPSIR framework is used to highlight the relationship between human activities and land-use change. Drivers are social, economic, demographic changes in societies, including consumption, lifestyle, and production patterns. These forces lead to human activities and processes which exert pressure on land resources resulting in various states of the environment. The change in state of the environment has consequences which are indicated in the framework as impacts that elicit responses. Responses are actions by individuals, society and the government to prevent and adapt to negative impacts. The arrows between components of the DSPSIR framework represent causal chains which show sequential processes that link causes of problems with their effects (Gabrielsen and Bosch, 2003; Kristensen, 2004). This chapter will conclude with an adapted DPSIR LULC change framework for the catchment of Lake Cyohoha North.

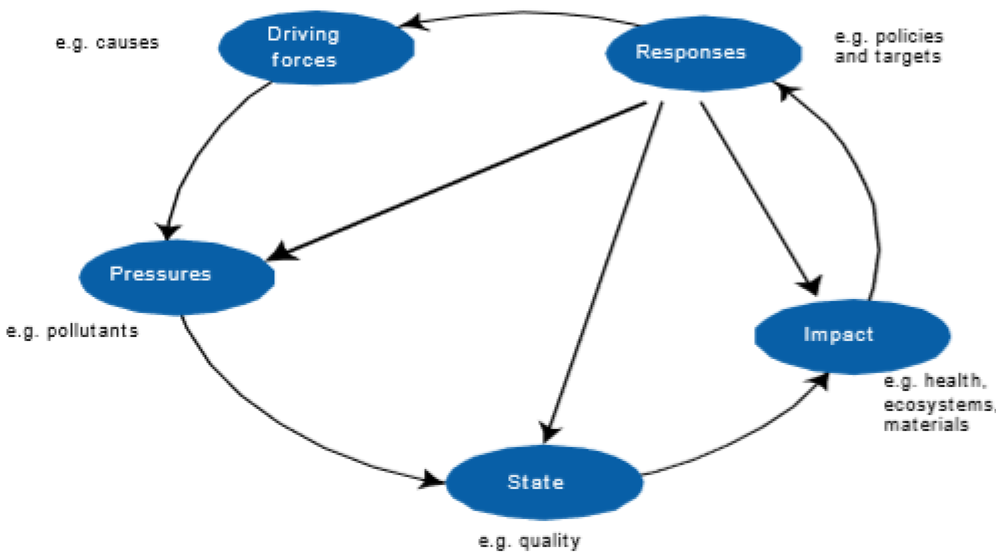


Figure 4-19: The DPSIR framework for reporting on environmental issues (Kristensen, 2004)

4.3.1 Driving Factors of LULC Change

This research identified both underlying and proximate driving factors of LULC change in the study area. Proximate factors are infrastructure expansion, agriculture, and expansion and while underlying factors are political, economic, technological, demographic, environmental and cultural factors. Underlying factors will be explained in detail as they are relevant to the scale of the study. A summary of all determined factors is provided in Figure 4-22.

- **Political Factors**

As outlined in the literature review on drivers of land-use change, legislation and policies play a significant role in land-use changes in Rwanda. For urban areas, land-use change is influenced by policies which can either encourage or hinder developments. An example of such a policy is the Green City Development policy, which establishes the country's pillars of green and climate-resilient urbanism and also demonstrates the viability of green cities in Rwanda. The Green City Development line is meant to develop a sustainable, lively, affordable and inclusive green urban neighborhood and to protect natural resources.

In rural areas like the catchment of Lake Cyohoha, the law of land tenure administration is applicable, but environment protection policy is restricted by several factors like poverty and climate change. Catchment management planners and land managers have to plan actions based on abilities of local communities and emphasize on building their capacity to increase their awareness in managing and protection of natural resources.

- **Economic Factors**

The economic development of the Lake Cyohoha catchment has strong links with agriculture, tourism, and fishing; which the government intends to prioritize. The rationale behind this is that high potential sectors promote job creation and inclusive growth. Therefore, resources can be channeled towards them instead of focusing on all sectors. This agrees with the Bugesera District Strategic goal of the development plan to create opportunities for growth and jobs.

A significant percentage of people in Bugesera are rural-based. They practice agriculture. Therefore, the best way to transform their lives economically is to modernize agriculture and increase productivity and revenues. To achieve this, Bugesera District planned various strategies over five years. The strategies include land consolidation from 63124 ha to 91830.3 ha and agricultural mechanization from 750 ha to 9700 ha. Each sector will have a mechanization center so that farmers can quickly get machines, improvement of quality and quantity of agricultural inputs and safe management of its distribution network. This increases the use of chemical fertilizers from 10% to 30% and organic manure from 5% to 12%.

The District is targeting the activities like improvement of soil conservation and protection with radical and progressive terraces, enhancement of agroforestry programs, and development of marshland whereby 3422 ha will be put to use from the current 1422 ha. Also, the district plans to develop and extend hillside irrigation systems (from 124 ha to 1774 ha), implement long-term capacity building for farmers organization cooperatives for both women and youth, adopt community-based nutrition programs with variety of crops for kitchen and school gardens, initiate and promote Public-Private Partnership and risk management for value chains, and develop banana, rice, cassava and maize processing units for value chains.

Apart from increasing the quality and quantity, priority is given to an increase of transformation of agricultural products aiming quality and quantity of agricultural exports. More post-harvesting facilities shall be constructed and agriculture research centers established. This shall go hand in hand with improved horticulture and agribusiness programs to target export and cross border trade.

The District is also addressing apiculture and aquaculture productivity as it has tremendous potentialities in this field. Equipping apiarists with modern hives and establishing bee's product centers is used as a strategy. Increased quality of livestock farming and value addition to livestock products have been targeted. Fish stocking dams, ponds, and lakes are to be given priority to diversify agricultural farming. The quality of livestock farming and value additional to livestock product is to be increased by improving cow breeds through artificial insemination and crossbreeding systems, transforming Milk Collection Centres (MCC) into dairy business centres and empowering them to produce milk bi-products constructing new valley dams, distributing cows, pigs and goats to poor and vulnerable families, establishing modern farms and increasing modern poultry farming, constructing veterinary laboratories for livestock disease control and implementing comprehensive disease control programs. Emphasis is put in the promotion of agriculture financing through the development of agriculture entrepreneurship, establishment of a fund for agricultural industries and improving farmers' accessibility to finance.

- **Demographic Factors**

The catchment of Lake Cyohoha is one of the most populated areas of Bugesera District, with a rapidly growing population. Population growth is due to mostly natural increase together with inflows of people from other regions to benefit from the fertile soil of Bugesera when there is means to irrigate and simply because Bugesera is not far from Kigali City. The district's ultimate target is to increase urban settlement from 3% (EICV3) to 35% and organized rural settlement for easy service accessibility and urbanization of the major trade centers as poles of rural development. This shall be done through completing and implementing local development master plans for towns and trading centers: it will develop basic infrastructures in the village to encourage grouped settlement, increasing grouped settlement sites. It will also develop IDP model villages with all necessary infrastructures, integrating the fire extinguishers, thunder and lightning protection systems for disaster management and increasing the urban population and mobilization of the private sector to construct affordable houses in Bugesera.

Advantages will moreover be seen in the construction and extension of modern markets. Developing sectors' cemetery sites, increasing greening and beautification in towns and trading centers via creation of vast spaces of greening areas and setting up TVETs strategically for the benefit of upcoming towns and trading centers will undoubtedly be done. Demographic factors are therefore very significant in driving land-use change.

- **Environmental Factors**

The effects of climate changes are evident in the catchment of Lake Cyohoha where extreme weather conditions in the form of droughts, heat, and floods are prevalent. This poses a challenge to the agricultural sector which must increase food production to cater for the expanding population. The most challenging factor in agricultural productivity in the Lake Cyohoha catchment is water availability. The decline in rainfall has led to reduced crop production and low profits, although the increased conversion of other land uses to agriculture. The impact of climate change on the agriculture sector also adversely affects other sectors that rely on agriculture for critical inputs. Furthermore, scorching and dry conditions in the catchment trigger fires which are partially responsible for loss of plantations. Moreover, the reduction in forests and open land has caused increased erosion leading to soil and water degradation.

- **Technological Factors**

Environmental factors discussed above have led to severe and increased poverty of smallholder farmers due to reduced production and consolidation of farm units to achieve economies of scale. Consolidation of farms implies less reliance on labor and increased mechanization which results in job losses. Land consolidation has also implied a market problem. The transformation of agriculture from traditional low input technologies to modern systems by using increased fertilization and improved cultivars encountered challenges for areas prone to erosion which aggravate the issue of water resources degradation. Other factors include low education, skills and awareness levels.

- **Cultural Factors**

As outlined in the literature review, cultural factors are connected to people's beliefs and attitudes towards land use. Interviews with catchments management officers and land managers revealed that land-use decisions in catchments are governed by sector's land managers together with local cell administration but still have challenges in implementation according to planned land use of the areas. Hence, lack of knowledge and understanding of the impacts of specific land uses can adversely affect both the environment and economy.

4.3.2 Pressures

The discussed political, economic, technological, demographic, environmental, and cultural factors lead to human activities which exert pressure on land resources. The most prominent pressures emerge from sectors with high economic development and increment in buildings and roads which occur in Mareba, Mayange, and Ngeruka Sectors and promote LULC change. Pressure from agriculture is in the form of land, water availability, and chemicals. The agricultural sector attracts private investors and circular temporary migrants within the district, which exerts pressure on transport, housing, and services. The recently opened institute for conservation agriculture (RICA) is expected to increase pressure in agriculture development of the region. Development pressures in the catchment are also influenced by district performance contracts which promote development projects and partnerships with the government. Institutions under the ministry of environment (RWFA & REMA) conduct studies and make recommendations which push government to approve changes, especially if the impacts align with government objectives.

4.3.3 State

LULC change drivers coupled with pressures on water resources affects the state of land in the catchment of Lake Cyohoha. The change in the state of land has been demonstrated with the results presented from the LULC change analysis which shows the changes that have taken place in LULC between 2000 and 2018. LULC maps for the catchment also show that occurred change is mostly linked to agriculture. The change, coupled with poor land management and climate change have had severe impacts on Lake Cyohoha North water quality and quantity depletion. Based on the interview respondents, most land-use changes and associated impacts occur in agricultural, tourism and industry-related areas.

Agriculture takes up the majority of land in the catchment of Lake Cyohoha North (21,507 ha). However, research and agronomists' reports indicate a decrease in land productivity. The decrease in agriculture production is due to land capability and water availability where the latter is a common restraining factor in the district. The increase in tourism has put a demand on residential, transport and other infrastructure, particularly in small emerging areas near the lakes where developments are taking place in the form of holiday homes, residential accommodation, hotels, and other tourism associated activities.

4.3.4 Impacts

The change in the state of land use has both positive and negative consequences. Agriculture promotes food security, job creation, economic stability, inputs to other industries amongst other advantages. However poor farming practices, overgrazing, and land clearance can lead to erosion and land degradation. Droughts and declining farming profitability have led to pluri-activity as farmers engage non-agricultural activities in order to supplement their income. If more profitable, this could contribute to farm exits and change in land use. Runoff from agriculture rich in nutrients, pesticides, and fertilizers that enters the lake have had a variety of effects, including eutrophication (Figure 4-20). The excessive growth of water hyacinth and other aquatic weeds in Lake Cyohoha north resulted from mismanagement of the catchment and impacted both ecologically and economically (Figure 4-20). The removal of papyrus and cultivation of the buffer zone, if not stopped coupled with currently happening droughts, will degrade excessively the lake and make life more complicated in this catchment. Unsustainable logging practices and forests mismanagement impaired the catchment, which leads to negative impacts on water quality and quantity of Lake Cyohoha north. Consequently, the human activities described above followed by catastrophic vegetation change and heavy rainfall created adverse effects that are costly to address and require significant investments (projects of restoration of Lake Cyohoha by REMA).

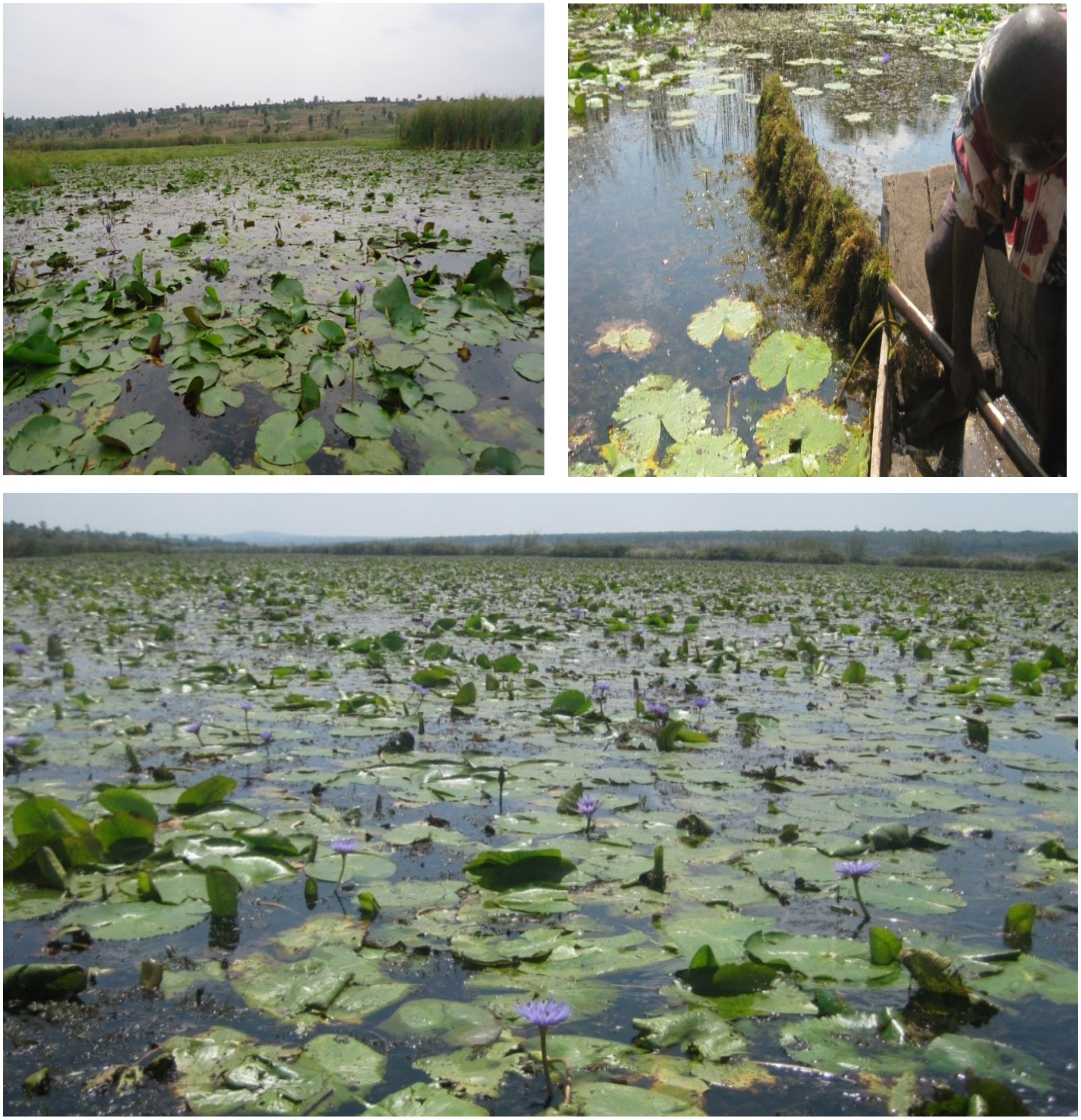


Figure 4-20: Figures of water hyacinth in Lake Cyohoha North

4.3.5 Responses

Responses are actions which the society or government undertake as a result of detrimental impacts which can take place at stages between driving factors and impacts in the DPSIR framework. Such responses in the study area have been in the form of policies and monitoring projects by the government after realizing that Lake Cyohoha North problem is to be taken as an emergency case.

Examples are Vulnerable Ecosystem Recovery Programme (VERP) & Supporting Ecosystem Rehabilitation and Protection for Pro-poor Green Growth Programme (SERPG) implemented for restoration of Cyohoha lakeshores and water hyacinth removal in Cyohoha lake. Under these projects, 400 ha have been cleaned from water hyacinth, 32 houses two in one for 64 HHs have been constructed to support implementation of green smart village for vulnerable families living in the high-risk zone in Bugesera District, 64 HHs have been supplied with Biogas in Rweru IDP Model Village, 104 HHs have been supported by supplying water harvesting equipment to vulnerable households, 500 Households and 2 Primary Schools are connected to solar system, 400 households have been supported with small scale irrigation subproject on Rweru and Cyohoha lakes and supplied with domestic animals for communities around Cyohoha lake, 104 cows have been distributed to families living in Rweru IDP model village and 5 ha have been planted with fruit trees in Rweru IDP model village to make it more clean and green. Also, the government through RAB supports smallholder farmers cooperatives in the Cyohoha catchment by giving them a water pump to irrigate their farms in dry seasons.

Figure 4-21: Removal of invasive aquatic weed species in Lake Cyohoha North by VERP and SERPG

4.3.6 Adapted DPSIR Framework

LULC aspects and issues which emerged from interviews with catchments management officers and land managers of sectors that occupy the catchment and document readings were grouped into themes of Driving Factors, Pressures, State, Impacts and Responses. An adapted DPSIR framework for LULC change in the catchment of Lake Cyohoha is presented in Figure 4-22. This framework was developed to structure and subsequently summarise qualitative findings on drivers of land-use change.

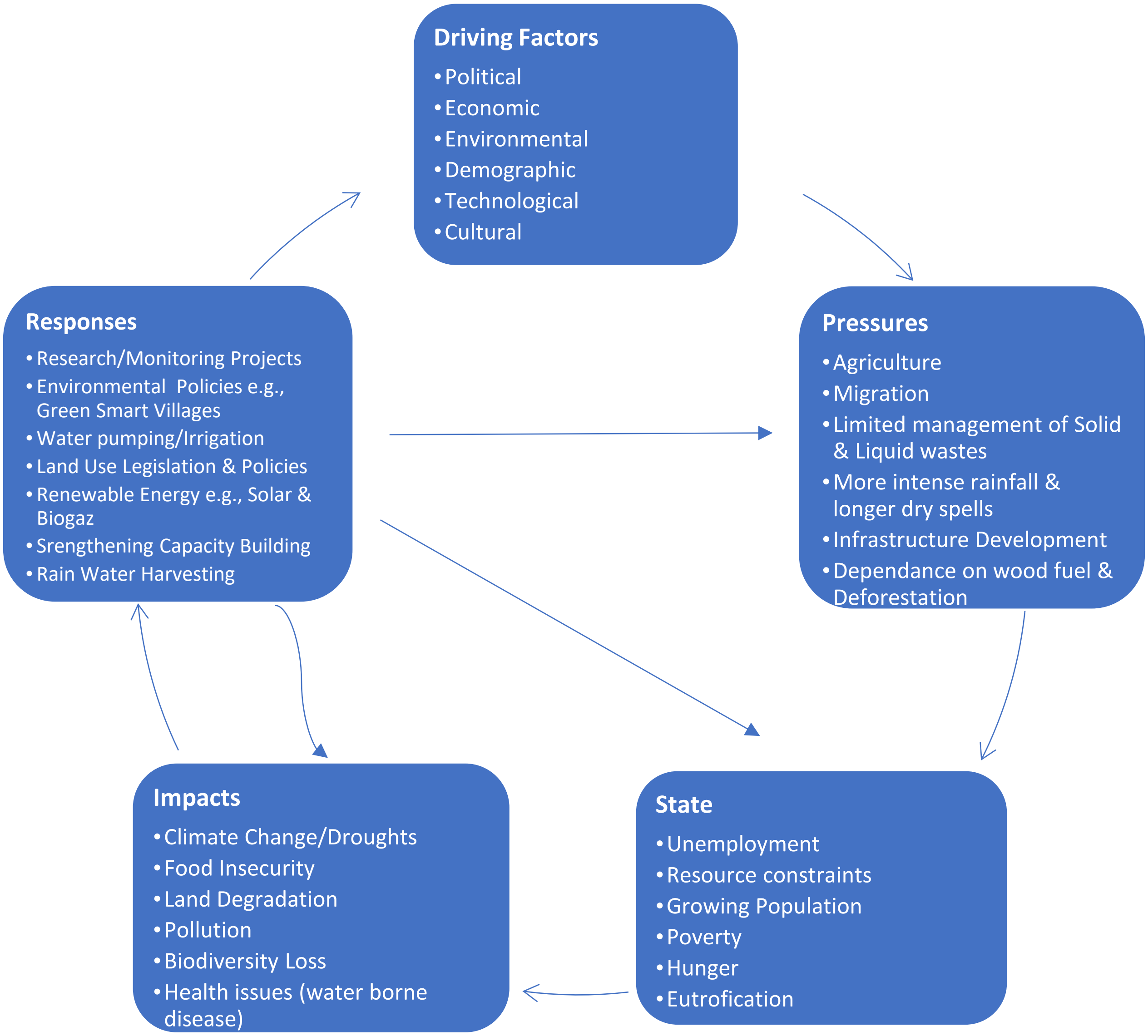


Figure 4-22: DPSIR Framework for LULC change in the catchment of Lake Cyohoha

4.4 Empowerment of the Community on Catchment Management Practices

According to (Hamdy and Lacirignola, 1991): “capacity building is the process of gaining technical, managerial and institutional knowledge and insight in relation to the socio-economic structure, cultural standards and values of the society concerned.” A fundamental goal of capacity building is to enhance the ability to evaluate and address the crucial questions related to policy choices and modes of implementation among development options, based on the understanding of environmental potentials and limits and on needs as perceived by the people of the concerned country.

Capacity building of smallholder farmers in the catchment of Lake Cyohoha North aims to improve the livelihoods of households dependent on dryland agriculture. To increase food security, it is critical to invest in soil and water conservation and associated technologies that enhance productivity and natural resource use efficiency, minimize risk, and increase incomes. Training that was given to this community is in line with Integrated Catchment Management. The findings from interviews from with catchment management officers say that before implementing any planned activities for the catchment all people involved must be trained to achieve the intended results. For the sustainability of the projects, beneficiaries in the catchment are also trained before and in the process of the project to ensure they understand what is being done and why so that they treat the actions like their own. Water resources management is one of the most critical challenges we face at the turn of the century. How well we manage water will determine our ability to pass on our natural heritage to future generation, maintain human health and feed a growing population. An example is the ongoing project of Lake Cyohoha North catchment restoration; awareness was raised and found very crucial to ensure that beneficiaries are contributing to the sustainability of those activities done by the project. Different sectors, including the army, participate along the way, given the severity of the issue of water resources management in this region.

Figure 4-23: Capacity building of the community of Rweru IDP model village and monitoring of constructed biogas to fight deforestation

4.5 Suggestion Policies

After collecting information from interviews with catchment management officers and land managers, a survey with respondents and observation made, the following policies were suggested to overcome water resources degradation and strengthen socioeconomic development of smallholder farmers in the catchment of Lake Cyohoha:

- Strengthening and advising smallholder farmers to work in cooperatives for ease attention in building the capacity and supporting them. To improve their living standards they must increase the production, to achieve this, they must be supported technically (farming systems, crop rotation, etc) and economically (pumping unit) to grow crops all agricultural seasons while preserving resource base and maintaining a high level of environmental quality.
- Improve access to credit and long-term loans, especially for smallholder farmers, in order to lift millions of people out of poverty. These will help smallholder farmers to be more productive and bring agricultural transformation shift from traditional towards modern agricultural production oriented towards the market or other systems of exchange.
- Promote Integrated Catchment Management, for a country like Rwanda that depends heavily on surface water resources and whose water resources are already under stress there must be severe measures to effectively and efficiently manage its water resources at catchment level balancing resource utilization and conservation with meaningful stakeholder participation and financial viability.
- Strengthening the crop value chain and supply of processing materials. Improving the availability of agricultural inputs especially selected seeds, pesticides and accepted agrochemicals and fertilizers at farm level.
- Facilitating training and experience sharing between farmers and also subsidizing agricultural inputs and rainwater harvesting equipment.
- Strengthening research institutions on conducting life-changing researches on catchment level and facilitating external researchers by providing needed support for achieving positive results towards sustainability of water resources.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to investigate the impact that LULC change has on water resources and to analyze the implication that it has on smallholder farmers of the Lake Cyohoha North catchment. This chapter provides conclusions of the research based on the findings from the previous chapters. The sections below explain how the research objectives were achieved and suggest recommendations at the end.

5.1 Conclusions

The LULC quantitative analysis results indicate that there were significant LULC changes between 2000 and 2018 characterized by declines in forest plantations, grasslands, water bodies, wetlands, open lands and settlements in general. In contrast, only agricultural land exhibited significant increase whereas the results show an increase in open lands during the first decade then a decrease in the next. Open lands and forests had the highest loss (-17.26%) and (-8.58%) mostly due to the increased demand for food security because of population growth. Most of the land lost from forests and open land (grassland, shrubland and bare land) were converted into agricultural land. Agricultural land had an increase up to 28.19%, owing to the government's policy of subsidizing agricultural inputs and agriculture transformation to fight food insecurity.

The LULC change results also show that there were slight decreases in wetlands (-1.57%) and water body (-0.69%). However, analyses reveal that poor management practices of the catchment had negatively impacted the Murago wetland and Lake Cyohoha North. Patterns of LULC changes are consistent with the nodes of agriculture intensification which occur in the Lake Cyohoha north catchment. The agriculture sector in this region attracts foreign investment leading to in-migration from other districts. Despite signs of climate change in the catchment, the warm climate of the region is suitable for cash crops like macadamia, blessed with the availability of water from Lake Cyohoha for irrigation. Migration, coupled with natural increase results in population growth which increases the amount and intensity of pressure exerted on resources and consequently changes the state of land and water resources.

Based on interviews, survey and document analysis, driving factors of LULC change were grouped into proximate and underlying causes as a fundamental prerequisite for developing effective policy responses. Proximate causes were identified as infrastructure, forestry and agriculture changes and underlying causes as political, demographic, economic, technological, and cultural factors. To understand these drivers, the DPSIR framework was adapted to show how driving factors lead to human activities which exert pressure on resources resulting in various states of the environment which have significant impacts and require responses. Strategies and policies based on responses to major drivers of LULC and their impacts are therefore recommended to avoid undesirable impacts of changes in LULC.

According to the survey with smallholder farmers, the change in LULC has had significant impacts both socially and economically. The results reveal that agricultural production has reduced drastically as Bugesera region used to be a breadbasket for the country in cereals and vegetables, but nowadays they do not even produce sufficient food crops for their families. The population is growing fast as most families have more than five children. The overall production was 2-3 tones (62%) before 2000 and became 1-2 tones (79%) in 2018, which explains the reduction in number of meals per day where 80% eat once a day. Capture fisheries were 62% 300-400 kg and have reduced to 100-200 kg (58%) per year. The findings indicate that the reduction in fish production is the results of eutrophication and excessive growth of water hyacinth that covered a big surface of Lake Cyohoha North. Based on the research findings, it can therefore be concluded that, Yes, LULC change in the catchment had impacted Lake Cyohoha North and had affected smallholder farmers within the catchment.

5.2 Recommendations

This study represents the LULC change impacts on water resources for supporting the sustainable development of agriculture production in Rwanda. This section discusses some recommendations and the issues that require further investigation.

From interviews and own observation, the activities for the restoration of Lake Cyohoha North are ongoing. However, the implementation is being done without any study done before to know what was the source of water quality and quantity depletion in Lake Cyohoha North.

Though, the findings of this research prove that the main problem comes from agriculture that releases nutrients from fertilizers and pesticides washed away through runoff, which promote the excessive growth of water hyacinth and other aquatic weeds shown under previous chapters. Therefore, removing aquatic weeds without stopping the source of the problem would not provide long term answer. Thus, I call for REMA and RWFA to invest more in practices of managing the catchment and help farmers to control erosion in their farms for the sustainability of Lake Cyohoha.

Data availability is still a challenging issue for research in Rwanda. For example, datasets of LULC in the 1990s could not be found. The unavailability of datasets limits the accuracy of findings since it misses the past situation. Data is therefore recommended to both government and private institutions in order to support and encourage research and developments and to maximize data benefits to society.

Although the policy of land consolidation was introduced by the government of Rwanda, in Bugesera district it is still having low applicability and alerted smallholder farmers lack profit and market. It is one of the challenges. For this reason, more sensitization is needed to improve the skills of people about the use of land together (cooperatives). This also will help the farmers to put together their financial power to afford water pumping systems. Also, the government should strengthen regional integration and ease of access to local and regional markets.

Agriculture production in Lake Cyohoha North catchment depends mostly on rain-fed subsistence farming that is affected by unpredictable and erratic rainfall pattern which cannot guarantee enough food production for the population throughout the region which is under persistent threat of hunger. To improve the output at the farm level, effective harvesting of green water through increased infiltration and storage is needed and would be cost-effective.

Last but not least, the effects of climate change in the Bugesera region are a significant threat to the development of local communities who are mostly smallholder farmers. Thus, the government of Rwanda is highly recommended to introduce the incentives and subsidies for PVWP systems in spite of DWP for environmental and economic reasons. PVWP running cost is cheaper than DWP and more affordable by smallholder farmers, using PVWP could be an added value to benefit from excessive sun of this region and prevent CO_2 emissions in the atmosphere.

5.3 Future Works

Rwanda is a developing country that is growing fast; there are many needs in studying future LULC change and its impact on the development of the country that is environmentally safe. Future work on LULC change modeling in Lake Cyohoha catchment would be required to perform future predictions. This can be achieved with the availability of LULC data sets at shorter intervals and more accurate driving factor data at a regional scale.

Further research would be of more concern on Lake Cyohoha water quality to estimate the quantity of fertilizers and pesticides that farmers lose in every agricultural season washed away by erosion. The study would therefore call for immediate support from MINAGRI to help smallholder farmers control erosion for efficient use of the given inputs. Lake Cyohoha water quality assessment would also alert WASAC to supply treated potable water for the local communities living in this catchment who lack access to safely managed drinking water services and still use Lake Cyohoha water for domestic and drinking purpose.

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APPENDICES

Appendix 1: Questionnaire

1. Answer all the questions (Subiza ibibazo byose)
2. Tick or cross in the box reserved for short answer (Shyira akamenyetso mu kazu k`igisubizo kigufi)

A. Identification of respondent

1. Sex *(Igistina)*

2. Age (*Ikiciro cy'Imyaka)*

3. Marital status/*Irangamimerere*

4. Level of Education / *Amashuri wize*

B. Socioeconomic status

1) How many children does your family have?

....

....

2) What was the agriculture production before 2000 and post 2000 per year?

....

....

3) How many times were you eating per day before 2000 and how many after 2000?

....

....

4) What was the production of fish before 2000 and post 2000 per year?

....

....

5) How many cows were you raising before 2000 and how many do you raise these days?

....

....

6) Have you ever received trainings?

....

....

7) If yes, what types of trainings have you received?

....

....

8) Are you aware of climate change? does the climate change caused Lake Cyohoha degradation?

....

....

9) Do you control erosion in your farm?

....

....

10) What type of erosion control measure do you use?

....

....

11) Does your farm have a boundary with the buffer zone of Lake Cyohoha?

....

....

12) Do you respect buffer zone boundaries?

....

....

Thank you for your time and cooperation!

Appendix 2: Interview Guide

DRIVERS OF LULC CHANGE INTERVIEW GUIDE QUESTIONS

1. What are the most significant LULC changes that have occurred in Lake Cyohoha catchment in the last 20 years?
2. Where did these changes occur and why in those particular locations?
3. When did the changes occur and why then?
4. What are the main reasons for these changes in LULC?
5. Have government policies played a role in LULC change?
6. What are the potential economic, social and environmental impacts of LULC changes?
7. What measures are being implemented or considered by your institution to address these potential impacts?
8. Does your institution use any population or economic growth projection tools; if so, is it in its own capacity/ consultants are hired to do it?
9. What do you think Lake Cyohoha North will look like in 10 years?
10. What are the major factors affecting future LULC?
11. Have you planned to conduct community trainings on management of Lake Cyohoha for the sustainability of your project through community engagement?

Thank you for your time and cooperation!

Appendix 3: Thesis Budget Report

Nº	Item Description	Total Amount (USD)
1	Flight Ticket	1,000
2	Data Collection Expenses	1,217
3	Internet Bundles	250
4	Photocopy, Printing & Binding	179
5	Field Transportation	354
Total		**3,000**