# IMPACT OF HUMAN ACTIVITIES ON CARBON STOCKS AND IMPLICATIONS ON SUSTAINABILITY OF COMMUNITY LIVELIHOODS IN KANYABAHA WETLAND IN RUKIGA DISTRICT, UGANDA


**BY**

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## DECLARATION

**DECLARATION BY CANDIDATE:**

This thesis presents my original work and has not been presented in any other university for award of any degree or other award. Where other research works have been cited, they have been duly acknowledged in the references in accordance with anti-plagiarism regulations.

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# DEDICATION

This doctoral thesis is dedicated to my cherished family, whose unwavering support and encouragement provided the foundation for my education throughout my studies.

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## OPERATIONAL DEFINITION OF TERMS

**Analysis of Variance** (ANOVA): is a statistical formula used to compare variances across the means (or average) of different groups. A range of scenarios use it to determine if there is any difference between the means of different groups. (spotfire, 2024).

**Climate Variability:** According to UNFCCC, climate change is a change of climate which is attributed directly or indirectly to any human activity that alters the composition of the global atmosphere, and which is in addition to natural variability observed over comparable time periods (Gebrechorkos *et al.,* 2019).

**Natural Climate Variability:** Natural climate variability is driven by internal processes within the Earth's climate system, such as atmospheric circulation patterns like the El Niño-Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), and the Indian Ocean Dipole (IOD) (Gebrechorkos *et al.,* 2019).

**Anthropogenic Climate Change:** In addition to natural variability, human activities have significantly altered the Earth's climate system, leading to anthropogenic climate change.

**Adaptation:** Involves adjusting societal and environmental systems to reduce vulnerability and enhance resilience to changing climate conditions. This may include implementing early warning systems, improving water management practices, developing drought-resistant crop varieties, and conserving natural habitats (International Federation of Red Cross & Red Crescent Societies, 2020).

**Mitigation:** Focuses on reducing greenhouse gas emissions and limiting global warming through measures such as transitioning to renewable energy sources, improving energy efficiency, and implementing policies to promote sustainable land use and transportation (Alejandro, 2021).

**Decomposition Dynamics:** Climate change can influence the decomposition of organic matter in wetlands, affecting carbon cycling and storage. For instance, Freeman et al. (2004) studied the impacts of warming and drying on carbon decomposition rates in temperate peatlands and observed accelerated decomposition under simulated climate change conditions (Fenner *et al.*, 2019).

**Carbon Sequestration:** Wetlands play a crucial role in carbon sequestration, acting as important sinks for atmospheric carbon dioxide (Bessah *et al.*, 2021).

# ABSTRACT

Climate change in addition to utilization of land and natural resources can negatively impact biodiversity, hydrology and soil carbon stocks of tropical wetlands, thereby negatively impacting the sustainability of wetland-dependent livelihood activities. Wetland cover has been steadily declining in Uganda primarily due to rapid population growth thereby rising food consumption and settlements. This study assessed the impact of wetland-dependent livelihood activities on carbon stocks and plant species diversity in Kanyabaha wetland, Rukiga District, Uganda, with a focus on carbon stock variations, land use changes affecting carbon sequestration and the implications for plant species diversity and local community livelihoods. The study combined both scientific methods and socio-economic survey designs. Landsat images containing multi-temporal datasets covering a period from 1990 to 2021 were processed using remote sensing software. Field verification was conducted through ground truth validation. Simpsons, Shannon-Wiener and Pairwise Jaccard diversity indices were applied to quantify vegetation diversity. Peat soil and vegetation samples were analysed to assess the carbon stocks. The socio-economic survey was conducted using questionnaires administered to 388 respondents across six villages found in the study area. Three key informant interviews and six focus group discussions were also conducted to purposively selected informants. Data were analysed using ANOVA, Chi square and regression analysis. The results of the study revealed that during past 30 years, the wetland vegetation cover in Kanyabaha wetland had significantly diminished. Land use and land cover analysis showed that papyrus was the dominant vegetation but its cover decreased from 51.5% in 1990 to 39.1%, ($P<0.05$; $R^2=0.757$) in 2021. During the same period, grassland cover decreased from 34.2% in 1990 to 9.5% ($P<0.05$; R2=0.893) in 2021. Tree plantations, built-up areas and bare ground expanded significantly during the 30-year period. Soil carbon density varied with soil depth and across land cover types. Woodlands had the highest mean soil carbon density (530.2±205.5 tons/ha), followed by built-up area (107.7±28.8 tons/ha) and then tree plantations (98.3±12.5 tons/ha). The least mean soil carbon density was observed in grasslands (45.5±3.7 tons/ha). The local community depended on wetlands for water, crop farming, harvesting of wetland plants and grazing their livestock. Eucalyptus trees had the highest total carbon stock (372.5±81.1 tons). Statistical analysis confirmed the relationship between livelihood activities and carbon stocks (F= 5.02, DF = (1, 4), $P<0.05$). The results for species diversity revealed a statistically significant effect of site on diversity ($F_{(5, 114)} = 12.88$, $p < 0.0001$), indicating that the diversity index varied meaningfully between sites. The key drivers of wetland utilisation were low income (65.8%), demand for farmland and settlements (8.2%), inadequate enforcement of existing wetland conservation and management regulations (10.8%) and community limited knowledge of the law and poor farming practices (4.5%). The adaptive strategies included diversified livelihoods (16.1%), climate-resilient agriculture (20.7%), rainwater harvesting and storage (12.5%), agroforestry (10.3%), strengthened social networks (18.3%), efforts to access climate information (13.3%), as well as wetland conservation (8.7%) initiatives. The study recommended that drivers of wetland biodiversity loss be addressed by sensitizing communities on the significance of wetland conservation, and promoting climate smart agriculture. Additionally, comparative research on season variations in carbon dynamics in relation to land use and climate variability was recommended.

# CHAPTER ONE: INTRODUCTION

## 1.1 Background to the Study

Among the most productive environments are wetlands in the world and they are the link between land and water (US EPA, 2022). The Ramsar Convention on Wetlands of International Importance According to the Ramsar Convention Secretariat (2013), wetlands are defined as "areas of marsh, fern, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salty, including areas of marine water, the depth of which at low tide does not exceed six meters." In terms of benefits, wetlands support human livelihoods as well as ecosystems (Sutton-Grier *et al.,* 2019). Ecologically, wetlands play a critical role in improving environmental quality as they serve as habitats for fish and wildlife species, support vegetation like papyrus and many plant species, some of which serve as food sources. Wetlands also supply vital ecosystem services, such as flood prevention, shoreline stabilization and climate change mitigation. Additionally, wetlands are valuable sources of clean water, fodder, construction materials, and play a vital role in sustaining biodiversity. The natural resources from wetlands promote human health, livelihoods, and survival, while offering essential economic, social, and ecological benefits that are critical for both present and future generations (Harris, 2008; Maltby, 2022).

Owing to these values, they have been indicated to have high-value ecological functions estimated at 23 % of the global ecosystem service value even though they occupy only 9 % of the global terrestrial land area (Costanza *et al.* 2020). However, despite the above ecological benefits, degradation and over exploitation of wetlands has occurred due to increasing demand for wetland services. “In addition, wetland degradation is growing in importance as a global environmental issue due to population growth, desertification, soil erosion, unsustainable use of finite natural resources, and decreased productivity of agricultural land." (Ekka *et al.*, 2023).

An estimated 131 million hectares of wetlands exist in Africa and these wetlands are a vital source of nutrients and water, both of which are necessary for human survival and biological productivity. (Donde *et al.,* 2023). Although wetlands are crucial, in Africa they are experiencing alterations or being converted, typically due to economic and financial reasons (Donde *et al.*, 2023). Thus, conservation-focused management of wetlands is vital to achieve sustainable health, safety, and well-being of many African societies (USAID, 2014). Degradation of wetlands denies the community an opportunity to access clean water in right quantities and increases the cost of restoring wetland amenities. Additionally, it impacts negatively on recreation benefits derived from wetlands as well as wildlife habitat (Adhya et al., 2022).

About 10% of Uganda's land is covered by wetland resources, such as the major river networks, deltaic mangroves, inland drainage systems, and the Great Lakes system. However, degradation of such resources poses a danger to their survival as it affects their size and ecosystem functions (Kayima *et al.,* 2018). Among the major wetland systems in Uganda include the Mpologoma wetland, Lake Wamala, Namatala-Doho, wetlands of river Semliki, Nomuremu-Reshebeya-Kashambya wetland system, Enyau wetland system, Achwa wetland catchment area, Kinawataka wetland, Lubigi and River Kafu wetlands. The Ugandan wetlands are also characterized by vegetation such as Papyrus, Miscanthidium and Phragmites that are used for crafts making by the local craftsmen (Behn *et al*., 2022). The country hosts numerous protected and non-protected wetlands such as Nabugabo, Lutembe Bay, Lubigi and

Mabamba-Bay which habour biodiversity of international importance such as the Sitatunga and other globally threatened bird species including Balaeniceps rex (Shoebill) and Hirundo atrocaerulea (Blue Swallow) (Adhikari *et al.,* 2022).

Wetlands in Uganda were once thought to be among of the world's last genuinely untamed and natural areas (MWE, 2014). Their ecological traits and people's disinterest in exploring these regions were the causes of this. They were devalued, drained, and destroyed into farmlands and development areas to accommodate an increasing population and other viable economic activities because they were viewed as little more than nuisance mosquito breeding sites (Alikhani *et al.,* 2021). Interference in these domains increased as economies and society evolved. As a result, numerous human populations no longer receive crucial ecosystem services. (Gardner *et al.* 2015). If this trend continues, it will be extremely difficult for the world to reach its targets for life on land, affordable and clean energy, food security, water and sanitation, and climate change action. (FAO, 2015).

To date wetlands still experience degradation threats occasioned by severe factors such as changing climate, nutrient loading and eutrophication resulting in the formation of dead zones. Additionally, anthropogenic activities like draining, pollution, agriculture and building of settlements decreases the ability of these ecosystems to provide the goods and services needed for human and environmental survival (Sarkar *et al.,* 2022).

Regardless of their significance to settlement and agriculture, wetlands in Uganda are subject to excessive exploitation of the products, services, and functions they offer to livelihoods because of the severe pressure they endure. The percentage of Uganda's surface covered by wetlands in 1994 was about 15.6% and declined to 10.9% in 2008 representing a reduction of

4.7% (Hedman *et al.* 2019). Massive wetlands degradation has been linked mostly to cultivation and dairy production, with sporadic conversion of wetlands for human habitation (MWE, 2014). The majority of Uganda's natural wetlands, which can be found throughout the country, are classified as peatlands because they include a thick layer of moist, organic soil that is made up of decomposing plant matter that absorbs carbon dioxide and helps to mitigate climate change. Many of these wetlands are now sources of greenhouse gas emissions due to anthropogenic activity like agriculture. Wetland drainage results in higher emissions of CO2 and N2O but lower emissions of CH4 (Zou *et al.*, 2022).

Due to the estimated yearly emissions of two billion tons of carbon dioxide caused by the degradation of wetlands, wetland loss has emerged as a major global agent of climate change. Given that wetlands contribute to the reduction of poverty and the growth of the national economy, Uganda accepted the Ramsar Convention on Wetlands, which resulted in the designation of several wetlands as Ramsar sites and the adoption of several legislative tools to support wetlands conservation. (MWE, 2014). It has been acknowledged that Uganda's wetlands are becoming more degraded despite the existence of these policy tools, which may have contributed to climate change. Rising temperatures, altered rainfall patterns and frequency, melting glaciers atop mountains, and the intensity of extreme weather events like floods and droughts are all signs of climate change (Muruganandam *et al.*, 2023).

Climate change intensifies already-existing environmental pressures, exacerbates food insecurity, and fuels disputes over natural resources, all of which have detrimental effects on people's livelihoods and the environment. Risks associated with climate change continue to exacerbate poverty and food insecurity, and they may even become a barrier to agricultural development initiatives, especially in tropical regions like Africa where farming systems mostly rely on rainfall. (UNFCC, 1992; IPCC, 1996). It is anticipated that Uganda's climate would get wetter due to higher precipitation, which might not be distributed uniformly. Changes in temperature patterns may have a substantial influence on food security and water resources in addition to other issues, regardless of changes in precipitation. According to the Uganda Climate Change Vulnerability Assessment Report, extreme climate events like storms, floods, droughts, waves, and others are anticipated to occur in Uganda as well as the rest of the world (Chambers 2013).

Uganda's economic and social progress is predominantly reliant on the utilization of its natural resources. Nonetheless, Uganda's social-economic growth is being negatively impacted by the seemingly ongoing degradation of these essential natural resources, especially the lives of millions of people living in rural areas (Chambers, 2013). Additionally, Uganda's ability to meet its development goals is under jeopardy because to the worsening degradation. By the 2020s, Uganda's temperature is expected to range between 0.7oC to 1.5oC, according to climate change projections. (Osaliya *et al.,* 2021). The models indicate a rise in rainfall variability and the likelihood of heavy rainfall in most locations. Over 70% of Uganda's GDP currently comes from agriculture, thus the changes in rainfall are likely to have a detrimental effect on this sector. In Uganda over 80% of the people living close to wetland areas mainly, depend on wetland resources to derive their livelihoods and attaining their food security needs (Ochoko *et al.,* 2023). This study therefore assessed the interplay between wetlands conservation and climate change modulation. It also examined the major wetland-based livelihood activities and assessed their impact on the conservation of wetlands in Rukiga District, Western Uganda.

### 1.2 Statement of the Problem

The study aimed at investigating the impact of wetland-dependent livelihood activities on carbon stocks in Kanyabaha Wetland in Rukiga District, Uganda. The reduction in wetland coverage in Uganda, attributed to population growth and increased human activities in wetlands, has raised concerns about the emission of greenhouse gases, particularly carbon dioxide, into the atmosphere (Were et al., 2019). In Rukiga District, the conversion of the Kanyabaha wetland into farmland for agriculture has led to soil exposure, resulting in greenhouse gas emissions. The extraction of peat for agriculture and water for horticultural use has disturbed the wetland ecosystem, altering its hydrology and greenhouse gas balance (Oestmann *et al.,* 2022). The investigation focused on the following aspects: (i) analysis of carbon stock variations within wetland ecosystem, (ii) the effect of wetland-dependent livelihood activities on carbon stocks and plant communities, (iii) the drivers of utilization of wetland resources and (iv) the adaptive techniques farmers have used to deal with the negative effects of climate change.

The investigation focused on those areas because they are crucial for understanding the interplay between wetland-dependent livelihood activities, carbon stocks, and climate change in the context of Kanyabaha Wetland in Rukiga District, Uganda. By examining the impact of these livelihood activities on carbon stocks and plant communities, the study provided insights into the environmental consequences of human activities in wetlands. Identifying the particular livelihood activities in the wetland that are most impacted by climate change is crucial for creating tailored mitigation and adaptation plans. Additionally, exploring how farmers have adapted to the changing wetland conditions and resources can offer valuable lessons for sustainable wetland management and conservation efforts

### 1.3 Objectives of the Study

#### 1.3.1 General Objective of the Study

To assess the impact of wetland-dependent livelihood activities on carbon stocks and plant communities in Kanyabaha wetland, Rukiga District, Uganda, with a focus on carbon stock variations, land use changes affecting carbon sequestration and the implications for plant species diversity and local community livelihoods.

#### 1.3.2 Specific Objectives

The study aimed at addressing the following objectives:

1. To analyze carbon stock variations within wetland ecosystem in Kanyabaha wetland in Rukiga District
2. To assess the effect of livelihood activities on carbon sequestration and plant species diversity in Kanyabaha wetland in Rukiga District
3. To determine the main drivers of wetland utilization in Kanyabaha wetland in Rukiga District
4. To determine the adaptation strategies adopted by farmers to cope with climate change in Kanyabaha wetland, in Rukiga District

### 1.4 Research Questions

The following questions guided the study:

1. What are the existing components and trends in carbon stocks in Kanyabaha wetlands in Rukiga District?
2. How have human activities affected carbon sequestration and plant species diversity in Kanyabaha wetlands in Rukiga?

3. What are the main drivers of utilization of wetland resources in Kanyabaha wetland in Rukiga District?
4. What adaptation strategies are adopted by farmers to cope with adverse impacts of changing climate in Kanyabaha wetland in Rukiga District?

## 1.5 Research Hypothesis

The following research hypotheses were tested:

1. **$Ho_1$:** There are no significant variations in the components and trends of carbon stocks in Kanyabaha wetland in Rukiga District
2. **$Ho_2$:** Livelihood activities of local community have no significant influence on the wetland carbon sequestration and plant species diversity in Kanyabaha wetland in Rukiga District
3. **$Ho_3$:** There is no relationship between drivers of wetland utilization and livelihood activities of local community in Kanyabaha wetland in Rukiga District
4. **$Ho_4$:** Socio economic status of local community has no significant effect on their capacity to adapt to climate change in Kanyabaha wetland in Rukiga District

## 1.6 Conceptual Framework

The study's conceptual framework illustrates the interrelationships that exist between the dependent and the independent variables. The independent variables comprise of existence of carbon stocks and their levels, baseline human activities and drivers of utilization of these wetlands.

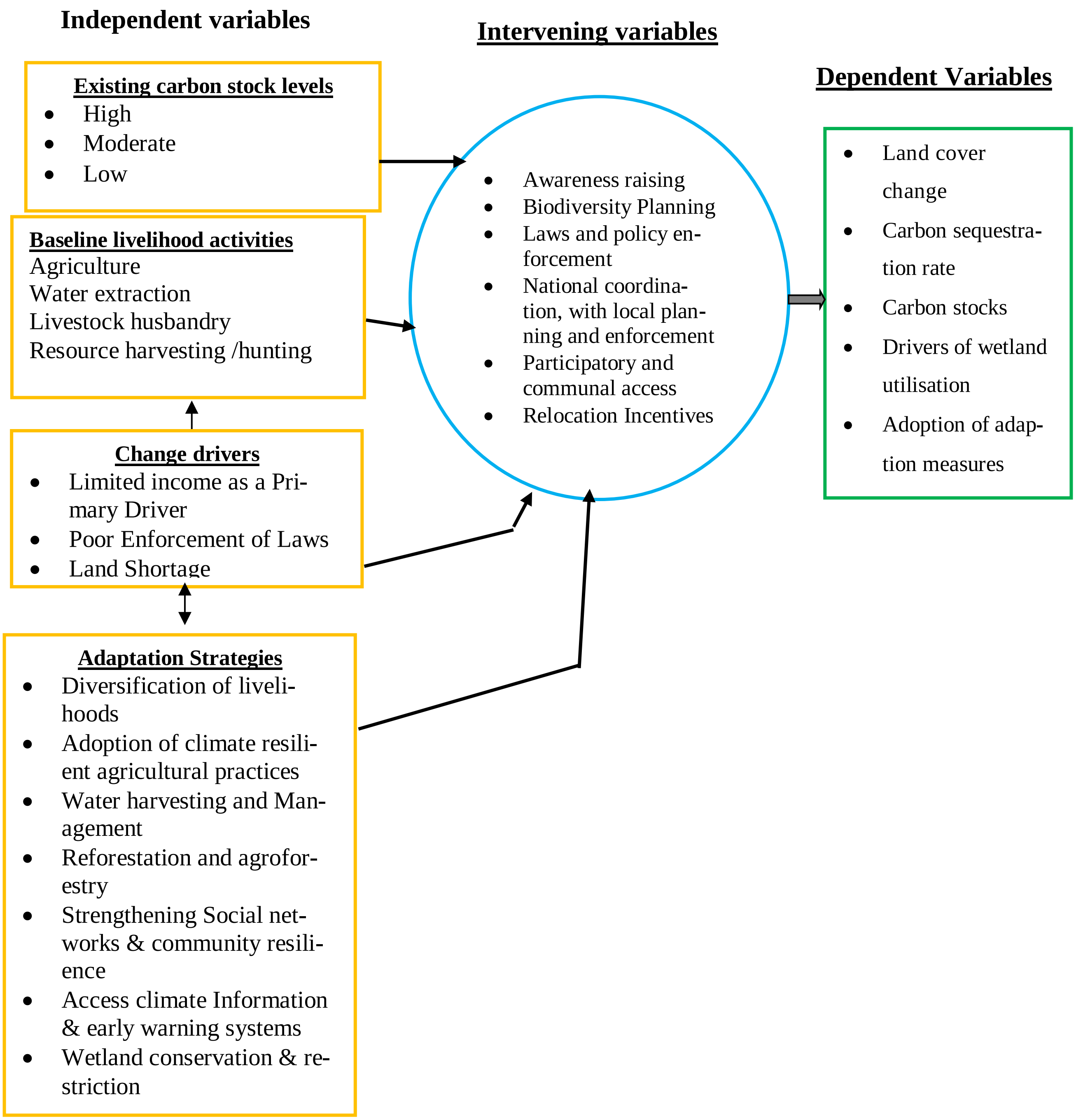


***Figure. 1.1 Conceptual framework (Source: Developed by the Researcher in 2020)***

The intervening variables include mass awareness campaigns, planning for biodiversity, guidance on appropriate tree species to plant, and the implementation of laws and policies pertaining to the conservation of wetlands.

### 1.7 Significance of the Study

The study's conclusions have important ramifications for the different parties involved in the management and conservation of wetland resources in Kanyabaha wetland, Rukiga District, as well as broader efforts to address climate change and sustainably utilize natural ecosystems.

**Local Communities:** Local people can continue to profit from wetland resources while limiting negative environmental effects by making informed decisions about their livelihood activities with the help of an understanding of the link between carbon stocks and land use. By gaining insights into the effects of land use changes on carbon sequestration and emissions, communities can adopt more sustainable practices that support both their immediate needs and long-term resilience.

**Government and Policy Makers:** Policymakers at the local and national levels can use the findings of this study to inform the development of policies and regulations aimed at protecting and conserving wetland ecosystems. By recognizing the importance of maintaining carbon stocks in wetlands, authorities can implement measures to mitigate land use practices that contribute to carbon emissions and degradation of these valuable ecosystems.

**Conservation Organizations:** Conservation organizations and environmental NGOs can utilize the study's results to advocate for the preservation of wetlands and the adoption of conservation strategies that prioritize the maintenance of carbon stocks. By highlighting the link between land use, carbon sequestration, and ecosystem health, these groups can mobilize support for conservation initiatives and promote sustainable management practices.

Researchers and Academia: The study contributes to the existing body of scientific knowledge on wetland management and carbon dynamics, providing valuable insights for future research endeavors. By expanding our understanding of the complex interactions between land use, carbon stocks, and ecosystem services, researchers can identify new avenues for investigation and develop more effective strategies for mitigating the impacts of climate change on wetland ecosystems.

Knowledge and information from this research will contribute to efforts towards improving benefits from the international carbon trade, implementing wise use principles of the Ramsar Convention (1971), maintaining benefits to populations reliant on wetlands and strengthening the role of wetlands in the preservation of biodiversity and the mitigation of climate change. Sustainable wetland management can be advanced by taking steps to finance actions connected to climate change. Furthermore, policymakers may utilize the information produced to sway decisions that will support wetland-dependent populations in Uganda using wetland resources sustainably.

Overall, the significance of this study lies in its potential to inform decision-making, guide policy development, and enhance community resilience in the face of environmental challenges. By elucidating the relationship between carbon stocks and land use in Kanyabaha wetland, the study offers practical solutions for achieving sustainable management of wetland resources and fostering environmental stewardship among all stakeholders.

## 1.8: Justification of the Study

Wetlands offer a multitude of ecological, economic, and social advantages, making them one of the planet's most valuable ecosystems. However, human challenges to these delicate landscapes are growing activities, particularly changes in land use patterns. Understanding the relationship between carbon stocks and land use in wetlands is essential for effective management and conservation efforts. This section provides a detailed rationale for the study, highlighting its significance in addressing key scientific and developmental challenges in Kanyabaha wetland, Rukiga District, Uganda.

The study seeks to contribute to the advancement of scientific knowledge by exploring the intricate relationship between carbon stocks and land use in wetland ecosystems. By analyzing carbon stock variations within Kanyabaha wetland, the study aims to expand our understanding of the factors driving carbon dynamics in these critical landscapes.

Despite the recognized importance of wetlands in carbon sequestration and climate regulation, there remains a significant gap in our understanding of how changes in land use patterns affect carbon stocks. This study seeks to address this gap by providing empirical data and insights into the specific mechanisms through which land use changes influence carbon dynamics in Kanyabaha wetland.

The findings of the study will provide valuable information for policymakers, land managers, and conservation practitioners. By elucidating changes in land use's effects on carbon stocks, the study will inform the development of evidence-based policies and management strategies aimed at conserving wetland ecosystems and mitigating climate change.

The Kanyabaha Wetland offers vital ecological services, such as habitat provision, flood control, and water filtering. It is important to comprehend the correlation between land use and carbon stocks in order to guarantee the sustainable administration of these resources. The study will provide insights into how land use practices can be optimized to maintain ecosystem integrity and support local livelihoods. Many communities in Rukiga District depend on wetland resources for their livelihoods, including agriculture, fishing, and water supply. By examining the impacts of land use change on resources utilized by local communities, the study will empower communities to adopt sustainable practices that enhance their resilience to environmental changes and economic shocks.

Wetlands store and sequester carbon, which helps to mitigate the effects of climate change. However, human-caused actions like drainage and deforestation can liberate carbon that has been stored in the atmosphere, increasing greenhouse gas emissions. By understanding the drivers of carbon dynamics in Kanyabaha wetland, the study will contribute to efforts to mitigate climate change and promote carbon sequestration in wetland ecosystems.

In sum, the study on the relationship between carbon stocks and land use in Kanyabaha wetland is justified by its potential to advance scientific knowledge, inform policy and management decisions, and promote sustainable development. By addressing key scientific and developmental challenges, the study has the potential to contribute to the conservation of wetland ecosystems and the well-being of local communities in Rukiga District and beyond.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Introduction

The pertinent literature from books, journals, periodicals, newspapers, reports, dissertations, and other publications that are cited is reviewed in this chapter including the internet sources. It examines the interplay among inland wetlands, climate change and sustainable livelihood of communities that live in or depend on wetland resources and their adaptations in Uganda specifically and throughout Africa as a whole. The theoretical and empirical reviews of the four concerns are included in the sub-sections of this chapter, which are organized according to the themes that each of the study's aims derives.

## 2.2 Definition of Wetlands

A wetland is a region of land that has continually or seasonally occurring shallow water covering its soil or saturation with water, and is home to unique flora and animals. "Areas of marsh, fen, Peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which does not exceed six meters," is the broad definition of wetlands given by the Ramsar Convention on Wetlands (2010). According to Uganda's National Policy for the Conservation and Management of Wetland Resources, wetlands are places where animals and plants have adapted to flooding, either temporarily or permanently. (The constitution of the Republic of Uganda, 1995).

A vast range of habitats, including marshes, peat lands, floodplains, rivers, lakes, and coastal regions like sea grass beds, coral reefs, salt marshes, mangroves, and other marine areas that are only six meters deep at low tide, are included in wetland ecosystems. They also include of wetlands created by humans, like paddy fields, waste-water treatment ponds, aquaculture pond systems, and water reservoirs. The Ramsar Convention aims to protect and responsibly use wetlands, acknowledging their vital ecological roles as well as the numerous goods and services they offer society.

### 2.3 Wetland Products, Services and Attributes

Numerous benefits, features, and goods that wetlands offer have been widely recognized. (McCartney & Finlayson, 2010; Kakuru *et al.*, 2013). Wetland products in Uganda, for example, include water, food (plants, fish, and wildlife), land (for farming, grazing, and foraging), materials for crafts and construction, plant mulch, and medicinal plants. Flood attenuation, drought management, groundwater replenishment, erosion and sediment control, wastewater treatment, carbon sequestration, climate modification, habitat function, ecotourism, and boat or raft transportation are only a few of the services provided bywetlands. Lastly, the conservation of genetic resources, biodiversity, aesthetics, and cultural legacy are all characteristics of wetlands. (MWE, 2014). Not all of the services that wetlands offer can be valued financially, even if many of their products can be adjusted for economic purposes. The Nakivubo urban wetland in Kampala serves as an illustration here; its annual economic worth was estimated to be USD 1.373 million in 2002 (Isunju, 2016), However, its actual value can be far higher than what was measured. When decisions are made based only on immediate financial gains, services like flood attenuation, fish breeding, water purification, climate moderation, and other hydro-ecological activities are frequently undervalued or not monetized at all. Wetlands are under tremendous pressure from rival users because of the prospects and rising demand for wetland goods. Given the difficulty of restoring the degraded wetlands, the rate of loss of natural wetlands has reached critical levels. (Ramsar, 2010; Lukooya *et al.,* 2013).

Wetlands are being converted at the expense of essential ecosystem services for the purposes of agriculture, business development, habitation, and other urgent uses. (Lukooya *et al.*, 2013). The loss of ecosystem services exposes vulnerable populations and water resources to risks, which has a knock-on effect of pollution, disease outbreaks, decreased fish productivity, and higher water treatment expenses. For instance, the Nakivubo wetland has been receiving polluted urban runoff and sewage effluent for more than 50 years, and as a result, its ability to handle these wastewater streams has drastically decreased. (Kansiime & Nalubega, 1999). To make up for the decreased capacity of wetlands, the Ugandan government, acting through the National Water and Sewerage Corporation (NWSC), has been building wastewater treatment plants. These sophisticated systems are expensive to build and maintain, though. Wetlands are naturally capable of filtering wastewater, at least somewhat. For naturally occurring wetlands, this service is free; nevertheless, when wetlands need to be created or, worse still, when the treatment system is fully designed, it can become highly expensive. The cost of treating wastewater can be greatly decreased by combining engineered systems with wetlands, even if wetlands have a limited capacity to do so. (Lukooya *et al.*, 2013). Moreover, wetlands are well known for their capacity to take in, hold, and release water gradually, which helps to mitigate the negative consequences of drought and flooding. (Horwitz *et al.*, 2012; Munroe *et al.*, 2012).

## 2. 4 Climate Variability

In addition to natural variability shown over comparable time periods, climate change is defined by the UNFCCC as any change in the global atmosphere that is directly or indirectly related to human activity that modifies the composition of the atmosphere. Climate variability pertains to the inherent oscillations and modifications in meteorological conditions across diverse temporal and spatial dimensions. It includes long-term trends spanning decades to centuries as well as short-term variations like daily weather patterns and seasonal variations. Climate variability is influenced by a complex interplay of natural processes, including atmospheric circulation patterns, oceanic oscillations, solar radiation, and volcanic activity, as well as elements brought about by humans, like changes in land use and greenhouse gas emissions.

### 2.4.1 Natural Climate Variability

Natural climate variability is driven by internal processes within the climatic system of the Earth, including atmospheric circulation patterns like the Indian Ocean Dipole (IOD), the North Atlantic Oscillation (NAO), and the El Niño-Southern Oscillation (ENSO) On a regional and global scale, these events cause variations in temperature, precipitation, and other climatic variables. For example, ENSO events can result in anomalous warming or cooling of sea surface temperatures in the tropical Pacific Ocean, leading to widespread impacts on weather patterns, agriculture, and ecosystems worldwide.

### 2.4.2 Anthropogenic Climate Change

Anthropogenic climate change is the result of substantial human activity modifications to the Earth's climate system, in addition to natural variability. The burning of fossil fuels, deforestation, and industrial operations release greenhouse gases such carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) that intensify the greenhouse effect and cause global warming and modifications to climate patterns. Rising sea levels, altered precipitation patterns, and more frequent and severe extreme weather events are all consequences of these changes, which further aggravate natural climate variability.

### 2.4.3 Impacts of Climate Variability

Climate variability has profound impacts on human societies, economies, and ecosystems. Extreme weather events such as heatwaves, droughts, floods, and storms can cause loss of life, property damage, disruptions to food and water supplies, and adverse effects on agriculture, infrastructure, and public health. Changes in temperature and precipitation patterns also affect ecosystems, leading to shifts in species distributions, phenology, and biodiversity loss.

### 2.4.4 Adaptation and Mitigation Strategies

Adaptation and mitigation methods are critical to addressing the difficulties presented by climate variability and change. Adaptation refers to the process of making changes to environmental and societal systems in order to increase resilience and decrease susceptibility to climate change. This could entail putting early warning systems into place, enhancing water management techniques, creating agricultural varieties resistant to drought, and protecting natural habitats. Mitigation is the process of lowering greenhouse gas emissions and slowing down global warming by putting policies in place to support sustainable land use and transportation, switching to renewable energy sources, and increasing energy efficiency.

Like in the rest of the world, climate change is already taking place in Uganda, and their effects are being felt (Mugeere *et al.,* 2021). Temperature and rainfall are the two climate variables having the most economic and social impact; the latter is more concerning than the former.

In Kabale, the average yearly rainfall falls between 500 and 2300 millimeters. Altitude and exposure to moisture-laden winds have a major impact on it. Due to the influence of southeast winds that bring rainfall, the southeast slopes of Lake Bunonyi in the Districts of Kisoro and

Kanungu get an average of up to 2200 mm of precipitation annually at an altitude of roughly 2500 m. (UNMA, 2018). Rainfall reduces as altitude rises because the trade wind inversion has less moisture in it. At lower elevations, the yearly average rainfall drops, reaching an average of 1600 mm at 1600 meters. Rainy seasons become significantly shorter at this altitude, with an average annual rainfall of less than 1000mm. Less than 650mm of rain falls on average a year in the hot, dry, lower zones. Other significant factors are air temperatures and evaporation rates. (UNMA, 2018).

## 2.5 Climate Change

The term "climate change" describes substantial, long-term changes to Earth's climate patterns, which often take decades to millions of years to manifest. These changes can include variations in temperature, precipitation, wind patterns, and other indicators. (IPCC, 2014). It encompasses both natural variations and human-induced alterations to the Earth's atmospheric composition and surface conditions. Human activities, the rate of climate change has accelerated due to the release of greenhouse gases, namely carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$). This has resulted in global warming and other disruptive impacts on the environment and ecosystems. (IPCC, 2014). Climate change is a complex and multifaceted phenomenon with wide-ranging impacts on weather patterns, sea levels, biodiversity, ecosystems, agriculture, and human societies (IPCC, 2014), posing significant challenges to sustainable development and necessitating coordinated efforts to mitigate its effects and adapt to its consequences.

Climate change, predominantly resulting from human endeavors like fossil fuel combustion and deforestation, stands as one of the most urgent issues of our day. (IPCC, 2014; Steffen *et al.,* 2018). This literature review aims to provide an overview of the current understanding of climate change, including its impacts on the environment and society, adaptation strategies, and mitigation efforts.

The concept of climate change dates back to the early 19th century when scientists began to recognize the potential impact of human activities on the Earth's climate (IPCC, 2014; Fleming, 2010). However, it wasn't until the late 20th century that climate change became a major focus of scientific research and public concern. The establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 played a crucial role in bringing together scientists and policymakers to assess the state of climate science and its implications for society.

## 2.6 Drivers of Climate Change

The main cause of climate change is human activity, including the burning of fossil fuels for energy and deforestation, which increases greenhouse gas emissions, especially those of carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) (IPCC, 2014). Changes in weather patterns and global warming are caused by these gases' ability to trap heat in the Earth's atmosphere. In addition to natural phenomena like solar radiation and volcanic eruptions, industrial activity and changes in land use are also major contributors to climate change.

### 2.6.1 Evidence of Climate Change

The evidence of climate change is supported by altered precipitation patterns, melting glaciers and ice caps, rising sea levels, and an increase in the frequency of extreme weather events including heat waves, droughts, and storms (IPCC, 2014).

### 2.6.2 Impacts of Climate Change

The environment, ecosystems, and human society are all significantly impacted by climate change (IPCC, 2014; Haines *et al.*, 2021). Crop failures, water shortages, and higher food costs are the results of rising temperatures and shifting precipitation patterns, which also have an impact on agricultural production, water resources, and food security. In addition to posing a hazard to coastal infrastructure and communities, extreme weather events also result in fatalities, property damage, and disruptions to lives and economies.

### 2.6.3 Adaptation to Climate Change

Adaptation refers to efforts to adjust to the impacts of climate change and reduce vulnerability to its effects (IPCC, 2014; Ford *et al.*, 2018). Adaptation strategies include building resilient infrastructure, improving water management practices, developing drought-resistant crop varieties, and implementing early warning systems for extreme weather events. Successful adaptation requires collaboration between governments, communities, businesses, and civil society organizations to identify and implement effective solutions.

### 2.6.4 Mitigation of Climate Change

Mitigation involves reducing greenhouse gas emissions to limit the magnitude of climate change (IPCC, 2014; Edenhofer *et al.*, 2014). This can be accomplished by taking steps like switching to renewable energy sources, enhancing building and transportation energy efficiency, protecting forests and other carbon sinks, and putting regulations like carbon pricing and emissions trading into place. International accords like the Paris Agreement offer a structure for nations to synchronize their efforts to mitigate climate change and strive towards shared objectives.

### 2.6.5 Climate Change and Carbon Stocks in Wetlands

Climate change has significant implications for carbon stocks in wetlands, influencing processes such as carbon sequestration, decomposition, and greenhouse gas emissions. Empirical studies have provided valuable insights into these impacts across different types of wetlands and geographic regions.

### 2.6.6 Carbon Sequestration

Wetlands play a crucial role in carbon sequestration, acting as important sinks for atmospheric carbon dioxide (CO2). For example, Neubauer *et al.* (2021) conducted a study and found that wetlands sequester large amounts of carbon in soil organic matter, particularly in peatlands and mangrove forests. Similarly, Bastviken *et al.* (2011) conducted a study in boreal and subarctic peatlands and observed substantial carbon accumulation rates, highlighting the importance of these ecosystems for climate change mitigation.

### 2.6.7 Decomposition Dynamics

Climate change can influence the decomposition of organic matter in wetlands, affecting carbon cycling and storage. For instance, Fenner *et al.* (2019) conducted a study in tropical peat swamp forests and found that increased temperatures and drought stress can lead to higher rates of carbon loss through microbial decomposition.

### 2.6.8 Greenhouse Gas Emissions

Changes in temperature, precipitation, and hydrological regimes associated with climate change can affect greenhouse gas emissions from wetlands, including methane (CH4) and nitrous oxide (N2O). Bridgham et al. (2013) conducted a review of studies on greenhouse gas fluxes from wetlands and found that warming and changes in water table depth can alter microbial processes and lead to increased methane emissions. Similarly, Joabsson *et al.* (2004) studied the impacts of drainage and rewetting on greenhouse gas emissions from boreal peatlands and observed significant changes in methane and nitrous oxide fluxes.

### 2.6.9 Feedback Mechanisms

Climate change can also trigger feedback mechanisms that further influence carbon stocks in wetlands. For example, Song *et al*. (2012) conducted a study in coastal wetlands and observed that sea-level rise and saltwater intrusion can lead to changes in vegetation communities and carbon storage.

In sum, the empirical literature on the effects of climate change on carbon stocks in wetlands underscores the critical role of these ecosystems in global carbon cycling and climate regulation. Wetlands serve as significant carbon sinks, sequestering atmospheric carbon dioxide through the accumulation of organic matter in soil and biomass. However, climate change poses multifaceted challenges to the carbon dynamics of wetlands, influencing processes such as decomposition, greenhouse gas emissions, and feedback mechanisms.

The observed and projected impacts of climate change on wetland carbon stocks highlight the urgent need for proactive conservation and management strategies. While wetlands have the potential to mitigate climate change by storing carbon, they are also vulnerable to environmental stressors associated with climate change, such as warming temperatures, altered precipitation patterns, and sea-level rise. These stressors can accelerate carbon loss through enhanced decomposition, increased greenhouse gas emissions, and changes in vegetation composition.

Addressing the challenges posed by climate change to wetland carbon stocks requires interdisciplinary approaches that integrate ecological, hydrological, and climatological perspectives. Conservation efforts should focus on preserving wetland ecosystems and restoring degraded habitats to enhance carbon sequestration potential. Furthermore, adaptive management strategies are needed to mitigate the impacts of climate change on wetlands, such as implementing sustainable land use practices, promoting reforestation and afforestation initiatives, and enhancing wetland protection and restoration efforts.

Overall, the preservation of wetland carbon stocks is essential not only for mitigating climate change but also for maintaining the ecological integrity, biodiversity, and ecosystem services provided by wetland ecosystems. Continued research, monitoring, and collaboration are crucial for advancing our understanding of the complex interactions between climate change and wetland carbon dynamics and for developing effective strategies to safeguard these valuable ecosystems for future generations.

## 2.7 Climate Change and Water Resources

Every society's social, economic, and environmental fabric is intricately linked to water as a resource. Consequently, the entire socio-economic system will be impacted by changes in its amount, quality, distribution, availability, and/or accessibility. Uganda's economy is extremely vulnerable to the hydrological cycle, and if climate change materializes as expected, the whole socioeconomic system would be affected (Kilimani, N., 2015).

As previously mentioned, projected climate change implies that Uganda would probably have higher temperatures along with a 5–20% increase in rainfall (IPCC, 2001). Rather than being primarily influenced by normal variations, the overall effects of these changes on the water resources will mostly be determined by increases in the intensity and frequency of extreme climatic events like droughts and floods (Kilimani, N., 2015). Rainfall-recharged wetlands, which are vital grazing grounds for pastoralists, could be seriously harmed by rising temperatures as they may completely disappear or dramatically reduce in size.

Higher evaporation rates in most of the rift Valley lakes could lead to additional solute concentration, which would raise salinity and lower water quality. As has been seen at Lake Bunyonyi, where changes in the species of the algae (Spirulina platensis) that birds feed on have an impact on bird populations, such changes may cause significant changes in the species composition of dominant biological communities. There is already much agitation around the increasing drying and pollution of lakes and predicted climate change is only going to make matters worse. Reduced water availability, quality, and quantity invariably lead to increased disputes over resource user rights (Bluemel, E. B., 2004). Increased soil moisture storage, an increase in the average water level in lakes, rivers, and groundwater resources, as well as an increase in runoffs, erosion, sediment load, and other related phenomena, may be observed in places where an increase in rainfall is anticipated. Water quality will inevitably decline. The entire impact of the predicted climate change on water resources is not yet fully understood from a scientific, social, or economic standpoint, like other sectors. (Kilimani, N., 2015). On the other hand, it is well known that the degree of community readiness and the management of the changes will determine how big an impact they have. Global water resource availability, distribution, and quality are all significantly impacted by climate change (Hussain *et al.*, 2021).

Numerous empirical investigations have offered substantial proof of these effects in various water systems and geographical areas. Climate change has significant implications for the availability, distribution, and quality of water resources worldwide (Hussain *et al.*, 2021).

Empirical studies have provided extensive evidence of these impacts across different regions and water systems.

### 2.7.1 Water Availability

Climate change influences the hydrological cycle, leading to changes in precipitation patterns, snowmelt, and evaporation rates, which in turn affect water availability. For example, El Jeitany *et al., (*2024) conducted a global analysis and found that climate change is likely to result in alterations in river flow regimes, with implications for water availability for irrigation, drinking water supply, and ecosystem functioning. Similarly, Miller *et al.,* (2021) studied the impacts of climate change on water resources in the western United States and observed changes in the timing and magnitude of streamflow, affecting water supply reliability and water management strategies.

### 2.7.2 Water Distribution

Changes in temperature and precipitation patterns associated with climate change can lead to shifts in the spatial distribution of water resources. For instance, Hunink *et al.,* (2019) conducted a study in Europe and observed changes in the distribution of river flows, with implications for water allocation among different sectors and regions. Additionally, Tariku *et al.,* (2021) studied the impacts of climate change on water availability in Africa's Nile Basin and identified potential shifts in the distribution of water resources, which could exacerbate water stress in downstream regions.

### 2.7.3 Water Quality

Climate change can also influence water quality by altering water temperature, nutrient levels, and the frequency of extreme events such as floods and droughts. For example, Smith et al. (2015) conducted a meta-analysis of studies worldwide and found that climate change-induced increases in water temperature can promote the growth of harmful algal blooms, leading to water contamination and public health risks. Similarly, Hossain et al. (2019) studied the impacts of climate variability on water quality in Bangladesh's coastal areas and observed changes in salinity levels and the intrusion of seawater, affecting freshwater resources and agricultural productivity.

### 2.7.4 Water Management

Water management is challenged by climate change practices, including water allocation, infrastructure planning, and drought preparedness. For instance, Brown et al. (2015) studied the adaptation strategies of water utilities in the United States to climate change impacts and identified investments in water storage and conservation measures as key strategies to enhance resilience. Additionally, Hirabayashi *et al.*, (2013) conducted a study in Asia and observed the importance of integrated water resources management approaches for adapting to climate change impacts such as changes in flood frequency and magnitude.

The anticipated impacts of climate change on water resources in Uganda and globally are multifaceted, ranging from alterations in water availability and distribution to changes in water quality and management practices. The interconnectedness of water with social, economic, and environmental systems underscores the significance of these anticipated changes, which are expected to have far-reaching implications across various sectors of society.

As highlighted by empirical studies, changes in precipitation patterns, snowmelt, and evaporation rates driven by climate change will likely result in alterations in river flow regimes and water availability for irrigation, drinking water supply, and ecosystem functioning. Moreover, shifts in the spatial distribution of water resources may exacerbate water stress in certain regions, impacting water allocation among different sectors and exacerbating conflicts over water resources. Additionally, changes in water temperature, nutrient levels, and the frequency of extreme events such as floods and droughts are expected to affect water quality, leading to contamination and public health risks.

Furthermore, climate change poses challenges for water management practices, including water allocation, infrastructure planning, and drought preparedness. Adaptation strategies such as investments in water storage and conservation measures, as well as integrated water resources management approaches, will be crucial for enhancing resilience to climate change impacts on water resources.

Despite the wealth of empirical evidence on the anticipated impacts of climate change on water resources, several research gaps remain. Firstly, there is a need for further research to understand the specific vulnerabilities and adaptive capacities of different water-dependent sectors and communities in Uganda and other regions. Additionally, more comprehensive studies are required to assess the effectiveness of adaptation strategies and to identify innovative approaches for mitigating the impacts of climate change on water resources. In conclusion, while the full magnitude of the impacts of climate change on water resources is yet to be fully understood, proactive measures and interdisciplinary collaborations are essential for addressing the challenges posed by climate change and ensuring the sustainable management of water resources for current and future generations.

## 2.8 Climate Change and Soil

Reviewing literature on the effect of climate change on soil reveals a range of significant impacts on soil properties, processes, and functions. Here's an overview with in-text citations and references:

### 2.8.1 Changes in Soil Temperature and Moisture

Climate change alters soil temperature and moisture regimes, influencing microbial activity, nutrient cycling, and soil organic matter decomposition (Medhi *et al.,* 2021). Warmer temperatures accelerate soil organic matter decomposition rates, leading to increased CO2 emissions (Navarro-Pedreño *et al.*, 2021). Changes in precipitation patterns affect soil moisture levels, potentially leading to drought stress or waterlogging in certain regions (Chen *et al.,* 2019).

### 2.8.2 Soil Erosion and Degradation

Intensified rainfall events and extreme weather events associated with climate change contribute to soil erosion and degradation (Borrelli et al., 2020). Increased runoff and flooding can wash away topsoil and nutrients, reducing soil fertility and productivity (Hooke & Martin-Duque, 2012). Soil erosion also exacerbates sedimentation in water bodies, leading to water quality issues and habitat degradation (Bryan *et al.,* 2013).

### 2.8.3 Shifts in Soil Carbon Dynamics

Climate change influences soil carbon dynamics, including carbon sequestration and emissions (Conant *et al.,* 2017). Warmer temperatures and prolonged growing seasons may enhance plant productivity and carbon inputs to soil, potentially increasing carbon sequestration rates in some ecosystems (Yang *et al.,* 2019). However, these gains may be offset by increased microbial activity and soil respiration under warmer conditions, leading to higher CO2 emissions (Yang *et al.*, 2019).

### 2.8.4 Alterations in Soil Microbial Communities

Climate change affects soil microbial communities and their functions, with implications for nutrient cycling and soil fertility (Bardgett & van der Putten, 2014). Changes in temperature and moisture regimes influence microbial biomass, diversity, and activity (Frindte *et al.*, 2019). Shifts in microbial community composition may affect nutrient availability and plant-soil interactions, ultimately influencing ecosystem productivity and resilience (Bardgett & van der Putten, 2014).

### 2.8.5 Impacts on Soil Biodiversity and Ecosystem Services

Climate change poses risks to soil biodiversity and the delivery of ecosystem services (Orgiazzi *et al.*, 2016). Soil organisms, including earthworms, microarthropods, and soil microbes, play critical roles in nutrient cycling, soil structure formation, and plant health (Eisenhauer *et al.*, 2017). Changes in temperature, moisture, and disturbance regimes can disrupt soil biota communities, compromising ecosystem functions and resilience (Eisenhauer *et al.*, 2017).

Literature on the effect of climate change on soil highlights the complex interactions between climate variables, soil properties, and ecosystem processes. While climate change poses significant challenges to soil health and functionality, there are also opportunities for adaptation and mitigation through sustainable land management practices and ecosystem restoration efforts.

The literature on the effect of climate change on soil highlights the intricate interplay between climatic variables, soil properties, and ecosystem processes. Through comprehensive studies, it is evident that climate change exerts profound and multifaceted impacts on soil dynamics, which have far-reaching consequences for ecosystem health and resilience.

One of the primary findings is the alteration of soil temperature and moisture regimes due to climate change. These changes significantly influence microbial activity, nutrient cycling, and soil organic matter decomposition. Warmer temperatures accelerate decomposition rates, leading to increased $CO_2$ emissions, while changes in precipitation patterns can result in drought stress or waterlogging in certain regions. Such alterations in soil conditions can disrupt soil fertility and productivity, posing challenges for agricultural systems and ecosystem functioning.

Furthermore, climate change exacerbates soil erosion and degradation processes, particularly through intensified rainfall events and extreme weather events. Increased runoff and flooding wash away topsoil and nutrients, diminishing soil fertility and productivity. Soil erosion also contributes to sedimentation in water bodies, leading to water quality issues and habitat degradation. Addressing soil erosion and degradation is crucial for maintaining ecosystem services and sustaining agricultural productivity, especially in vulnerable regions.

Additionally, climate change influences soil carbon dynamics, with implications for carbon sequestration and emissions. While warmer temperatures and prolonged growing seasons may enhance carbon sequestration rates in some ecosystems, increased microbial activity and soil respiration under warmer conditions can offset these gains, resulting in higher $CO_2$ emissions. Understanding the factors driving soil carbon dynamics is essential for accurately predicting future carbon fluxes and informing climate change mitigation strategies.

Moreover, climate change affects soil microbial communities and biodiversity, with potential consequences for nutrient cycling, soil structure formation, and plant health. Changes in temperature, moisture, and disturbance regimes can alter microbial biomass, diversity, and activity, disrupting ecosystem functions and resilience. Investigating the resilience of soil microbial communities to climate change and identifying key microbial drivers of ecosystem functioning are critical research areas for advancing our understanding of soil dynamics under changing climatic conditions.

## 2.9 Climate Change and Livelihoods

The primary economic sectors—agriculture, energy, water, and health—are severely impacted by climate change, which makes achieving the MDGs and reducing poverty in Uganda and the surrounding area extremely difficult. Thus, it is essential to have a deep comprehension of how livelihood systems and climate change are interconnected. Thoroughly tracing the connections between various agricultural (crop and livestock) production systems and climatic variability/change is a crucial first step in this endeavor, especially for smallholder farmers. Individuals who primarily depend on their own agricultural output to meet most of their food needs are the most vulnerable groups. An estimated 7 million Ugandans were projected to be food impoverished in 1990. (Downing, 1992). This percentage has increased to almost 50% of the overall population as of late, and it will only go up as long as the population keeps growing and economic growth stays in the single digits. The impact of climate change will only exacerbate the dire socioeconomic issues now plaguing the nation. According to Downing (1992), the number of people without a sufficient supply of food would rise dramatically if both the cultivated and appropriate areas were reduced. Especially in the marginal agricultural areas, this is the most likely situation. The seven Ugandan community groupings listed below are the most susceptible to climatic variability and change, according to Downing (1992): pastoralists on the move who don't engage in agriculture face an 85%

food risk; 33% of food risk are agro pastoralists who frequently produce some crops;55% of food risk is associated with migrant farmers who maintain livestock on permanent farms; impoverished landless farmers who own little to no land and experience ongoing food insecurity (85% food risk);Squatters, or farmers occupying sizable public or absentee-owned estates without a valid claim to the property and without making any long-term investments in the land parcels, pose a 33% danger to food supply;50% of farmers in each province are smallholder farmers, meaning they own less than 20 hectares of land and pose a 29% food risk; additionally. Urban-poor – households with low incomes (e.g. casual labourers) inhabiting metropolitan areas like Kampala and mainly depend on open air markets for food (40% food risk).

Since there would be a decline in the ability to produce enough food, the vulnerable groups would likely expand as a result of the expected shortening of the food crop growing season. Climate change may also result in changes in the appropriateness of the land for different farming practices, which could lower agricultural productivity. For example, certain regions that currently grow primarily food crops (potatoes, beans, and corn) may switch to producing income crops like tea and coffee. A change this significant could jeopardize food security. However, variables other than climate change will determine how much of a change this is and how big an influence it has. (Portier *et al.*, 2013).

A wide range of human livelihoods are significantly impacted by climate change, from pastoralism and tourism to agriculture and fisheries. Numerous empirical investigations have offered convincing proof of these effects in various parts of the globe. Agriculture: Because of its effects on temperature, precipitation patterns, and the frequency of extreme weather events, climate change presents serious challenges to agricultural livelihoods. As an illustration, Lamptey *et al.,* (2022) conducted a study in Sub-Saharan Africa and discovered that crop yields have declined, especially in rainfed agricultural systems, as a result of rising temperatures and shifting rainfall patterns. In a similar vein, rising temperatures and altered precipitation patterns were found to have decreased wheat and maize yields in South Asia and Sub-Saharan Africa by Rosenzweig *et al.,* (2014).

### 2.9.1 Fisheries

Climate change affects marine and freshwater ecosystems, thereby impacting fisheries and the livelihoods dependent on them. Cheung *et al.,* (2010) conducted a global analysis and found that climate-driven changes in ocean temperature and productivity have resulted in shifts in fish distribution and abundance, affecting the livelihoods of fisher communities. Additionally, Barclay *et al.,* (2017) studied the impacts of climate variability on inland fisheries in Cambodia and observed fluctuations in fish catches and income, highlighting the vulnerability of small-scale fishers to climate change.

### 2.9.2 Tourism

Climate change can influence tourism patterns and destination attractiveness, thereby affecting livelihoods reliant on tourism revenues. Gössling *et al.,* (2012) conducted a meta-analysis of studies across various regions and found that climate change impacts such as rising temperatures, sea-level rise, and extreme weather events can lead to shifts in tourist preferences, affecting destinations' competitiveness and the income of tourism-dependent communities. Similarly, Hall *et al.,* (2015) studied the vulnerability of tourism in the Caribbean to climate change impacts and identified potential economic losses due to coral reef degradation and beach erosion.

Pastoralism: Climate change poses challenges to pastoral livelihoods by affecting the availability and quality of grazing resources and water sources. Opiyo *et al.*, (2016) conducted a study in East Africa and observed changes in rainfall patterns and temperature variability, leading to shifts in vegetation cover and the timing of seasonal migrations, which impact pastoralists' livestock management practices and food security. Furthermore, Stenseth *et al.*, (2022) studied the vulnerability of Mongolian pastoralists to climate change and observed increased livestock mortality and decreased productivity due to extreme winter conditions and summer droughts.

These empirical studies provide evidence of the diverse and significant impacts of climate change on various livelihoods worldwide. Understanding these impacts is essential for developing effective adaptation strategies to enhance the resilience of communities' dependence on these livelihoods.

## 2.10 Different Types of Wetlands

Wetlands are diverse and dynamic ecosystems that play crucial roles in maintaining biodiversity, regulating water cycles, providing habitat for wildlife, and offering numerous ecosystem services (Mitsch & Gosselink, 2015). Understanding the different types of wetlands is essential for effective conservation and management strategies. Here's a summary of the main types of wetlands:

### 2.10.1 Peatlands

Peatlands are wetlands characterized by the accumulation of partially decayed organic matter (peat) under waterlogged conditions (Omar *et al.*, 2022). They include bogs, fens, and mires. Bogs are nutrient-poor acidic wetlands dominated by sphagnum mosses, while fens are nutrient-rich wetlands fed by groundwater with a higher pH. Peatlands store vast amounts of carbon, making them significant in climate regulation.

### 2.10.2 Marshes

Marshes are wetlands characterized by periodically or continuously inundated soil, supporting emergent vegetation such as reeds, rushes, and sedges (Mitsch & Gosselink, 2015). They are found in both freshwater and saltwater environments and serve as important habitats for waterfowl, fish, and other wildlife.

### 2.10.3 Swamps

Swamps are wetlands characterized by saturated soil and standing water, often dominated by trees or shrubs adapted to waterlogged conditions (Sharma *et al.,* 2021). They can be freshwater or saltwater and occur in a variety of climates worldwide. Swamps provide important habitat for diverse flora and fauna, including migratory birds, amphibians, and mammals.

### 2.10.4 Riparian Wetlands

Riparian wetlands are transitional zones between terrestrial and aquatic ecosystems, found along the banks of rivers, streams, lakes, and estuaries (Pandey *et al.,* 2022). They are influenced by fluctuating water levels and support a diverse array of plant and animal species adapted to both wet and dry conditions.

### 2.10.5 Tidal Wetlands

Tidal wetlands, also known as estuarine wetlands, occur in coastal areas and are influenced by the ebb and flow of tides (Barbier *et al.,* 2011). They include salt marshes, mangrove forests, and tidal flats. Tidal wetlands provide important habitat for marine and terrestrial species, protect coastlines from erosion and storm surges, and serve as nurseries for fish and shellfish.

## 2.11 Existing Carbon Stocks in Different Wetland Types

One of the world's ecosystems with the highest carbon content is tropical wetlands. Many mangroves and tidal marshes have extraordinarily large carbon stocks in their organic-rich soils, sometimes two or three times larger than those found in most terrestrial forests. (Sreelekshmi, 2022). Because of their potential for extraordinarily high carbon stores, coastal wetlands would be a useful tool for mitigating climate change if they were preserved and restored. Quantification of carbon stocks is necessary to determine emissions or sequestration over time when including coastal ecosystems into mitigation measures. (McNeill *et al.,* 2014). Changes in land use have significantly impacted the carbon fluxes and stores in wetlands. Wetland draining and the ensuing conversion to forestry or agriculture cause organic waste that was once kept under anaerobic circumstances to decompose at significantly faster rates, which can release significant amounts of carbon into the atmosphere (Uwimana, 2019). Depending on the kind of wetland and peat, different rates of organic matter decomposition occur when wetlands are converted to other land uses (Bai *et al.*, 2013; Zauft *et al.,* 2010). According to reports for the wetlands of North America, peat lands changed to other land uses exhibit higher rates of decomposition and hence larger C loss than mineral soil wetlands, which may lose very little carbon as a result of land-use change (Loder *et al.,* 2020).

The amount of carbon thought to be stored in natural wetlands and the effect that land-use alteration has on these stocks are still very much up in the air. Reducing the level of uncertainty surrounding carbon stocks in wetlands is therefore imperative. Peat areas have been the primary subject of reports about carbon stocks (Yu 2012; Loisel *et al.,* 2014). It has been estimated that peat areas in the north with a temperate climate contain 500 ± 100 Gt C (Yu 2012). However, Loisel *et al.,* (2014) pointed out that there can be a lot of error surrounding these estimations (between 234 and 547 GtC) due to the various calculation techniques used as well as the high level of uncertainty surrounding bulk densities and depth. The most recent estimate, according to Loisel *et al.,* (2014), was 436 Gt C.

Although variations have been documented between fens and bogs, these calculations were based on the assumption that all the peat lands had a single carbon density value (Loisel *et al.*, 2014). Information on mineral soils is limited, with the exception of Loder *et al.,* 2020, who compiled data on area and carbon pools to suggest the first carbon balance for wetlands with both organic and mineral soils in North America. In addition, little data indicate that carbon stocks in mineral soil wetlands vary greatly (12–557 t/ha, Page and Dalal, 2011). Overall, several assumptions about soil depth and carbon concentrations are acknowledged in the majority of investigations.

Currently, inland wetlands make up less than 1% (250,000 ha) of the world's total land area (Ausseil *et al.,* 2011a). Since Europeans began to settle in North America in the 1840s, more than 90% of the original wetland area has been destroyed as a result of land-use conversion (mostly through drainage for agricultural use). Wetland losses are still happening, according to recent regional analyses (Pompei and Grove 2010; Ausseil *et al.,* 2011), and this could be a substantial source of atmospheric carbon release. It has been challenging to estimate the national carbon loss from wetlands converted to agriculture because there is a dearth of data on the amount of carbon stored in wetlands. The National Greenhouse Gas Inventory computes changes for mineral wetland soils.

## 2.12: Effects of Land Use and Land Cover Changes on Wetland Plant Communities

One major element changing the land surface is anthropogenic land-use and land-cover change (LULCC) (Mohibul *et al.,* 2024). LULC are two separate yet connected characteristics of the Earth's surface. According to Mahendra *et al.,* (2024), a LULC change is any modification made to the existing land cover or a whole conversion of the land cover to a new type of cover. Land use change is the term used to describe how human activity results in changes in land use for a range of purposes, including transportation and production, parks, farming, settlement, recreational usage, mining, and fishing (Kumi, 2024). LULC alterations may be influenced by underlying (indirect) or proximate (direct) driving stimuli (Melaku *et al.,* 2024). The former are unsustainable land management practices and biophysical variables.

Despite making up only 9% of the world's surface area, wetlands provide high-value ecological functions that contribute roughly 23% of the value of ecosystem services worldwide (Costanza *et al.,* 2014; Xiong *et al.,* 2024). In addition to providing a variety of ecosystem services, such as water, grazing for animals, harvestable resources, carbon storage, and crop production, the wetlands are rich in plant diversity (Chatanga & Seleteng-Kose, 2021). Wetland plant communities are essential to these generally productive environments, even if wetlands are also home to a wide variety of animals (Singh *et al.,* 2024). Wetland plant communities are essential to the preservation of these processes, but human landscape alterations like road construction and deforestation are thought to be posing an increasing threat to these communities. A few factors endangering the integrity of natural wetlands include conversion to cropland, urban built-up areas and infrastructure, pollution of the air and water, eutrophication, increasing nutrient concentration, invasive plants, diversion of wetland tributaries, construction of dams and irrigation canals, use of chemical farm inputs, drought, intensive exploitation, and unsustainable management. According to Wang *et al.*, (2022), the main driver of wetland degradation has been found to be human disturbance, which can be immediately indicated by changes in plant communities.

Changes in land use in wetlands cause dominant species of wetland vegetation to be replaced, altering the species diversity and features of plant communities (Wan *et al.,* 2024). In southwest China, the land use structure had seen mutual conversion between farmland and marsh, with decreased plant species variety and evenness, as demonstrated by Mu, Wen & Zhang *et al.,* (2024). However, as noted by Boru *et al.*, (2024), disturbances brought about by pollution, overgrazing, drainage, and farming enhanced species diversity by generating a variety of habitats that were welcoming to invasive species. These findings concur with those of Takuwa *et al.,* (2024), who reported a considerable increase in the total species richness of plants due to wetland degradation. This result tends to imply that a number of new species appear as secondary vegetation after degradation DeBerry and Hunter (2024),

### 2.13 Assessment of Land Use and Land Cover (LULC) Changes

The investigation of wetland transformations and the factors that propel them is essential to attaining sustainable socioeconomic growth. Despite this, Peng *et al.,* (2024) highlights the lack of sufficient study being done on the factors that drive changes in wetland areas, indicating a large research vacuum. In response, researchers have created several indicators and techniques to study wetland dynamics across time, including conversion matrices and landscape indices (Zhang *et al.,* 2021). Remote sensing (Braimoh, 2006), statistical analysis (Fischer *et al.,* 2002), local actor interviews (Mertz *et al.*, 2009), and/or a mix of these techniques are frequently used to determine the factors influencing changes in Land Use and Land Cover (LULC) (Antwi-Agyei *et al.,* 2012). Although these techniques successfully identify particular features of wetland changes, they often fall short in fully capturing the complexity of wetland degradation or restoration due to the diverse and intricate nature of wetlands.

But novel approaches to filling these research gaps in wetland classification have been made possible by notable advances in geo-computation and geospatial artificial intelligence (GeoAI) (Husman *et al.,* 2024). Furthermore, Kirk *et al.,* (2024) evaluated plant diversity at three different levels: alpha diversity within sampling quadrats, beta diversity indicating species turnover among local sites, and gamma diversity across the region. Whittaker's hierarchical biodiversity framework was utilized for this purpose.

This study used a mixed-methods approach, integrating ground truthing, remote sensing, and GIS to investigate the vegetation dynamics of Uganda's Kanyabaha Wetland over a three-decade period (1990–2021). During the data collecting process, quadrats were used to sample the vegetation and gather environmental factors (soil, disturbance). Plot-scale vegetation study was conducted using the traditional quadrat method (Brandt *et al.,* 2015). VečeŞa *et al.,* (2021) pointed out that although the quadrat approach has its uses, it might not accurately depict the regional landscape patterns of wetlands. On the other hand, promising technologies for mapping landscapes are unmanned aerial vehicles (UAVs) and remote sensing.

### 2.14: Drivers of Utilization of Wetland Resources

The Ramsar Convention Secretariat (2021) estimates that the value of wetland ecological services to human health, wellbeing, and security is about £35.5 trillion annually on a worldwide scale. Poor farming practices have, however, impacted wetland health over time by negatively altering wetland ecosystems. In a 2013 study, Vermaat et al. conducted a meta-analysis of 105 wetland study cases and found that the primary proximate cause of wetland conversion has been agricultural development, with population density and economic growth being the most commonly recognized underlying drivers. In order of significance, the following significant factors explain wetland conversion: agricultural or built-up area, mean annual temperature, total wetland area, and market effect.

Munishi *et al.,* (2014) state that the conversion of wetlands into agricultural land and the growing human population are the main causes of the use of wetland resources in many parts of Uganda. Wetland areas around the world are still under threat from inappropriate grazing regimes and stocking rates linked to rising livestock populations, increased irrigation activities, and a lack of effective wetland management policies and strategies. This is causing changes in the goods and services derived from wetland resources (URT, 2007).

Nowadays, disputes between farmers and livestock keepers are frequent in Uganda, particularly in wetlands that appeal to both farmers and pastoralists. This is because there is a greater demand for land for agriculture, cattle grazing, food production, and revenue generating as a result of an increasing human population. Due to overexploitation, this demand has caused significant degradation of wetlands (Kashaigili *et al.*, 2006).

Wetland areas are being invaded by multiple cultures worldwide, including both native farmers and immigrant livestock keepers. The numerous uses of the rivers and the lack of funding and manpower for effective management of water resources pose a threat to the preservation of wetlands and their ecological variety. Furthermore, wetlands management programs across the nation have faced extra difficulties due to people's relationships with the environment. Urbanization, industrial expansion, and population growth are a few other factors that have been shown to act as drivers of wetland degradation. The lack of a particular wetland policy contributes to the inadequate application of current wetland-related legislation, placing wetlands under strain from anthropogenic activities that degrade them. The lack of an institutional framework with proper structure OF institutional framework creates a loophole through which various factors driving wetland degradation can exert severe consequences in numerous regions worldwide. Let us examine key drivers of land use change in Uganda.

### 2.14.1 Human Population Growth

One of the main causes of wetlands being invaded for settlement, agriculture, and other purposes is the increasing population. According to the 2014 Ugandan population census, the country's population nearly tripled from 12.6 million in 1980 to 34.8 million in 2014, expanding at a rate of 3.2 percent annually (UBOS, 2014). With a 6.6 percent urbanization rate in 2014, the nation has been quickly urbanizing (UBOS, 2014). Due to the increasing population, there is a great demand for land, which puts a great deal of strain on wetland ecosystems, food supplies, medical research, fuel wood, clay mining for bricks, and other raw commodities.

### 2.14.2 Socio-economic Pressures

Lwasa (2005) asserts that there is a strong correlation between the extent of wetlands invasion and variables such built-up area and road proximity, market influence, and population density and accessibility to markets. Roads next to wetlands make it simple to move goods from wetlands to marketplaces. By allowing investors and even government organizations to get licenses to develop wetlands, inaccurate development plans may on occasion encourage the degradation of wetlands.

### 2.14.3 Industrial Development

Wetlands have always been viewed as vast, unrestricted, cheap territory that is available for development. The 1972 Kampala Development Plan, which set aside wetlands for industrial development, allowed wetlands to expand. Industries stress wetlands in a number of ways, including drainage for infrastructural growth and heavy pollutant loads

### 2.14.4 Managing Wetlands

The Ministry of Water and Environment's Wetlands Management Department (WMD) is responsible for overseeing wetlands in Uganda. The WMD management strategy combines sustainable usage with conservation objectives to guarantee that people will continue to gain from the goods and services that wetlands offer. Eight catchment systems, or drainage basins, have been established to effectively manage the nation's wetlands. The main human reasons causing the degradation of these wetlands are pressure from the population, political meddling, and the necessity to support livelihoods. Soil erosion causes the wetlands to become silted due to cultivation and communities being built up to the lakeshores. While the retreating lake levels are believed to be caused by climate change, deterioration of the fringing wetlands further complicates the situation. The use of pesticides and fertilizers in agriculture has contributed to water pollution and has led to changes in the nutrient levels in the lake leading to algal proliferation (Natugonza *et al.,* 2021). Siltation is having multiple impacts including shrinkage in the lake depth and declining quality of water. This interferes with fish breeding and refuge sites for juvenile fish, affects other aquatic biodiversity and ultimately impacting the productivity of the lake. Fish output has been reducing for instance, from 5,600 tons in 2010 to 4,590 tons in 2014 (UBOS, 2015).

## 2.15 The Adaptation Strategies Adopted by Local Residents to Cope with Adverse Impacts of Changing Climate

Inland wetlands, characterized by their unique hydrological and ecological features, play a crucial role in climate change mitigation and supporting sustainable livelihoods in various regions worldwide. In the context of Rukiga District, Uganda, these ecosystems are of particular importance due to their contributions to local economies, biodiversity conservation, and climate regulation. However, the adverse impacts of climate change pose significant challenges to the sustainability of inland wetlands and the livelihoods dependent on them. Understanding the role of inland wetlands in mitigating climate change and supporting sustainable livelihoods is essential for developing effective adaptation strategies to address these challenges.

Climate Change and Inland Wetlands: Inland wetlands act as natural carbon sinks, sequestering carbon dioxide from the atmosphere and thereby mitigating climate change (Davidson et al., 2015). The vegetation and soils of wetlands store large amounts of carbon, preventing it from being released into the atmosphere as greenhouse gases. Additionally, wetlands play a crucial role in regulating local and regional climates by moderating temperatures and influencing precipitation patterns (Ramsar Convention Secretariat, 2018). However, climate change poses significant threats to inland wetlands, including altered hydrological patterns, increased frequency of extreme weather events, and habitat degradation (Davidson *et al.*, 2015).

Sustainable Livelihoods Dependent on Inland Wetlands: The communities rely heavily on inland wetlands for their livelihoods, including agriculture, fishing, and tourism. Wetlands provide fertile soils for agriculture, support diverse aquatic ecosystems that sustain fisheries, and attract tourists seeking nature-based experiences (Nabalegwa *et al.*, 2019). However, the impacts of climate change, such as changes in rainfall patterns and increased frequency of droughts and floods, threaten the sustainability of these livelihoods (Nabalegwa *et al.*, 2019). Local communities facing the impacts of climate change on inland wetlands have implemented diverse adaptation strategies to safeguard their livelihoods and ecosystems. These strategies, observed across different regions, include:

Diversification of livelihoods: Recognizing the vulnerability of single income sources to climate variability, communities have diversified their livelihood activities. For instance, in the Mekong Delta, Vietnam, farmers have diversified their crops to include salt-tolerant varieties and aquaculture to adapt to increased salinity due to sea-level rise (Nguyen *et al.*, 2020). By spreading their sources of income, communities can better withstand the fluctuations in climate that affect specific sectors.

Climate-smart agricultural practices: Farmers and landowners have adopted climate-smart agricultural techniques to enhance the resilience of their farming systems. In Sub-Saharan Africa, smallholder farmers have implemented conservation agriculture practices such as minimum tillage and mulching to conserve soil moisture and improve soil fertility (Tittonell & Giller, 2013). In Uganda, smallholder farmers have implemented techniques such as agroforestry, crop rotation, and integrated pest management to adapt to changing climatic conditions (Nabalegwa *et al.*, 2019). Similarly, in Kenya, farmers have adopted conservation agriculture practices such as minimum tillage and cover cropping to conserve soil moisture and improve soil health (Kassie *et al.*, 2019). By implementing these techniques, communities can reduce vulnerability to extreme weather events and maintain agricultural productivity.

Community-based natural resource management: Local communities have established community-based organizations and initiatives for the sustainable management of inland wetlands. For example, in the Sundarbans mangrove forest of Bangladesh, community-based co-management approaches have been implemented to regulate fishing activities and conserve biodiversity (Islam & Haque, 2018). In Uganda's Rwenzori Mountains, community-based conservation efforts have led to the restoration of degraded wetlands and the promotion of sustainable fishing practices (Plumptre *et al.*, 2014). Similarly, in Zambia's Kafue Flats, community-based management of fisheries has contributed to the conservation of wetland ecosystems and the enhancement of livelihoods (Kumwenda *et al.*, 2018). By actively participating in the management of their natural resources, communities can enhance the resilience of ecosystems and livelihoods.

Infrastructure development and disaster preparedness: Communities have invested in infrastructure development and disaster preparedness measures to mitigate the impacts of climate-related hazards. In the Netherlands, coastal communities have constructed dikes and sea walls to protect against sea-level rise and storm surges (Howard *et al.*, 2018). In Uganda, communities living in flood-prone areas have constructed raised platforms for housing and elevated latrines to minimize damage during floods (Nabalegwa *et al.*, 2019). Similarly, in Ethiopia, communities have built stone terraces and check dams to reduce soil erosion and mitigate the impacts of flash floods (Teferi *et al.*, 2019). By building resilience to extreme weather events, communities can reduce the loss of lives and livelihoods during disasters.

Knowledge exchange and capacity building: Communities have engaged in knowledge exchange and capacity-building activities to enhance their understanding of climate change impacts and adaptation options. For instance, in the Pacific Islands, traditional knowledge and modern science are integrated to develop climate-resilient agriculture practices (Campbell *et al.*, 2014). In Uganda, farmer field schools have been established to promote the adoption of climate-smart agricultural practices and sustainable land management techniques (Nabalegwa *et al.,* 2019). Similarly, in Ghana, traditional knowledge sharing platforms have been used to disseminate information on climate change adaptation strategies among rural communities (Kpelle *et al.*, 2017). By empowering community members with knowledge and skills, communities can make informed decisions and take proactive measures to adapt to changing environmental conditions.

By implementing these adaptation strategies, communities can enhance their resilience to the impacts of climate change on inland wetlands and support sustainable livelihoods for present and future generations. In sum, the diverse adaptation strategies implemented by communities facing the impacts of climate change on inland wetlands highlight the resilience and resourcefulness of local populations across Uganda, Africa, and beyond. Strategies such as livelihood diversification, climate-smart agricultural practices, community-based natural resource management, infrastructure development, and knowledge exchange have demonstrated their effectiveness in enhancing the resilience of ecosystems and livelihoods.

However, amidst these commendable efforts, a significant research gap persists in understanding the long-term effectiveness and scalability of these adaptation strategies, particularly in the context of changing climate patterns and socio-economic dynamics. While numerous studies have documented the implementation and short-term outcomes of adaptation measures, there remains a dearth of comprehensive research that evaluates the sustained impact of these strategies over time.

Addressing this research gap presents an opportunity to delve deeper into the factors influencing the success or failure of adaptation efforts, the potential trade-offs and synergies between different strategies, and the role of governance structures and policy frameworks in facilitating effective adaptation. By conducting longitudinal studies that assess the durability and scalability of adaptation interventions, researchers can provide valuable insights to inform evidence-based decision-making and enhance the adaptive capacity of communities in the face of ongoing climate change.

### 2.16 Summary of Knowledge Research Gaps

Evidence of how climate change is affecting the environment, natural ecosystems, and socioeconomic activities may be found in the literature review above. The main effects of climate change on community members have been determined to be destructive floods and droughts, which cause disruptions to everyday economic activity, food insecurity, and family home displacement. The relationship between inland tropical wetlands and climate variability, despite the vast amount of data being gathered in various parts of the globe, is not fully understood. Furthermore, it is also well known how human activity and climatic fluctuation affect the carbon reserves in tropical inland wetlands.

People whose livelihoods depend on wetlands typically have a limited perspective on environmental changes, making it difficult for them to connect actions like reclaiming wetlands and exposing peat to sunlight to the effects of climate change. Their limited ability to adapt makes them susceptible to the effects of climate change as well. Communities who depend on wetlands for their livelihoods must be made aware of the effects that food production practices have on wetlands and climate change. The effects of human activity on

Uganda's inland wetlands vary greatly based on the resources available for subsistence, the terrain of the area, and the wetland's precise position.

This study aimed to determine the state of the carbon stocks in a typical inland wetland, evaluate the impact of external and internal drivers of ecosystem change, and ascertain how local communities are adapting to adverse climate change impacts in order to maintain their livelihoods. Prior to this study, there was a dearth of comprehensive data on the external and internal drivers of change in Uganda's inland wetlands.

# CHAPTER THREE: MATERIALS AND METHODS

## 3.1 Introduction

This study combines both scientific and socio-economic survey methods used to gather the required data and information. This chapter describes the study area, study design, the target population and the methods of sampling. It also describes how the sample size was estimated, field and secondary data collected and how the data gathered was managed and analyzed.

## 3.2 Study Area

### 3.2.1 Location

The study was undertaken around Kanyabaha wetland in Rukiga District, which is located in southwestern Uganda (Fig. 3.1). Kanyabaha wetland covers an area of 33 km2 and is located between latitude 1.1326° S and longitude 30.0434° E in Kigezi Sub region. The wetland lies in a river valley, and the average elevation of the surrounding landscape is about 2000 meters above sea level. Kanyabaha wetland complex is located in Rukiga County in the northeast of Kabale District. The upper part of the wetland complex has two tributaries; the Nomuremu river, which flows northwest under the Kabale-Mbarara highway at Muhanga, passing through Kanigondo, Kyerero and Nomuremu wetland systems, and the Lwakizameura river which flows northwards through Lwakizamburn and Rushebeya wetlands where the two systems join. At this confluence, the wetland is permanent and papyrus dominated with deep water. The system continues through a series of intact permanent wetlands; Kanshanana, Kanyabwig and Kanyabaha. In the middle of Kanyabaha there is a deep lake called Lake Bunyonyi. Below Kanyabaha wetland, the valley bottom was drained under Government programme in the 1960s and 70s, and the wetlands of Rushoma and Ruborga are significantly degraded. The system continues to drain northwest where it passes into Rukungiri District. At Kisizi, the river powers a hydro scheme generating electricity for a hospital and the surrounding communities, before draining into Lake Edward, a RAMSAR site. The wetland originally stretched the whole length of the valley from Muhanga to Kisizi crossing 3 subcounties; Bukinda, Rwamucucu and Kashambya, a distance of about 33 km.

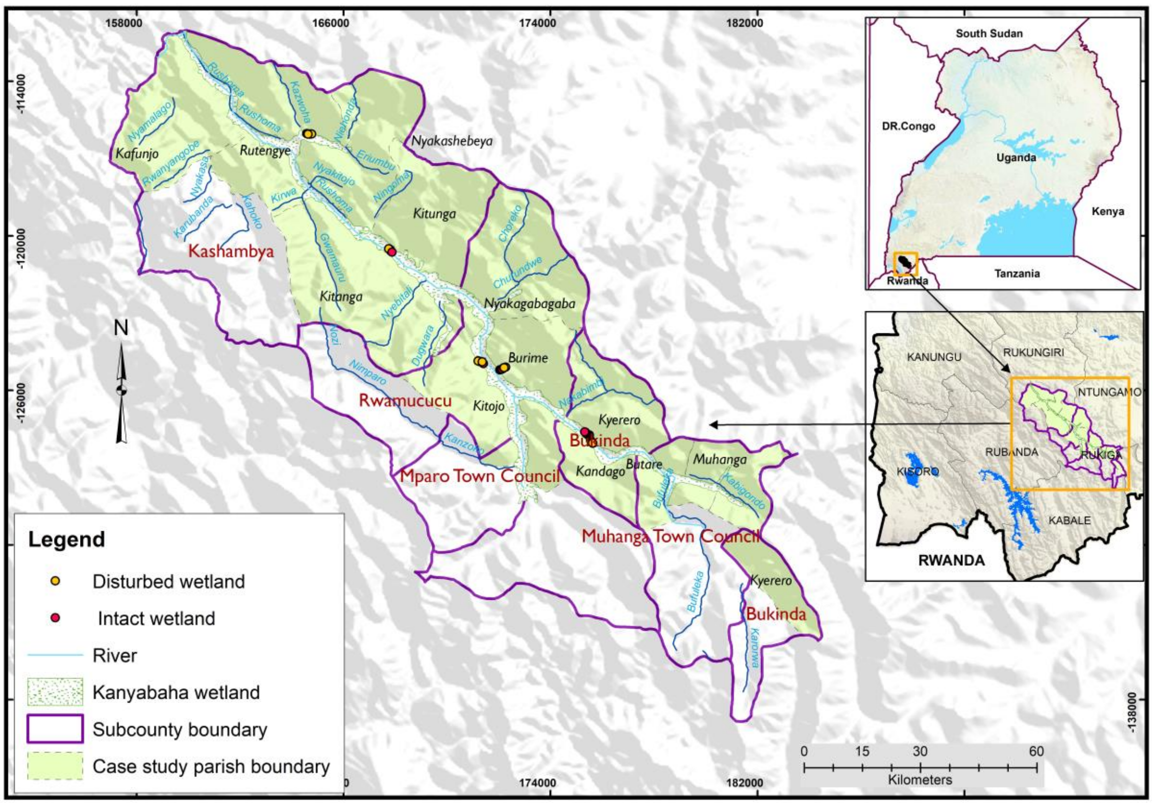


**Figure 3.1: Map of the Study Area: Source: Developed by the Researchers using ArcMap 10.7.1 Software**

### 3.2.2 Climate and Hydrology

#### *3.2.2.1 Climate*

Kanyabaha Wetland experiences a humid subtropical climate, typical of the southwestern region of Uganda. This climate is characterized by relatively consistent temperatures throughout the year, with moderate to high levels of precipitation.

#### *3.2.2.2 Temperature*

The wetland generally experiences mild to warm temperatures, with average highs ranging from 22°C to 26°C and average lows ranging from 11°C to 15°C. These temperatures create favorable conditions for the growth and development of wetland vegetation.

#### *3.2.2.3 Precipitation*

The wetland receives significant rainfall throughout the year, with the highest precipitation occurring during the wet seasons. The long rainy season typically occurs from March to May, while the short rainy season occurs from September to November. These periods of increased rainfall contribute to the waterlogging of the wetland, sustaining its hydrological functions and supporting the growth of aquatic vegetation.

#### *3.2.2.4 Hydrology*

The hydrology of Kanyabaha Wetland is characterized by its waterlogged conditions and its role as a vital component of the local hydrological cycle.

#### *3.2.2.5 Waterlogging*

The wetland is heavily waterlogged, with the landscape characterized by standing water and saturated clay soils for significant portions of the year. This waterlogging creates ideal conditions for the growth of wetland vegetation, such as papyrus and wetland grasses.

Surface Water Dynamics: Surface water dynamics within the wetland are influenced by both precipitation patterns and local topography. Rainfall runoff and surface water from surrounding areas contribute to the wetland's water levels, while evaporation and transpiration processes regulate water loss from the ecosystem.

#### 3.2.2.6 Hydrological Connectivity

The upper part of the wetland complex is fed by two main tributaries: the Nomuremu River and the Lwakizameura River. These tributaries flow northwest and northwards, respectively, passing through various wetland systems before converging at a point where the wetland is characterized by permanent water bodies dominated by papyrus vegetation and deep water. Beyond this confluence, the wetland continues through a series of intact permanent wetlands, including Kanshanana, Kanyabwig, and Kanyabaha, with Lake Bunyonyi situated in the middle of Kanyabaha Wetland. However, downstream drainage efforts in the 1960s and 70s have significantly impacted the wetland's hydrology, leading to the degradation of wetlands such as Rushoma and Ruborga. The system continues to drain northwest into Rukungiri District, ultimately reaching Lake Edward, a RAMSAR site. At Kisizi, the river powers a hydro scheme generating electricity for a hospital and surrounding communities before draining into Lake Edward.

#### 3.2.2.7 Geology and Soils

Kanyabaha is wetland characterized by a diverse array of soil compositions and vegetation types. Soil composition plays a crucial role in understanding the ecosystem's dynamics and its capacity for carbon sequestration. The wetland's soils exhibit a mosaic of textures and compositions, ranging from rich alluvial deposits to mineral-rich substrates. These soils support a varied vegetation profile, shaping the landscape into patches of natural vegetation, interspersed with open water bodies and agricultural fields.

#### *3.2.2.8 Natural Vegetation*

The natural vegetation of Kanyabaha Wetland in Rukiga, Kabale District, consists primarily of a mixture of papyrus and wetland grasses, thriving in the heavily waterlogged conditions characteristic of the area. This vegetation forms a dense and diverse canopy, providing habitat and sustenance for a variety of wildlife species endemic to wetland ecosystems.

*Papyrus* (C. papyrus) dominates significant portions of the wetland, its tall, slender stems towering above the water's surface. These stands of papyrus provide crucial nesting sites for birds and habitat for various aquatic organisms.

Interspersed among the papyrus are patches of wetland grasses, which contribute to the overall biodiversity and structural complexity of the ecosystem. These grasses, including species like *Cladium mariscus* and *Cyperus dives*, create a mosaic of habitats within the wetland, supporting a range of plant and animal species. Additionally, herbaceous plants, such as *Polygonum senegalense*, are found along the wetland edges and in degraded patches, adding to the vegetative diversity of the area.

#### *3.2.2.9 Socio-economic Activities*

The wetland is maintained primarily as a source of fisheries and *papyrus* materials for local communities. There is unlimited papyrus harvesting with is used to make mats, fish traps and other handicrafts. Burning of the wetland is not allowed, however this has been a significant problem in the past. Hunting is permitted on a subsistence basis only. At the Kitanga wetland section, there is a fishponds project, belonging to a community-based organisation, however there are complicated access issues due to a private individual claiming ownership. Further downstream, from Kantare village through the rest of the Kashambya sub-county and down to Kisizi, the wetland has been drained by a main drainage canal. The degraded wetland area is used for planting crops such as Irish potatoes, and grazing pastures for dairy cattle. Eucalyptus is commonly found along the wetland edge. Irish potatoes are planted out in the wetlands in April to June, at a time when raised beds are dug and prepared, to keep the potatoes out of any water logging of the soil. After this time the potatoes are then harvested, and from October onwards the soils are left fallow or cultivated for maize and cabbages. All around the wetland are steep slopes that are heavily cultivated or planted with eucalyptus. Tea is a recently introduced crop, which is being promoted by the Government and starting to be planted on the slopes around, and encroachment of tea into the wetlands has occurred by the Kitanga fishponds. Due to increased frequency of flooding and landslides, disaster management committees have been set up within each sub-county.

## 3.3 Research Design

The research adopted a scientific and socio-survey design involving both quantitative and qualitative research strategies. These research strategies facilitated triangulation and dovetailing of the findings and helped to offset the weaknesses of either of the two approaches (Bryman, 2008).

### 3.3.1 Scientific Design

For the scientific methods, the materials and methods employed in this study aimed to characterize vegetation changes in Kanyabaha Wetland between 1990 and 2021, utilizing satellite imagery and field sampling techniques. Two multi-temporal datasets were utilized, comprising Landsat 4-5 TM imagery for the years 1990, 2001, and 2011, and Landsat 8 OLI/TIRS imagery for 2021. These images, downloaded from the USGS Global Visualization geoportal, were selected based on their low cloud cover and captured during the dry season months of December-January to ensure consistent spectral reflectance. Image processing involved pre-processing and interpretation using ArcMap 10.x remote sensing software, including band enhancement, atmospheric correction, and geometric correction. A hybrid of unsupervised and supervised classification methods was employed due to the heterogeneous vegetation types in the study area. Field verification involved random point sampling and ground truth validation using Garmin GPS devices and Google Earth imagery. Accuracy assessment was conducted using a confusion matrix approach, with Kappa statistics calculated to measure overall agreement. Peat soil sampling was conducted within randomly selected quadrats, with soil cores collected at depths of 0-20 cm, 20-50 cm, and 50-100 cm. Bulk density and soil organic carbon were determined in the laboratory following established procedures, including oven drying, ashing, and calculation of organic carbon content. The biomass of vegetation was harvested within the same quadrants that were used to collect peat soil samples and dried to a constant weight. These methods provided comprehensive data for assessing vegetation dynamics and sedimentary carbon stocks in Kanyabaha Wetland over the study period.

### 3.3.2 Cross-sectional Social Economic Survey

The socio-economic survey was conducted between May and September 2021 in the study area aimed to gather quantitative data to address specific research objectives. A purposive sampling technique was used to select six villages based on their proximity to Kanyabaha Wetland and their involvement in various socio-economic activities. Simple random sampling was then employed to select 388 household heads from these villages. Additionally, three key informant interviews were conducted. Informants such as water management committee members and government officials were purposively sampled for interview schedules. Six focus group discussions, one in each village were also conducted to gather primary data and clarify issues arising from the interviews.

Sample size estimation for the household survey followed the Cochran formula, resulting in a sample size of 388 house heads respondents (William Cochran, 1963). Pre-testing of data collection tools was conducted on 30 individuals to ensure validity and reliability, with validity coefficients of at least 70% considered acceptable. Reliability was assessed using Cronbach's Alpha Coefficient tests for quantitative data and verification of response consistency for qualitative data. Data analysis included descriptive statistics for quantitative data using SPSS, and linear regression analysis for qualitative data obtained from focus group discussions and interviews. These methods provided a comprehensive understanding of the socio-economic dynamics surrounding Kanyabaha Wetland and facilitated the fulfillment of research objectives.

## 3.4 Experimental Procedures

### 3.4.1 Scientific Data sources

This study used two satellite multi-temporal datasets to characterize the vegetation changes in the Kanyabaha wetland between 1990 and 2021. For the year 1990, 2001 and 2011, Landsat 4-5 TM (30m) dataset was selected while, for the 2021 period, Landsat 8 OLI/TIRS (30m) imagery was used. The images were downloaded from the USGS Global Visualization (https://glovis.usgs.gov/) geoportal captured in the same months from December-January (dry season) when the spectral reflectance was quite similar. The criterion for the selection of the images to be downloaded included images with less than 5% cloud cover. Table 3.1 presents the satellite image specifications including path and row, year of acquisition and spatial resolution of each.

**Table 3.1. Satellite Specifications of the Spatial Data Imagery Used in the Study Areas**

| Year | Sensor | Imagery Id | Resolution |
|---|---|---|---|
| 1990 | Landsat 4-5 TM | LT04_L1TP_173061_19900604_20170129_01_T1 | 30m |
| 2001 | Landsat 4-5 TM | LT05_L1GS_173061_20011029_20161213_01_T2 | 30m |
| 2011 | Landsat 4-5 TM | LT05_L1TP_173061_20110708_20161008_01_T1 | 30m |
| 2021 | Landsat 8 OLI/TIRS | LC08_L1TP_173061_20210719_20210729_01_T1 | 30m |

### 3.4.2 Image Processing

The downloaded images were pre-processed and interpreted using ArcMap 10.x remote sensing software. In the software, the image bands were enhanced to improve on visualization and distinction of spectral features. The images were then atmospherically corrected using the dark object subtraction method to remove haze. In addition, the images were also geometrically corrected and co-registered. Image composites of both years were then developed to facilitate interpretation. For the pre-processed images, the areas of interest were masked out for faster rendering. The images were analyzed using a hybrid of unsupervised (ISO data) and supervised (Maximum likelihood) because of the heterogeneity of Vegetation types within the case study area. The definition and description of land use/cover classes was based on field knowledge and observations. Table 3.2 shows the vegetation cover types identified in the study area and their descriptions.

**Table 3.2: Description of Different Land use / Land cover (LULC) Categories**

| LULC category | General description |
|---|---|
| Built-up areas | Area characterized with settlements, roads and bear ground |
| Grassland | Vegetation type dominated with large, rolling terrains of grasses, and herbs. |
| Farming | Land covered with crops on a small-piece of land for house use without using advanced and expensive technologies. |
| Papyrus | A tall aquatic sedge plants (*Cyperus papyrus*) with small green-stalked flowers arranged like umbrella spokes around the stem top usually found in swampy areas |
| Woodland | Land covered with densely scattered trees with or without grassland underneath |
| Tree plantation | Large scale tree plantations of a single species (Eucalyptus trees, Coniferous tree) to produce timber |

### 3.4.3 Field Verification

The classified images were validated in the field following randomly generated points in the area of interest. These points were generated using an area frame sampling methodology. The points were visited to confirm if the classified classes collated with ground information. The sampled points were reached with the help of using Garmin handheld global positioning systems. The mapped validated points were also used to compute accuracy assessment with obtained classes after image classification.

For 1990, 2001, 2011, random points were extracted from each classified map and thereafter overlaid on google earth for validation. Google earth time slider was used to move between time series of each year.

### 3.4.4 Image Accuracy Assessment

This study developed a confusion matrix to define the producer and user accuracies for each classified class. The overall Kappa statistics and overall accuracy for each classified image were calculated from the corresponding error matrix with a total of 500 points collected from different Vegetation covers types between 1990, 2001, 2011 and 2021. The confusion matrix was performed by comparing error values for each class that was classified with its respective value in the ground truth data. The accuracy points were used as reference points to develop the image error matrix. The Kappa statistics is a measure of overall statistical agreement of an error matrix, which considers non-diagonal elements. Kappa analysis is recognized as a powerful method for analyzing a single error matrix and for comparing the differences between various error matrices (Foody, 2004).

### 3.4.5 Peat Soil and Vegetation Sampling

Systematic Sampling method was used to determine the sampling points during data collection. This involved the placement of quadrats along three transects stretched from the middle of the wetland towards the edge of the wetland. Quadrats of size 1m x 1m at 10-meter intervals along each transect were set. The starting point was randomly selected for the first quadrat along transect and placed the remaining 9 quadrats at 10-meter intervals from this starting point. Vegetation (understorey biomass and litter) and peat soil samples were collected within the quadrats.

The site was first cleared of vegetation using a hand hoe with a 20 cm long wedge before the soil penetration. At this point care was taken to create minimum disturbance and contamination, such as compaction of the soil around the area of sampling. A soil auger or hand hoe depending on the soil conditions was then used to dig down to a depth of 100cm. Three depths range 0–20 cm, 20–50 cm and 50–100 cm were considered sufficient. For 0–20 cm, the hoe was used to penetrate the ground once after clearing the surface area of a square meter. The soil was then carefully removed from the wedge and put aside from the dug ground. Due to the interference of the hoe handle, the wedge cannot fully penetrate the ground and so about 5cm of the wedge remained on the soil surface. This resulted in the creation of a 15cm depth. So, the hole was deepened by 5cm and first sample was taken at a depth 20 cm. For the 20–50 cm depth, digging was done twice using the same hoe resulting into a depth of 45cm. For 50–100 cm, tilling was done thrice resulting into a depth of 90 cm.

At each of these depths, a soil core ring removed with open front and back with a 5 cm internal diameter (height 5 cm) and the sample taken as described by Agus *et al.,* (2011). The sample was carefully removed to avoid spillage and any contamination. The sample was placed in a polythene bag marked with the sample identification number. The soil ring was cleaned in between each sampling occasion (Farmer *et. al.,* 2016).

In order to avoid collecting soil samples from the same horizon, soil samples were collected and placed on a white piece of paper to examine the color and texture carefully (Figure 3.2)

Surface (0-20cm) (b) Middle depth (21-50cm) (c) Bottom (51 -100 cm)

***Figure 3.2 Peat Samples Drawn from Different Soil Depths***

The samples were kept in a dark, cool place away from any sunlight during the field work period and later brought to Kyambogo University Laboratories in Kampala for assessment of bulk density and ash content. Bulk density was determined using only the undisturbed cores (Jabro *et al.,* 2020).

For tree sampling for aboveground biomass determination, sampling plots of 40m x 40m were set at 10-meter intervals along the each transect. The height and diameter of all the trees greater than 1.3 m from the surface were measured. The height of the tree was measured using a clinometer and its diameter at breast height (BDH) was estimated using a tape measure (tree circumference value at the breast height divided by pie).

### 3.4.6 Determination of Belowground Biomass, Aboveground Biomass and Total Carbon Stocks

#### *3.4.6.1 Laboratory Determination of Bulk Density and Soil Organic Carbon*

The bulk density and soil organic carbon were determined from the laboratory following the procedure described by Agus *et al*., (2011). The procedure is briefly described below.

#### *3.4.6.2 Bulk Density*

The soil samples were oven dried at 105$^0$C for 48 hours until a constant weight was achieved. The dry soil was put within an Aluminium can in a desiccator for about 10 minutes. The dry weight of the soil ($M_s$) and the can weight ($M_c$) were determined. The volume of soil sample, $V_t$ was determined from;

Volume of soil sample, Vt = where r is the inside radius and t is the height of the soil sampling ring.

The bulk density, BD was then calculated as; BD = (Ms+Mc) – (Mc)/Vt………Equation 3.1

#### *3.4.6.3 Soil Organic Carbon*

One tablespoon of oven-dried soil was ground using a pestle and a porcelain dish. 2g of the fine sample was weighed and transferred into a porcelain cup of known weight, $M_c$. The porcelain cups containing the samples were placed into a furnace. The furnace was ignited at 550$^o$C for 6 hours. The furnace was then turned off and the samples allowed to cool down for approximately 8 hours. The weight of the ash remaining in the cup, $M_{ash}$ was weighed. 3g of the fine sample (BB) was weighed and transferred to an Aluminum can of known weight. This was oven-dried at 105$^0$C for 24 hours and thereafter, the dry weight (BK) was determined. The water content of the sample was calculated as follows;

The water content $KA_m$ = (BB-BK)/BK*100 %...................................................Equation 3.2

The soil sample dry mass was then calculated from the following equation;

Dry mass $M_s = M_t * (1-KA_m)$…………………………………………………..Equation 3.3

Where $M_t$ is the 2g sample used in the ignition process.

For tropical wetland sediments where no inorganic carbon forms are present, total organic carbon is equal to the organic carbon present in the sample.

The organic carbon content, $C_{org}$ was therefore calculated based on the dry weight (g of C/g of dry soil):

The formula for calculating organic carbon content (Corg) based on the dry weight is:

Corg = (Weight of carbon in the sample (g) / Weight of dry soil sample (g))

This formula represents the ratio of the weight of organic carbon present in the soil to the weight of the dry soil sample. It provides a measure of the concentration of organic carbon within the soil, expressed as grams of carbon per gram of dry soil.

#### *3.4.6.4 Quantification of Above Ground Biomass*

The above ground biomass (AGB) for trees was calculated using Chave et al., 2005 shown in equation 3.4

AGB (kg) = $0.0673 * (pDBH^2H)^{0.976}$…………………………………………. Equation 3.4

Where;

AGB = Above Ground Biomass density;

DBH is diameter at breast height;

H is total height and p is wood specific gravity = 0.50 g $cm^{-3}$ (the arithmetic mean for tropical Africa).

Understorey biomass and litter were dried at 80°C to a constant weight and the dry weight for the biomass was calculated following the method described by Hairiah *et al.*, 2001

### *3.4.6.5 Estimation of Total Carbon Stock*

Total carbon stock ($C_t$) was estimated from all the carbon pools and computed as the sum of woody biomass, soil carbon, understory and litter from each land use/cover type, with biomass assumed to contain 0.47C (Nadelhoffer and Raich, 1992) as shown in equation 3.5

$C_t$ (t/$ha^{-1}$) = (AGC + BGC) + SOC……………………………………………….Equation 3.5

where, AGC = above ground carbon stock, BGC = below ground carbon stock, and SOC = soil organic carbon.

## 3.4.7 Plant Species Determination

### *3.4.7.1 Transect Establishment and Plot Layout*

A total of 12 transects were established across six wetland sites (Rutenje, Kitanga, Kitojo, Kyerero, Kandago, and Burime), with two transects established at each site. A systematic transect sampling technique was employed to assess plant species diversity across the six wetland sites. At each site, two transect lines were established in a north-south orientation, each measuring 1 km in length (Figure 2). The first transect was positioned randomly, while the second was laid parallel to it at a distance of 300 meters. Along each transect, the first quadrat (20 m × 20 m) was randomly located, and subsequent quadrats were systematically placed at 100-meter intervals, offset by 5 meters from the transect line to minimize edge effects.

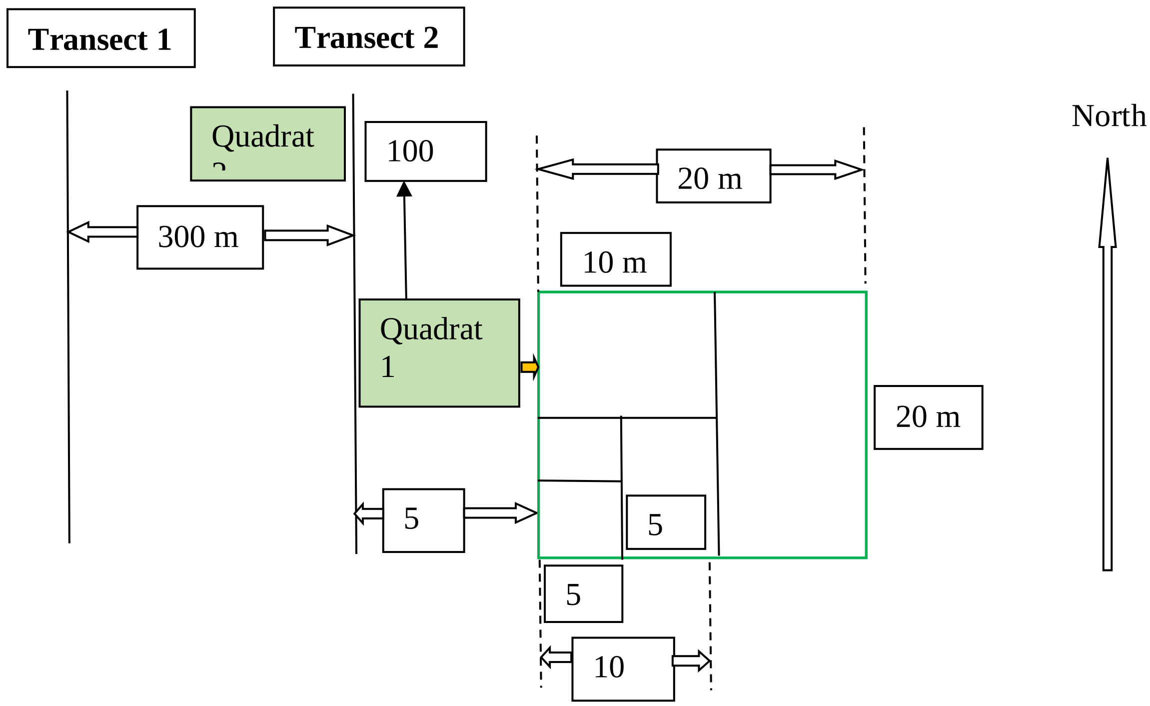


**Figure 3.3. Diagrammatic Presentation of Plot Layout along Transects.**

**Figure 3.4. Field sampling procedures in Kanyabaha Wetland: (left) layout of a vegetation transect used to guide systematic quadrat placement; (right) a research assistant establishing a 5 m × 5 m quadrat for plant species identification and abundance assessment.**

#### *3.4.7.2 Vegetation Sampling*

Vegetation sampling was conducted within 20 m × 20 m plots established across the study area. Within each plot, a nested quadrat approach was applied to assess woody vegetation based on diameter at breast height (DBH). Individuals with a DBH >20 cm were recorded in the full 20 m × 20 m plot; those with a DBH of 10-20 cm in a 10 m × 10 m subplot; and stems <10 cm DBH in a 5 m × 5 m subplot. A total of 120 plots were surveyed across all wetland sites. All recorded woody individuals were identified to species level, measured for DBH, and documented using a standardized data collection sheet. Plant taxa were grouped into six life form categories: trees, shrubs, herbs, sedges, grasses, and ferns.

Non-woody vegetation was assessed within the 5 m × 5 m subplots. For each taxon, the number of individuals, percentage cover, and assigned life form were recorded. Life forms were classified based on shared morphological and structural characteristics (Kuechler & Zonneveld, 1988). Cover was estimated as the vertical projection of plant canopies onto the ground surface, expressed as a percentage of the quadrat area (Mueller-Dombois & Ellenberg, 1974). Coarse cover classes (<20%, 20-80%, >80%) were used, and estimates were validated through consensus among multiple observers (Helm & Mead, 2004).

#### *3.4.7.3 Analysis of Plant Species Composition and Diversity*

Plant species composition was defined as the assemblage of plant species characterizing the wetland vegetation. Plant species encountered in each plot were identified, enumerated, and recorded to describe their composition. Plant species diversity in the six Kanyabaha wetlands was assessed using three indices: Simpson's Diversity Index (D), Shannon-Wiener Diversity

Index (H'), and Jaccard's Similarity Index (J) (Shannon, 1948; Simpson, 1949). These indices were selected to capture both within-site diversity (richness and evenness) and between-site similarity. Species richness (total number of species) and species evenness (distribution of individuals among species) were analyzed following Okullo et al. (2024). To test for significant differences in species diversity and composition among wetland sites, a one-way ANOVA was conducted. Where significant differences were found, Tukey's Honest Significant Difference (HSD) test was applied for post-hoc comparisons, as it controls for Type I error across multiple pairwise comparisons (Tukey, 1949).

#### *3.4.7.3.1 Shannon-Wiener Diversity Index*

The Shannon-Wiener Diversity Index, an information statistic index, assumes that all species are represented in the sample and that sampling is random. The index was calculated using the formula (equation 3.6):

$H' = -\Sigma Pi \times (\ln Pi)$………………………………………………………….(equation 3.6)

where H′ = is the Shannon Diversity index, Pi = is the proportion of individuals of the ith species (ni/N), ni is the number of individuals of the ith species, N is the total number of individuals across all species, ln = is the natural log, Σ = is the sum of the calculations.

#### *3.4.7.3.2 Simpson's diversity index*

Simpson's Diversity Index, a measure of diversity that accounts for both species richness and evenness, was calculated using the equation (equation 3.7):

$$D = \frac{\sum_{i=1}^{S} n_i(n_i - 1)}{N(N-1)}, \qquad \text{……………………………………………… (equation 3.7)}$$

where D = Simpson Diversity Index, ni is the number of individuals of ith species and N is the total number of individuals.

#### 3.4.7.3.3 *Jaccard's Similarity Index*

Jaccard's Similarity Index was used to assess the similarity between wetlands based on the presence or absence of shared species and their uniqueness. The formula applied was (equation 3.8):

$C_j = a / (a + b + c)$……………………………………………………….(equation 3.8)

Where:

- a represents the number of species shared between two wetlands (e.g., Wetlands A and B),
- b represents the number of species unique to the first wetland (e.g., Wetland A),
- c represents the number of species unique to the second wetland (e.g., Wetland B).

#### *3.4.7.3.4 Importance Value Index*

The Importance Value Index (IVI) is a widely used ecological metric that quantifies the relative ecological significance of plant species within a community. It is calculated by summing up relative density, relative coverage, and relative distribution of every species. In this study, the IVI was calculated for both woody and non-woody (herbaceous) plant species using the following equation (equation 3.9):

**IVI =** Relative Density + Relative Dominance + Relative Frequency ……………..(equation 3.9)

Where:

**Relative Density** = (density of individuals species / total density of all species) × 100

**Relative Dominance**

- **For woody species** = (basal area for a species / total basal area for all species) × 100
- **For non-woody species** = estimated using percent cover

**Relative Frequency** = (frequency of a species/sum of frequencies for all species) × 100.

##### *3.4.7.3.5 Research Flow Chart*

The research process for this study followed a structured and sequential framework comprising five interlinked phases: preparatory phase, tool development, field survey, data processing and analysis, and results interpretation (figure 4). The preparatory phase involved a comprehensive literature review, identification of knowledge gaps, refinement of research questions, stakeholder consultations, and logistical planning. This laid the foundation for tool development, customization of sampling protocols, and acquisition of relevant reference datasets. Subsequently, a systematic field survey was conducted across six sites within the Kanyabaha Wetland using established ecological methods to collect data on species composition, diversity, and environmental conditions. In the data processing and analysis phase, field data were cleaned, validated, and subjected to descriptive analysis. Key indices such as Shannon-Wiener diversity, Simpson's dominance, Jaccard Similarity, and Importance Value Index (IVI) were computed. Finally, the results interpretation phase synthesized the ecological patterns observed, assessed the influence of anthropogenic disturbances, and generated recommendations for ecosystem-centered wetland governance.

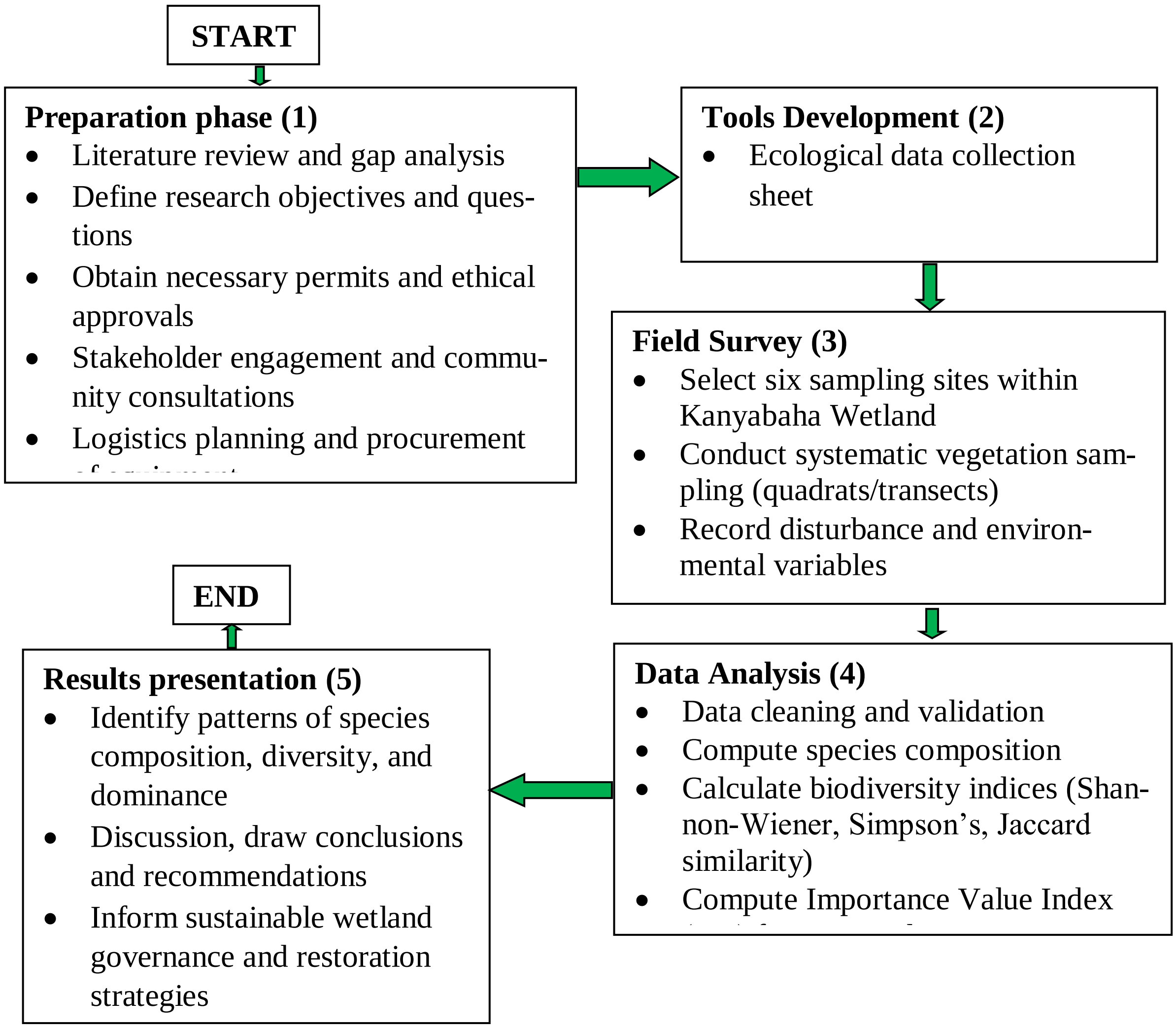


**Figure 3.5. Research flow chart illustrating the main phases: preparation, tool development, field survey, data analysis, and result interpretation.**

### 3.4.8 Socio-economic Survey

#### *3.4.8.1 Sampling Site Selection*

This section describes the cross-sectional household survey through which quantitative data were gathered to address objectives 3 and 4. Specifically, it describes sample size determination and sampling procedure, the research study tools, data collection procedure, and data processing and analysis. A purposive sampling technique was used to select six villages from the study area based on their proximity to the wetland and the use of the wetland for various socio-economic activities. The villages were Kandago, Burime, Kitojo, Kitanga, Rutenje and Kyeroro (Fig. 3.1). Simple random sampling was employed to obtain a sample of 388 household heads from the six villages. Purposive sampling technique was used to administer interview schedules to key informants, such as water management committee members in each village, government agricultural officials, and Rukiga District natural resource officer who formed a part of the sampling frame for this study. Six focus group discussion groups containing 6 to 15 opinion leaders were organized using local Rukiga language fluently spoken by some team members during the study period to obtain more primary data and clarify contentious issues arising from the interview schedules.

### *3.4.8.2 Sample Size Estimation*

The sample size for the household survey was calculated using the Cochran (1963) formula for survey sampling, which assumes considerable homogeneity within a study population to permit generalization of findings. This formula was preferred because it helps in determining the maximum sample size of the unknown population size. The study sample size was determined as follows:

$$n_0 = \frac{Z^2 pq}{e^2}$$

Where;

$n_0$ is the sample size,

$Z^2$ is the abscissa of the normal curve that cuts off an area $\alpha$ at the tails

($1 - \alpha$) equals the desired confidence level, e.g., 95%)

e is the desired level of precision,

p is the estimated proportion of an attribute that is present in the population and q is 1-p.

The value for Z is found in statistical tables which contain the area under the normal curve. e.g; Z = 1.96 for 95 % level of confidence

Therefore, calculating a sample size of a large population whose degree of variability is not known, we assume maximum variability, which is equal to 50% (p = 0.5). Taking 95% confidence level with ±5% precision, the calculation for required sample size was as follows; p = 0.5 and hence q =1-0.5 = 0.5; e = 0.05; z =1.96

So,

$$n_0 = \frac{Z^2 pq}{e^2}$$

$$n_0 = \frac{(1.96)^2(0.5)(0.5)}{(0.05)^2} = 384.16 = 384 \text{ respondents}$$

This formula was preferred because it helps to determine the maximum sample size needed from the unknown population size, which is assumed to be large. The sample of 384 was increased marginally to 388 respondents, so as to capture at least 10% of the target population in the study area. Survey questionnaires were administered to household heads while interview schedules were administered to purposively selected opinion leaders and key informants.

### 3.4.9 Pre-Testing of Data Collection Tools

In order to ensure that the desired attributes were captured by the research tools used, a pilot study was conducted to evaluate the validity and reliability of the research tools used. The pre-testing tools involved administering of the tools to at least 30 randomly selected adult individuals in the six villages and conducting analysis of their responses. The data collected during pre-testing of the tools were not included in the analysis of data from the main study that followed.

### *3.4.9.1 Validity of the Tools*

To control quality of the data, the researcher endeavoured to attain validity of coefficients of at least 0.70 or 70%. Kathuri & Pal (1993) asserts that items with validity coefficients to at least 0.70 are accepted as valid and reliable in research. Pre-testing of data collection tools was carried out a month before starting data collection. Upon performing the test, the results obtained were 70% or 0.7 and above and the tools were considered to be reliable. To establish validity for qualitative data, the tools were given to experts to evaluate the relevance of each item in the instrument to the objectives and rate each item. According to Amin (2005) a content validity index of 0.7 qualified the questionnaire a valid instrument and adopted for use. (CVI = K/N Where, CVI= Content Validity Index, K =Number of items considered relevant/suitable and N = Number of items considered in the instruments).

### *3.4.9.2 Reliability*

During the qualitative data collection process, the researcher diligently ensured that the recorded data from interviews accurately reflected the facts, responses, observations, and events as they occurred. This meticulous approach involved taking multiple measurements, observations, or samples to capture the full scope of the subject matter. Additionally, the researcher cross-checked the veracity of the recorded information with an expert to ensure response consistency and accuracy. Customized questions were crafted to ensure that only relevant inquiries were posed, thereby enhancing the quality and relevance of the data collected. Furthermore, the researcher carefully compared responses against previous answers when appropriate and promptly identified and addressed any inadmissible or inconsistent responses to maintain the integrity of the data.

For quantitative data, the Cronbach's Alpha Coefficient tests were performed. The Cronbach's Alpha Reliability Coefficient for Likert-Type Scales was done. In statistics, Cronbach alpha is coefficient of reliability. It is commonly used as a measure of the internal consistency or reliability of a psychometric test score for a sample of examinees. According to Sekran (2003) some professionals as a rule of thumb, require a reliability of 0.70 or higher (obtained on a substantial sample) before they use an instrument. Upon performing several alpha computations using data collected, the average Cronbach alpha was 0.7 and above and hence the tools were considered reliable as suggested by Sekaran (2003).

### 3.4.10 Ethical Considerations

The researcher or his assistant introduced themselves and explained the purpose of the study to each respondent before administering the questionnaire or interview schedule. Consent was obtained from all participants before being interviewed and an assurance given that the information collected was handled confidentially by using codes and not personal identifiers. Wherever necessary, permission from employers was obtained before interviewing the relevant state officers. Further, written authorization was secured from Kenyatta University and Ministry of Water and Environment (Wetlands Department). Permission and assistance were also sought from the local administration in the study area.

## 3.5 Data Analysis

This section presents a comprehensive analysis of data related to vegetation dynamics, carbon stocks, and socio-economic factors impacting wetland utilization in Kanyabaha Wetland.

### 3.5.1 Analysis of Vegetation Data

#### *3.5.1.1 Remote Sensing and Image Classification*

Vegetation characterization in Kanyabaha Wetland involved the analysis of Landsat satellite images spanning a ten-year interval period (1990-2001, 2001-2011, and 2011-2020). Remote sensing techniques were employed to classify the vegetation cover types using Landsat imagery. Supervised classification algorithms, such as maximum likelihood classification or support vector machines were utilized to categorize the land cover types present in the wetland area.

#### *3.5.1.2 Accuracy Assessment*

Accuracy assessment of the classified images was conducted to evaluate the reliability of the vegetation cover classification. Overall accuracy (OA) and Kappa statistics were calculated to determine the agreement between the classified images and reference data. The Kappa statistics served as a measure of agreement between the classified land cover types and ground truth data, with values above 0.75 indicating excellent agreement. The accuracy assessment ensured the reliability of the classification results for further analysis.

#### *3.5.1.3 Analysis of Plant Species Composition Data*

The analysis encompassed the assessment of plant species composition, species diversity, and the calculation of Importance Value Indices (IVIs) to estimate the ecological significance of plant communities.

#### *3.5.1.4 Statistical Analysis*

Statistical analysis techniques, including regression analysis and correlation analysis, were employed to examine the quantitative relationship between vegetation types and changes over time. Regression analysis was used to assess the relationship between specific vegetation types and temporal changes, with correlation coefficients indicating the strength and direction of the relationship. Correlation coefficients close to 1 suggested a strong positive correlation, while coefficients close to 0 indicated a weak correlation. ANOVA was used to assess if there was any significant difference between carbon stocks and associated livelihood activities.

#### *3.5.1.5 Land Use/Cover Transition Matrix*

The land use/cover transition matrix was used to analyze temporal changes within the vegetation cover types over the study period. The transition matrix quantified the transitions between different land cover categories from one time period to another. Each cell in the matrix represented the transition probability from one land cover type to another, providing insights into the dynamics of land cover change. Terra Sat Land Modeler v17 software was employed to calculate the transition potential matrix based on existing land cover conditions and explanatory variables.

### 3.5.2 Analysis of Carbon Stock

#### *3.5.2.1 Soil Organic Carbon Analysis*

To analyze soil organic carbon content, descriptive statistics were computed for soil samples collected at various soil depths and land use/cover types in Kanyabaha Wetland. Mean values were calculated for each soil depth and land use/cover type to understand the overall trends and variations in soil organic carbon content.

#### *3.5.2.2 Soil Carbon Density Analysis*

Soil carbon density analysis involved examining soil samples collected at different soil depths, soil types, and land use/cover types in Kanyabaha Wetland. Descriptive statistics, including mean values, were computed for soil carbon density at each soil depth and land use/cover type. Additionally, spatial mapping techniques were utilized to visualize the distribution of soil carbon density across the wetland.

#### *3.5.2.3 Aboveground, Belowground, and Total Carbon Stocks Analysis*

The analysis of aboveground, belowground, and total carbon stocks in Kanyabaha Wetland involved several steps. First, aboveground carbon stocks were calculated for different wetland use/cover types using appropriate equations or models. Trends over time were analyzed by comparing carbon stocks data from different years. Belowground carbon stocks were determined by analyzing soil samples collected at various soil depths and land use/cover types. Total carbon stocks were computed by summing up aboveground and belowground carbon stocks for each wetland use/cover type and year.

#### *3.5.2.4 Bulk Density Analysis*

Bulk density analysis required computing descriptive statistics for soil samples collected at various soil depths and land use/cover types in Kanyabaha Wetland. Mean bulk density values were calculated for each soil depth and land use/cover type to assess the overall soil compactness and variations across the wetland.

#### *3.5.2.5 Analysis of Variance (ANOVA)*

ANOVA was performed to statistically assess the significance of differences in carbon stocks among different wetland dependent livelihood activities. This analysis helps determine if there are significant variations in carbon stocks attributable to different activities such as crop growing and tree planting. Additionally, ANOVA was used to assess if there was any significant difference in plant species diversity among the different wetlands. Statistical tests, particularly the p-value obtained from ANOVA, were used to determine the significance level of the observed differences in carbon stocks. A significance level of $p < 0.05$ indicates that the differences are unlikely to be due to random chance and are therefore considered statistically significant.

### 3.5.3 Analysis of Socio-economic Survey Data

The data from households' questionnaire survey was coded and assigned variables in Statistical Package for Social Sciences (SPSS) version 20 whereby quantitative data was subjected to descriptive statistics. Outputs such as frequencies and percentages were obtained. Information obtained from Focus Group Discussions, key informant interviews and other qualitative information from household questionnaires were analyzed using thematic analysis and presented in the report using direct quotes from the respondents. Chi square test was conducted to establish if there was any relationship between drivers of wetland utilization and livelihood activities, and adaptive strategies and socio-economic factors.

# CHAPTER FOUR: RESULTS AND DISCUSSION

## 4.1 Introduction

This chapter presents the results and the discussion of those results. It comprises of five sections, namely; vegetation characterization (4.2), estimation of soil carbon stocks (4.3), effects of livelihood activities on carbon stocks and plant species diversity (4.4), drivers of utilization of wetland resources (4.5) and climate change adaptation strategies of local communities in the study area (4.6).

## 4.2 Vegetation Characterization of Kanyabaha Wetland

Wetlands are diverse ecosystems in their spatial patterning, hydrological conditions and species of plant communities (Tan Z et. *al.*, 2016). This section addresses the vegetation types found in Kanyabaha wetland and the surrounding landscape. The types of vegetation in the wetland and the surrounding watershed is important because it contributes to the amount of organic carbon in the soil. It also constitutes an important resource base and is therefore exploited by local residents in different ways. Figure 4. 1 shows the vegetation cover maps from the classification of Landsat images for a ten-year interval period (1990-2001, 2001-2011, 2011-2021). It shows the distribution of cover types in the study area during the period between 1990 and 2021. The main cover types comprised built-up areas, grasslands, papyrus reeds, farmland, tree plantation and woodland. The results confirmed that the total land area covered by this study was 15.4 km2 (Table 4.3). Over these years, the most dominant vegetation cover was papyrus followed by grassland especially in 1990 and 2001. Papyrus vegetation types were continuously distributed throughout the study area with patches of other vegetation types within the wetland area.

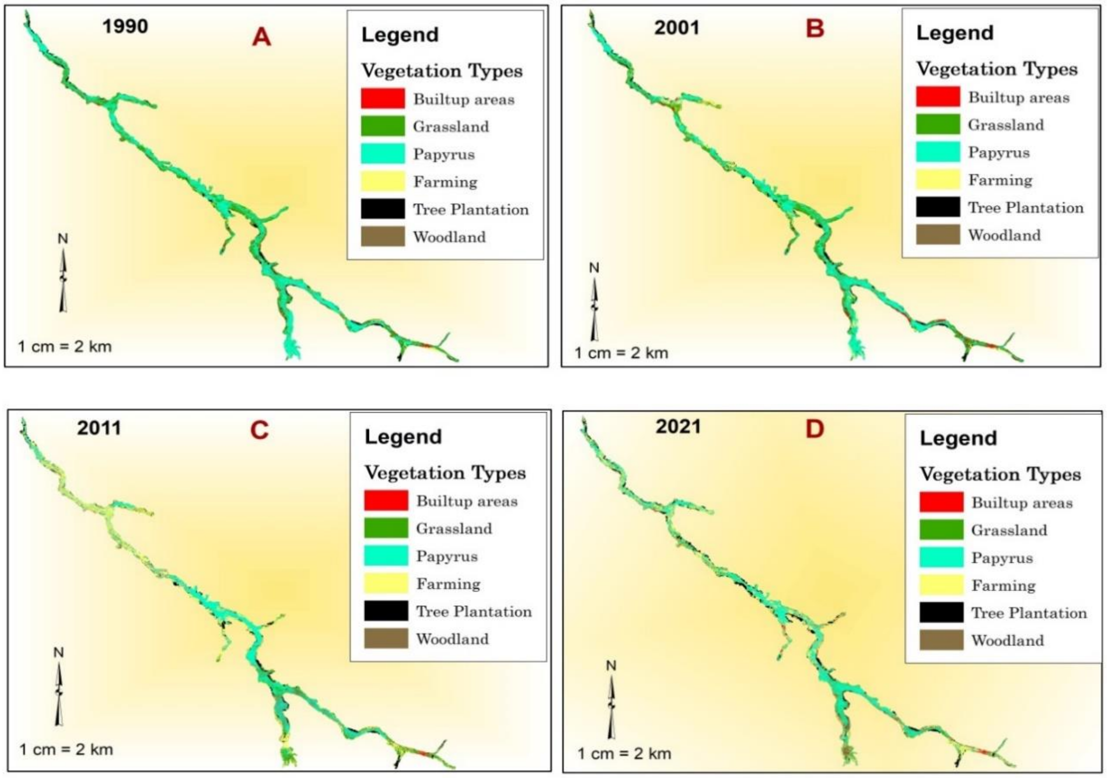


***Figure 4.1. Spatial and Temporal Coverage of Vegetation Cover Types Change 1990, 2001, 2011 and 2021***

### 4.2.1 Accuracy Assessment for Land Cover Classifications

During the study period spanning from 1990 to 2021, the assessment of land use and land cover (LULC) within the Kanyabaha wetland yielded an overall accuracy (OA) of 75% for the images captured in 1990, 2001, 2011, and 2021. Following the criteria established by Mohd et al. (2008), which categorized the agreement of Kappa statistics (K) as poor when K was < 0.4, good when K ranged from 0.4 to 0.7, and excellent when K was > 0.75, the results indicated a high level of accuracy in LULC classifications for each studied year. Specifically, the Kappa statistics for 1990, 2001, 2011, and 2021 were determined to be 0.85, 0.81, 0.86, and 0.78, respectively, signifying excellent agreement between the classified images and reference data (Table 4.1).

Comparatively, the overall accuracy of this LULC assessment aligns with findings reported by Tadese *et al.,* (2020), who achieved a satisfactory overall accuracy of 86.6%. The robustness of the Kappa statistics in this study demonstrates a strong agreement across all classified images, meeting the recommended standards for further analysis of vegetation changes, as advocated by Kindu *et al.,* (2013).

Table 4.1 summarizes the producer accuracy, user accuracy, overall accuracy (OA), and Kappa statistics for land cover classifications conducted in the Kanyabaha Wetland across four different years: 1990, 2001, 2011, and 2021. Producer accuracy refers to the probability that a specific land cover type identified by the classifier is indeed present on the ground. On the other hand, user accuracy represents the likelihood that a land cover type identified on the map corresponds to the actual land cover present in the field. Overall accuracy (OA) provides a general measure of the correctness of the classification results across all land cover types.

In 1990, the overall accuracy of the land cover classification was 87.8%, with a Kappa statistic of 0.85, indicating excellent agreement between the classified images and reference data. The producer and user accuracies ranged from 78.8% to 92.2%, demonstrating high reliability in identifying various land cover types. In 2001, the overall accuracy slightly decreased to 83.8%, with a Kappa statistic of 0.81. Although still considered good, there was a slight decline compared to 1990. However, producer and user accuracies remained relatively consistent across different land cover types.

By 2011, there was a notable improvement in the overall accuracy, reaching 88.6%, with a Kappa statistic of 0.86, indicating excellent agreement. This improvement suggests a refinement in classification techniques or better image quality, resulting in more accurate land cover mapping. Producer and user accuracies also showed improvements, particularly for some land cover types like papyrus and farming. In 2021, there was a slight decrease in overall accuracy to 82%, with a Kappa statistic of 0.78, still indicating good agreement but slightly lower compared to previous years. This decline may be attributed to changes in land cover patterns over time or potential challenges in image interpretation. However, producer and user accuracies remained relatively consistent across different land cover types.

Overall, the results suggest that the classification accuracy varied slightly over the study period, with some fluctuations observed in overall accuracy and Kappa statistics. However, the producer and user accuracies generally remained high, indicating the reliability of the land cover classification methodology used in mapping the Kanyabaha Wetland across different years.

**Table 4.1: Summary of producer, user, overall accuracy and kappa statistics taken between 1990, 2001, 2011 and 2021 in Kanyabaha Wetland, Uganda**

| 1990 | *Built-up areas* | *Grassland* | *Papyrus* | *Farming* | *Tree Plantation* | *Woodland* |
|---|---|---|---|---|---|---|
| Producer accuracy (%) | 89.9 | 92.2 | 86.5 | 90.7 | 89.2 | 78.8 |
| User accuracy | 81.3 | 89.9 | 91.7 | 87.6 | 83.5 | 80.7 |
| Overall accuracy (OA) (%) | *87.8* | | | | | |
| Kapa statistics | *0.85* | | | | | |
| **2001** | *Built-up areas* | *Grassland* | *Papyrus* | *Farming* | *Tree Plantation* | *Woodland* |
| Producer accuracy (%) | 81.5 | 84.9 | 82.1 | 85.1 | 84.5 | 85.0 |
| User accuracy | 81.3 | 81.6 | 82.1 | 88.1 | 84.5 | 94.4 |
| Overall accuracy (OA)- (%) | *83.8* | | | | | |
| Kapa statistics | *0.81* | | | | | |
| **2011** | *Built-up areas* | *Grassland* | *Papyrus* | *Farming* | *Tree Plantation* | *Woodland* |
| Producer accuracy (%) | 85.0 | 87.0 | 96.0 | 82.6 | 88.2 | 94.8 |
| User accuracy | 81.3 | 81.1 | 91.1 | 94.7 | 90.1 | 84.9 |
| Overall accuracy (OA) - (%) | *88.6* | | | | | |
| Kapa statistics | *0.86* | | | | | |
| **2021** | *Built-up areas* | *Grassland* | *Papyrus* | *Farming* | *Tree Plantation* | *Woodland* |
| Producer accuracy (%) | 81.3 | 88.2 | 82.9 | 87.8 | 77.2 | 76.9 |
| User accuracy | 81.3 | 82.2 | 90.0 | 80.0 | 92.2 | 79.5 |
| Overall accuracy (OA)- (%) | *82* | | | | | |
| Kapa statistics | *0.78* | | | | | |

### 4.2.2 Vegetation Cover Types in Kanyabaha Wetland

During the last thirty-year period, there has been considerable change in vegetation of Kanyabaha wetland. The LULC image analysis indicated that in the year 1990, 2001, 2011 and 2021 shown (Figures 4.1-A, B, C, D), papyrus was the dominant vegetation cover type, which occupied 51.5%, 46.5%, 35.9%, and 39.1% of the wetland respectively. Grassland cover was also extensive, covering 34.2% in 1990 and 32.1%) in 2001 respectively. In 1990 (Figure 4.1(A), other vegetation cover types occupied relatively small areas of Kanyabaha wetland with woodland covering 2.5%, crop fields covering 3% and built-up areas covering 3.2%. Tree plantations covered 5.6% of wetland margins from the year 2011 to 2021 (Figure 4.1 C, D). These vegetation cover types that occupied small areas of the wetland in the 1990s expanded continuously at the expense of Papyrus cover in 2011 and grassland cover in 2011 and 2021. However, in 2021, Papyrus cover increased to 39.1% and appeared to have been regenerated faster than in all the other years, (Table 4.2).

**Table 4.2: Vegetation Cover Types in Kanyabaha Wetland during the Period between 1990 and 2021**

| | 1990 | | 2001 | | 2011 | | 2021 | |
|---|---|---|---|---|---|---|---|---|
| Vegetation Types | Area ($Km^2$) | % | Area ($Km^2$) | % | Area ($Km^2$) | % | Area ($Km^2$) | % |
| Build up area | 0.50 | 3.2 | 0.60 | 3.9 | 0.69 | 4.5 | 0.79 | 5.1 |
| Grassland | 5.29 | 34.2 | 4.93 | 32.1 | 2.00 | 13.0 | 1.46 | 9.5 |
| Papyrus | 7.95 | 51.5 | 7.15 | 46.5 | 5.52 | 35.9 | 6.03 | 39.1 |
| Farming | 0.46 | 3.0 | 1.43 | 9.3 | 5.58 | 36.3 | 4.88 | 31.6 |
| Tree Plantation | 0.87 | 5.6 | 0.91 | 5.9 | 1.30 | 8.5 | 1.74 | 11.2 |
| Woodland | 0.39 | 2.5 | 0.34 | 2.2 | 0.29 | 1.9 | 0.54 | 3.5 |

**Trends in cover types over the period between 1990 and 2021 in Kanyabaha wetland**

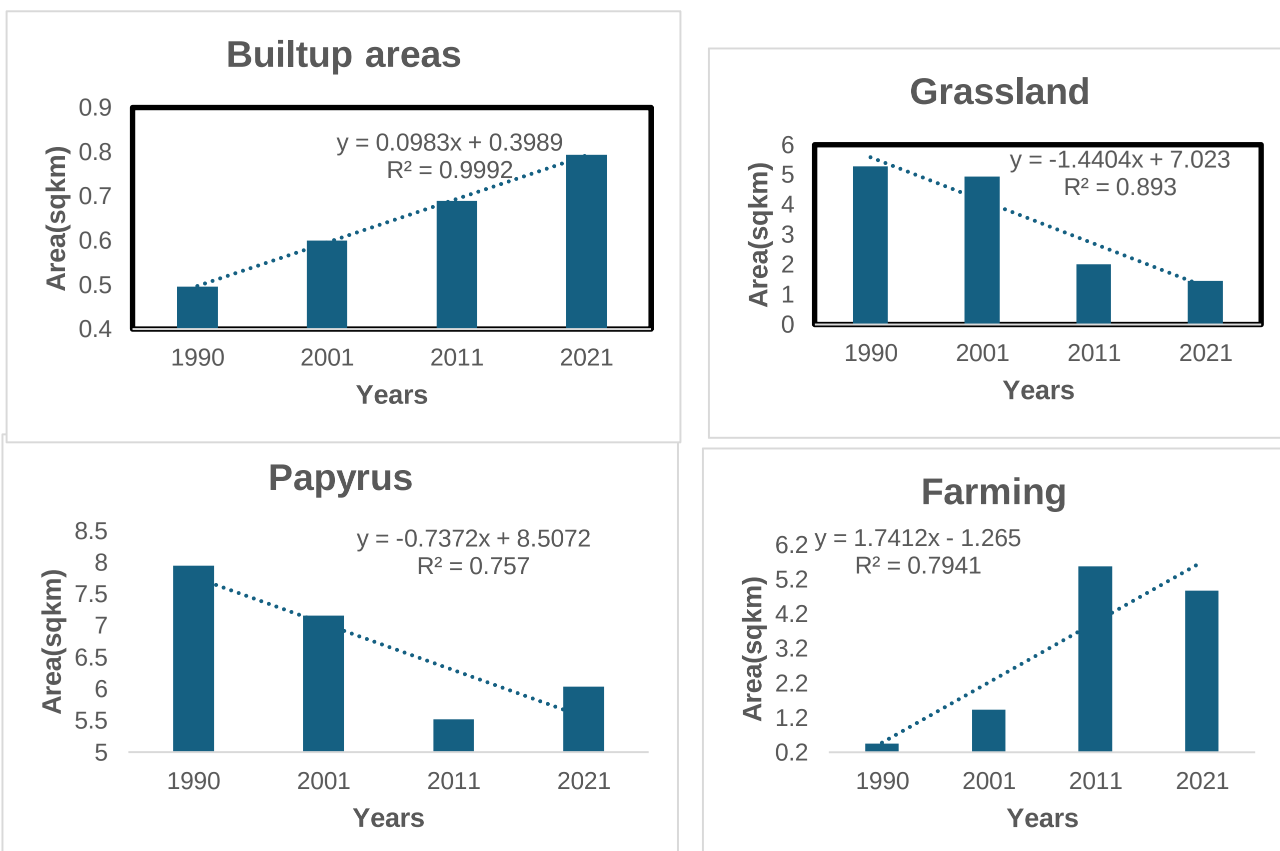

***Figure 4.2. Trends in Cover Types over the Period between 1990 and 2021 in Kanyabaha Wetland***

Linear regression was performed to examine the quantitative relationship between a particular vegetation type with changes in years as shown in Figure 4.2 above. In correlation analysis, the magnitude of the correlation coefficient indicates the strength of the relationship. Built up area increased steadily during the 30-year period, indicating increase in settlements and reflecting population growth and expanded business opportunities. This strong positive trend was found in areas under tree plantation (reflecting growing demand for wood for fuel and construction), and crop cultivation. A weak positive trend was also detected in the area under woodland, implying a steady expansion of woody vegetation into the wetland. This could be attributed to reduced water levels in the wetland due to siltation from farmland and built-up areas. However, there was a strong negative trend in areas occupied by papyrus swamp and grassland. The gradual loss of these cover types was attributed to expansion of farmland and built-up areas.

#### *4.2.2.1 Dynamics of Land Use/Cover Overtime (Land Use/Cover Transition Matrix)*

The transition matrix plays an essential role in analyzing temporal changes within a set of LULC categories. The rows of the matrix table represent the categories in the initial year, while the columns show the same order of LULC categories in the final year. The diagonal entries show the size of class stability, and each off-diagonal entry represents the size of the transition from one class to different classes (Table 4.3, 4.4 and Table 4.5). To show how each LULC type was projected to change in our study area, we calculated the transition potential matrix with the help of the Terra Sat Land modeler v17 during the periods of 1990-

2001, 2001-2011 and 2011-2021based on the existing LULC conditions and explanatory variables.

Table 4.3 shows the transition potential matrix during 1990–2001, in which Papyrus, and grassland were the most stable landscapes with probabilities of 7.1, and 4.7, respectively, while farming, woodland and built-up areas increased with a transition probability of 0.36, 0.37 and 0.48 respectively, which contributed nothing to the papyrus vegetation. The stable papyrus and grassland showed no serious encroachment by the years 1990-2001.

**Table 4.3: Transition Matrix of LULC Change ($Km^2$) from 1990 to 2011 in Kanyabaha Wetland**

| Year | | 2001 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Landuse/cover | Builtup areas | Farming | Grassland | Papyrus | Tree Plantation | Woodland | Grand Total |
| 1990 | Builtup areas | 0.48 | 0.02 | 0.00 | | | | 0.50 |
| | Farming | 0.10 | 0.36 | 0.00 | | | 0.00 | 0.46 |
| | Grassland | 0.10 | 0.47 | 4.65 | 0.01 | 0.06 | 0.00 | 5.29 |
| | Papyrus | 0.05 | 0.57 | 0.28 | 7.05 | 0.00 | 0.00 | 7.95 |
| | Tree Plantation | 0.00 | 0.02 | 0.00 | 0.00 | 0.85 | 0.00 | 0.87 |
| | Woodland | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.37 | 0.39 |
| | Grand Total | 0.74 | 1.43 | 4.93 | 7.05 | 0.91 | 0.38 | 15.4 |

Table 4.4 shows the transition potential matrix during 2001–2011, in which Papyrus, Farming and grassland were the most stable landscapes with probabilities of 3.49, 0.78 and 0.69, respectively, while woodland, Built-up areas and Tree plantation decreased with a transition probability of 0.03, 0.18 and 0.43 respectively, and woodland and Tree plantation contributed 0.52 and 0.39 respectively to papyrus.

**Table 4.4: Transition Matrix of LULC Change from 2001 to 2011 in Km$^2$**

| Year | | 2011 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Land covers | Built-up areas | Farming | Grassland | Papyrus | Tree Plantation | Woodland | Grand Total |
| 2001 | Built-up areas | 0.18 | 0.40 | 0.08 | 0.05 | 0.03 | 0.01 | 0.74 |
| | Farming | 0.04 | 0.78 | 0.22 | 0.25 | 0.11 | 0.03 | 1.43 |
| | Grassland | 0.08 | 2.36 | 0.69 | 1.40 | 0.32 | 0.08 | 4.93 |
| | Papyrus | 0.02 | 1.79 | 0.85 | 3.49 | 0.39 | 0.52 | 7.05 |
| | Tree Plantation | 0.01 | 0.20 | 0.09 | 0.16 | 0.42 | 0.04 | 0.91 |
| | Woodland | 0.00 | 0.05 | 0.08 | 0.18 | 0.03 | 0.03 | 0.38 |
| | Grand Total | 0.32 | 5.58 | 2.00 | 5.52 | 1.30 | 0.71 | 15.4 |

During 2011–2021 (Table 4.5), the built-up area and farming were 0.2 and 2.7, respectively, those of grassland and papyrus were 0.4 and 3.1, respectively, and that of Tree plantation and woodland was 0.6 and 0. Farming and grassland again contributed 1.5 and 0.7 to the papyrus, respectively. Accordingly, during 1990-2001, 2001-2011 and, 2011–2021, papyrus (7.1, 3.49 and 3.1) and Farming (0.36, 0.78 and 2.7) had higher stable transition respectively while grassland, tree plantation and woodland had fragmentation values during 1990-2001, 2001-2011 and, 2011–2021, respectively.

**Table 4.5: Transition Matrix of LULC change from 2011 to 2021 in Km$^2$**

| Year | | 2021 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Land use/cover | Built-up areas | Farming | Grassland | Papyrus | Tree Plantation | Woodland | Grand Total |
| 2011 | Built-up areas | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| | Farming | 0.4 | 2.7 | 0.5 | 1.5 | 0.5 | 0.1 | 5.6 |
| | Grassland | 0.1 | 0.7 | 0.4 | 0.7 | 0.1 | 0.1 | 2.0 |
| | Papyrus | 0.1 | 1.2 | 0.5 | 3.1 | 0.4 | 0.3 | 5.5 |
| | Tree Plantation | 0.0 | 0.2 | 0.1 | 0.3 | 0.6 | 0.0 | 1.3 |
| | Woodland | 0.0 | 0.0 | 0.1 | 0.5 | 0.1 | 0.0 | 0.7 |
| | Grand Total | 0.79 | 4.88 | 1.46 | 6.03 | 1.74 | 0.54 | 15.4 |

During the study period, papyrus was the most stable vegetation possibly due to the conservation policy in Rukiga, which encourages residents to vacate the Kanyabaha wetland for conservation of crested cranes (Tugume, 2022). Farming areas expanded most likely due to population increase leading to opening new farmlands to meet the demand for food by the expanded population. This implied that farmland expansion has been a major threat to Kanyabaha wetland.

The case study District being characterized with a hilly terrain, therefore the continuous increase in farming between 1990-2011 is attributed to the limited availability of land on the hilly areas since they are intensively cultivated (National Environment Management Authority, 2006) hence forcing farmers to opt for Kanyabaha wetland to grow their crops. The dominant crops include Maize and Irish potatoes as stressed by Akampa, (2018). The population of the Rukiga District, just like any other part of the country has been the major driver which contributed to the change. Demand for more food by this population has necessitated the expansion of farming lands, thus contributing to the degradation of wetland vegetation. As revealed in the most recent national census, Rukiga Districts has a population of 100,726 people (UBOS, 2014) and currently being projected to have a population of 105,400 by 2021(UBOS, 2021). The same arguments have agreed by Olson, 2003; NEMA, 2006 that population growth in particular is cited as a major contributing factor to shortages of agricultural land, and the loss of riparian wetlands in Uganda leading to ecosystem degradation. Increasing agricultural activities may cause declining carbon storage due to transition of wetland habitats to farmlands (Marques et al., 2019). Researchers like Moomaw *et al.,* (2018); Ramsar Convention, (2018) have emphasized that drainage of wetlands for agricultural development causes soil oxidation and major greenhouse gas (GHG) emissions, as well as lost capacity for continued carbon sequestration and storage.

However, in 2021, farming tremendously reduced, giving way to riparian vegetation cover like papyrus increasing as an indicator of restoration of the wetland system. This may be attributed to the fact that by 2017 to date, the Ministry of Water and Environment (MWE) started implementing the wetland restoration project funded by the Green Climate Fund (GCF) and the United Nations Development Program (UNDP) in 24 Districts of East and South Western Uganda (United Nations Development Program, 2017) inclusive of Rukiga District. The project is working tirelessly to empower the community to restore wetlands since the project's objective is to increase resilience of ecosystems and communities living around the wetlands. However, a number of conservation partners like UNDP, IUCN, and government institution have encouraged and practically implemented the restoration. On the other hand, IUCN, 2022 supported and encouraged 248 households in Rukiga Districts to conserve 9,987 hectares in Kanyabaha wetland for long term proper management of Grey Crowned Cranes (Lloyd, 2020). This confers with Ostrovskaya *et al.,* 2013 and Scholte *et al.,* 2016 who also emphasized that most wetland restoration interventions in Africa are either government-led with support of development partners or spearheaded by Non-Governmental Organizations and Civil Society Groups

The act to cancel illegal land titles acquired on public land especially in wetlands has been one of the measures to restore wetlands (Ministry of Finance, 2022) leading to reduction of human activities like agriculture in Kanyabaha wetland. Therefore, in line with previous research, (Saunders *et al.,* 2012) emphasized that, transformation of agricultural land to riparian wetland vegetation, the aboveground papyrus vegetation is completely recovered, resulting in both an increase in carbon dioxide gains and increase in the physical stability of the wetland areas that have been converted to Agriculture land.

Papyrus, woodland and Grassland's persistence decrease for the last 20 years (1990-2011) of the study, indicating that this wetland has over time been frequently encroached hence affecting the size of the vegetation cover in the wetland. The continuous decline in the wetland vegetation coverage could be attributed to anthropogenic activities like clay mining, grazing, papyrus harvesting and grass cutting carried out in the area have also greatly contributed to the gradual diminishing of the Kanyabaha wetland. The study is also in line with (John & Aloyce, 2018) who carried out a research on the characteristics of macrophytes in the Lubigi Wetland in Uganda and (Owino & Ryan, 2007) in western Kenya in the shores of Lake Victoria where both studies emphasized that human population growth around the wetland sites, with increasing land use activities and papyrus harvesting are the major factors that account for papyrus area and habitants reduction.

During the 1990s-2000's, the population was slightly increasing, and the nature of buildings was traditional. Therefore, the persistent decrease of papyrus and woodland could have been due the demand of construction materials in form of house thatching, firewood, medicine, production of mats, baskets and building poles. The decreasing grasslands could be attributed to the demand of grazing land especially in the dry season since a big number of the population are pastoralists. The mounting population pressures have caused significant degradation of natural resources in the wetland, resulting in declining water availability, loss of wildlife habitats and soil quality, and posing a long-term threat to the soil carbon and food security(Self Help Africa, 2020).The findings and argument is in with (Turyahabwe *et al.*, 2013) emphasizing that permanent grasslands and seasonal grasslands due to pressure from livestock grazing by pastoralists in the area and the collection of grass for mulching banana plantations in regards to the local perceptions of changes of wetlands in south western Uganda.

The increasing trend of tree plantation in the case study area is attributed to the Saw-log Production Grant Scheme (SPGS) and the Farm Income Enhancement and Forest Conservation Project (FIEFOC) projects that have endeavored to support the tree farmers with finances and technical advice in South Western Uganda(Tumushabe *et al.,* 2023). This describes the changes in size and coverage of the tree plantation over the years from 1990–2021.The eucalyptus and pine tree plantations have transformed the land cover and use in the Kigezi Sub-region. According to (Balimunsi *et al.,* 2012), pine and eucalyptus trees are the dominant tree species that have become the most attractive venture especially on the out- skirts of the wetlands in southeastern Uganda.

On the other hand, The National Forestry Authority (NFA) has promoted tree planting on the catchment area with indigenous species through the National Community Tree Planting Project. The promotion has been in form of free tree seedlings, provision of extension workers among others (Jacovelli, 2009). A number of trainings were also conducted in Eastern, South and Southwestern Districts of the importance of tree planting to reduce environmental disasters like the drought, floods and landslides (NFA, 2019).

The persistent increase in built up areas throughout the study area despite the restoration done on the wetland could be due to the frequent expansion and construction of roads and other development that creates significant problems for maintaining wetland restoration within Rushebeya wetland catchment. For example, the Kanyeganegye-nyakisa Road 5.0km, Rushebeya –Mpayo road, Rushebeya-Kitaraka Footbridge snaking through Kitanga-

Rushebeya wetland and connecting Burime and Nyakagabagaba parishes in Rwamucucu Sub County as well as Kitunga and Ngoma parishes in Kashambya Sub County (Amanya, 2022) among others. Most of the roads are frequently rehabilitated because they are often affected by mudslides and running water resulting from heavy rains. The commonly rehabilitated and expanded roads pass through the wetlands system and connect to other sub counties that are commonly known for Irish potato growing production which is both a staple food and a source of income for farmers in the region.

However, the increasing influx of refugees in through South Western Uganda from Democratic Republic of Congo(Berwouts, 2023;Turyahabwe *et al,* 2013), Burundi and Rwanda (UNHCR, 2018) resulting majorly from tribal and political conflicts has increasing the movements of refugees to nearby Districts like Kabale, Rukiga and Rubanda for settlement which has escalated the degradation of fragile ecosystems forest and wetland hence leading to competition and conflicts on access to farmlands(UNCDF & UNCHR, 2018). Therefore, the events have led to the creation of settlements to accommodate the refugees, of which the majority live on humanitarian aid and the environment to survive as an alternative livelihood (Bernard *et al.,* 2022). The results are in line with (Bernard et al., 2022) that revealed a rarefied increase in areas under builtups and refugee-settlements as more effects (loss of diversity, fauna, deforestation) were observed in savannah-grasslands, wetlands and woodlands due to high-refugee population in West Nile Sub-region in Uganda.

### 4.3 Carbon Stock Changes in Kanyabaha Wetland

The natural vegetation, especially the papyrus reeds, crops grown by farmers as well as the grass and woody vegetation in the watershed were the main sources of carbon found in the wetland soils. Dead plant matter accumulated beneath the papyrus beds while organic matter from the surrounding land was transported to the wetland by surface runoff. Changes in land use and land cover had strong influence on the carbon stocks in the wetland.

### 4.3.1 Soil Organic Carbon at various Soil Depths and Land Use/Cover Types in Kanyabaha Wetland

The descriptive statistics of soil organic carbon at various soil layers in Kanyabaha Wetland reveal notable differences in organic carbon content across different soil depths. In the topsoil layer (0-20 centimeters deep), soil organic carbon ranged from 1.2% to 45.7%, with an average of 9.3%. In the subsoil layer (20-50 centimeters deep), soil organic carbon ranged from 1.9% to 51.0%, with an average of 8.6%. In the deep soil layer (50-100 centimeters deep), soil organic carbon ranged from 0.8% to 56.4%, with an average of 9.3%. Comparing the mean soil organic carbon concentrations across the different layers, it was observed that the deepest soil layer had the highest average concentration, followed by the topsoil layer, and then the subsoil layer (Table 4.6).

**Table 4.6 Descriptive Statistics of Soil Organic Carbon at various Soil Layers in Kanyabaha Wetland**

| Soil Depth (cm) | Sample size (n) | Range | Mean (%) |
|---|---|---|---|
| 0-20 | 50 | 1.2% - 45.7% | 9.3±1.1 |
| 20-50 | 60 | 1.9% - 51.0 | 8.6±1.3 |
| 50-100 | 40 | 0.8% - 56.4% | 9.3±1.6 |

The concentration of soil organic carbon (SOC) in Kanyabaha wetland increased with soil depth. These findings are consistent with Bae & Ryu (2015) who observed the wetland soils of 0.7-1.0m depth to have a higher SOC concentration than the 0.3-0.7m depth. Carbon accumulation in the topsoil layer of wetland soils is affected by soil saturation and the continuous flooding (Vymazal, 2007). The higher concentrations of carbon at the deep soil layer (50-100cm) has also been attributed to the "cultural layer" increase vertical heterogeneity in SOC concentrations, representing anthropogenic disturbance of the of the soil profiles (Vasenev *et al.*, 2013). Bae & Ryu (2015) argued that the fine root mass density in wetland soils could also enhance the concentration of SOC. The converted wetland classes such as farmlands had lower SOC concentrations. Were *et al.*, (2020) argued that conversion of Uganda's natural wetlands into other land uses will approximately reduce the former's SOC storage potential by a range of 38-46%.

Soil organic carbon also varied among the various land cover types in Kanyabaha and wetlands. The soil organic carbon under built-up areas ranged between 2.5% and 36.2%. In grasslands, soil organic carbon ranged between 1.9% and 56.4%. The soil organic carbon under papyrus ranged between 1.2% and 32.2%. In small-scale farmlands, soil organic carbon ranged between 1.7% and 9.8%. The soil organic carbon under tree plantations ranged between 2.2% and 16.1%. In woodlands, soil organic carbon ranged between 0.8% and 33.4%.

Generally, grasslands exhibited the highest mean soil organic carbon content (14.1%), followed by built-up areas and then papyrus. Woodlands exhibited the least mean soil organic carbon content (3.1%) followed by small-scale farmlands (Table 4.7).

**Table 4.7: Soil Organic Carbon in Different Land Use/Cover Types in Kayabaha Wetland**

| Land Use/Cover Type | Sample Size (n) | Mean Soil Organic Carbon Content (%) | Range of Soil Organic Carbon Content (%) |
|---|---|---|---|
| Built-up | 50 | 13.3±2.1 | 2.5% - 36.2% |
| Grasslands | 60 | 14.1±2.6 | 1.9% - 56.4% |
| Papyrus | 40 | 9.4±2.1 | 1.2% - 32.2% |
| Small-scale Farming | 30 | 4.6±0.3 | 1.7% - 9.8% |
| Tree Plantations | 35 | 5.9±0.5 | 2.2% - 16.1% |
| Woodlands | 45 | 3.1±1.7 | 0.8% - 33.4% |

The highest Soil organic Carbon (SOC) concentrations in Kanyabaha wetland were observed under grasslands. In the traditionally managed rangeland biomes of Karamoja sub-region, Uganda, the highest SOC stocks were also observed under grasslands (Challenge *et al.,* 2022). Similarly, grazing lands exhibited the highest SOC stocks in the topsoil 30cm of the afro-montane landscape in southwestern Uganda (Twongyirwe *et al.*, 2013). Grasslands have been estimated to contain about 20 percent of the world's soil organic carbon stocks, indicating their significant role in the global carbon and water cycles (Puche *et al.,* 2019). In 2010, global SOC stocks under grasslands at 30cm were estimated at 63.5 Mt of carbon, and unimproved systems stored slightly than improved grassland systems (33.8 vs 29.8 Mt C) (Dondini *et al.,* 2023). This highlights the impact of human-induced activities in reducing SOC stocks stored in grassland ecosystems. The high SOC stocks under grasslands in wet environments such as wetlands have been attributed to lower average temperatures that subsequently result into lower decomposition rates, hence accumulation of SOC (Ma *et al.,* 2016); and the high productivity of grasslands under wet conditions (Wiesmeier *et al.,* 2015). Improved management practices on grasslands such as rotational grazing provides a chance to sequester large amounts of carbon, contributing to the global mitigation efforts and regenerating degraded landscapes (Dondini *et al.,* 2023).

The lowest concentration of SOC in Kanyabaha wetland was observed in woodlands (3.08%). This finding of the study agrees with those of Upson *et al.,* (2016) who reported woodlands to have the least soil organic carbon content among pastures, woodlands, and silvopastoral trees at the Clapham Park England. The low concentration of SOC in woodlands has been attributed to a decline in grass cover and reduced soil water content due to grazing activities (Eldridge *et al.,* 2013). However, higher concentration of SOC has been reported in Southwestern Uganda by Njagi *et al.,* (2022).

The difference in the amount of SOC stored in woodland ecosystems has been linked to management practices, soil biological and physical characteristics, and plant species growth characteristics (Yazdanshenas *et al.,* 2018). The results indicate that although low concentrations of SOC were observed in woodlands for this study, improved management practices in these ecosystems could potentially improve their carbon sequestration rates, thereby contributing to climate change mitigation.

The tree plantations had higher SOC concentrations than woodlands and small-scale farmlands and this could be attributed to the litter layer that is less exposed to removal by human activities (Abebe *et al.,* 2020). Leaf litter plays a crucial role in nutrient cycling and energy flow, enhancing soil fertility, accelerating soil organic matter formation, and increasing net carbon storage in forest ecosystems (Sayer *et al.,* 2021). Secondly, the multilayer canopy structure of tree plantations and shrubs underneath could enhance the fine root mass density and SOC concentration through the different rooting systems in the soil profile (Brassard *et al.*, 2013).

The SOC concentration for small-scale farmlands from this study (4.58%) is in the same range of previous studies about the influence of LULC on soil organic carbon content (Njagi *et al.*, 2022). Carbon sequestration in farmlands has been associated with soil texture; with coarse-textured soils sequestering significantly more SOC than fine and medium textured soils in the top 35cm (Rosinger *et al.*, 2023). Other factors such as tillage intensity, crop diversity, and sustainable land management practices like intercropping, cover cropping, and application of organic manure; also influence the amount of organic carbon sequestered into farmland soils (Morugán-Coronado *et al.*, 2020). These findings suggest that improved farm management practices such as minimum tillage and C input could improve the amount of C sequestered into farmland soils, thereby contributing to climate change mitigation and stabilization of the global carbon cycle.

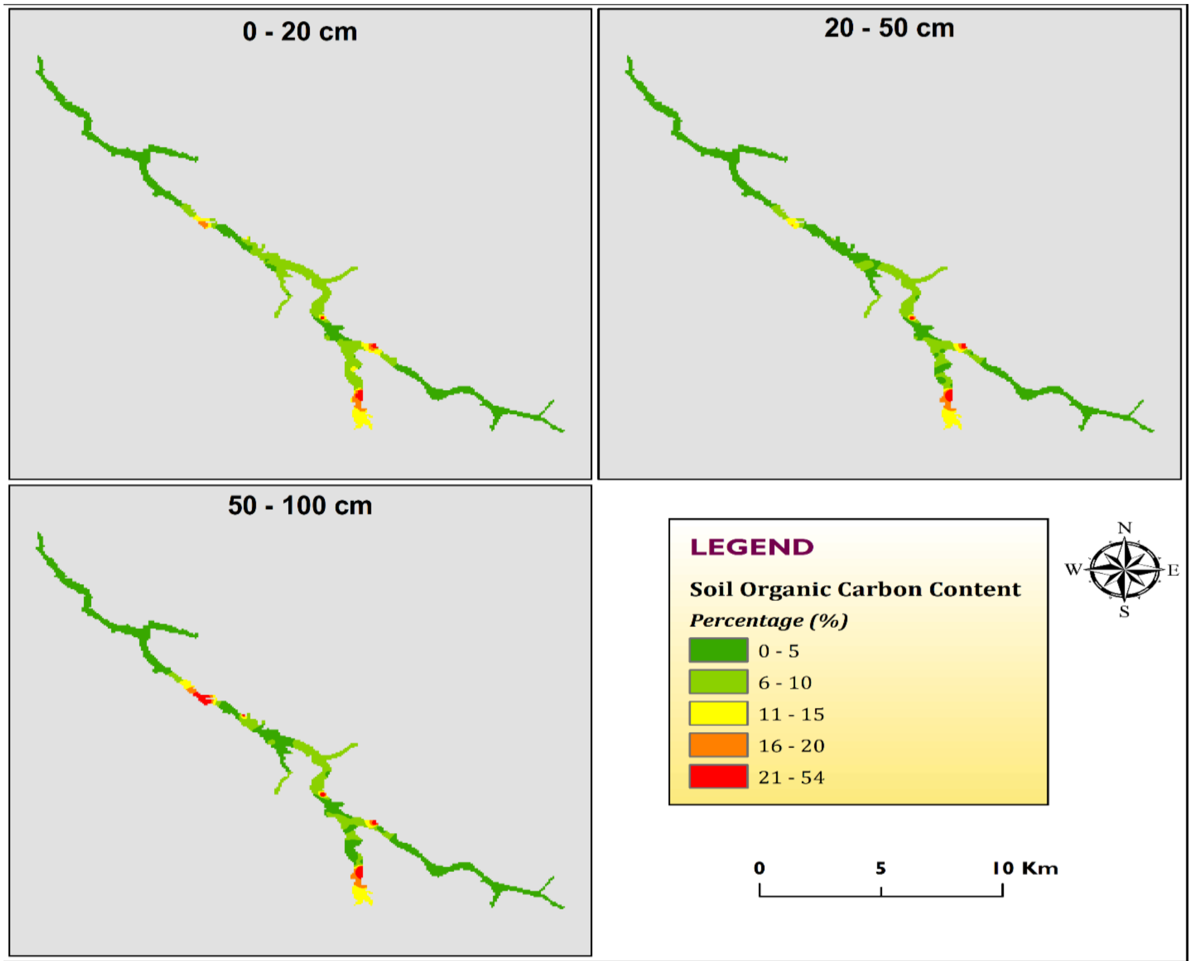


*Figure 4.3: Spatial Distribution of Soil Organic Carbon Content in Kanyabaha Wetland*

### 4.3.2 Soil Carbon Density at Various Soil Depths, Soil Types and Land Use/Cover Types in Kanyabaha Wetland

At 0-20cm soil depth, soil carbon density ranged between 11.8 ton/ha and 196.9 tons/ha. At 20-50cm soil depth, soil carbon density ranged between 21.2 tons/ha and 313.1tons/ha. At 50-100cm soil depth, soil carbon density ranged between 35.1tons/ha and 1,116.5tons/ha. The mean soil carbon density was highest in the deepest soil layer (50-100cm), followed by the middle soil layer (20-50cm), and then the topsoil layer (0-20cm) (Table 4.8).

**Table 4.8: Variation of Carbon Density with the Depth of Soil in Kanyabaha Wetland**

| Soil Depth (cm) | Mean soil carbon density (tons/ha) |
|---|---|
| 0-20 | 45.4±4.1 |
| 20-50 | 61.0±6.5 |
| 50-100 | 120.4±21.6 |

There was great variation in the soil carbon density at the various soil depth in Kanyabaha wetland. At 0-20cm, the least carbon density in Kanyabaha wetland was found downstream, average amounts of carbon density are located upstream, and the highest carbon density was found in the middle of the wetland. At 20-50cm, the highest soil carbon density was still found in the middle of the wetland with the downstream soils having low carbon density. At the depth of 50-100cm, the highest carbon density was found upstream and in the middle of the wetland. Lower densities of soil carbon at this soil depth found downstream (Figure 4.4) and (Table 4.8).

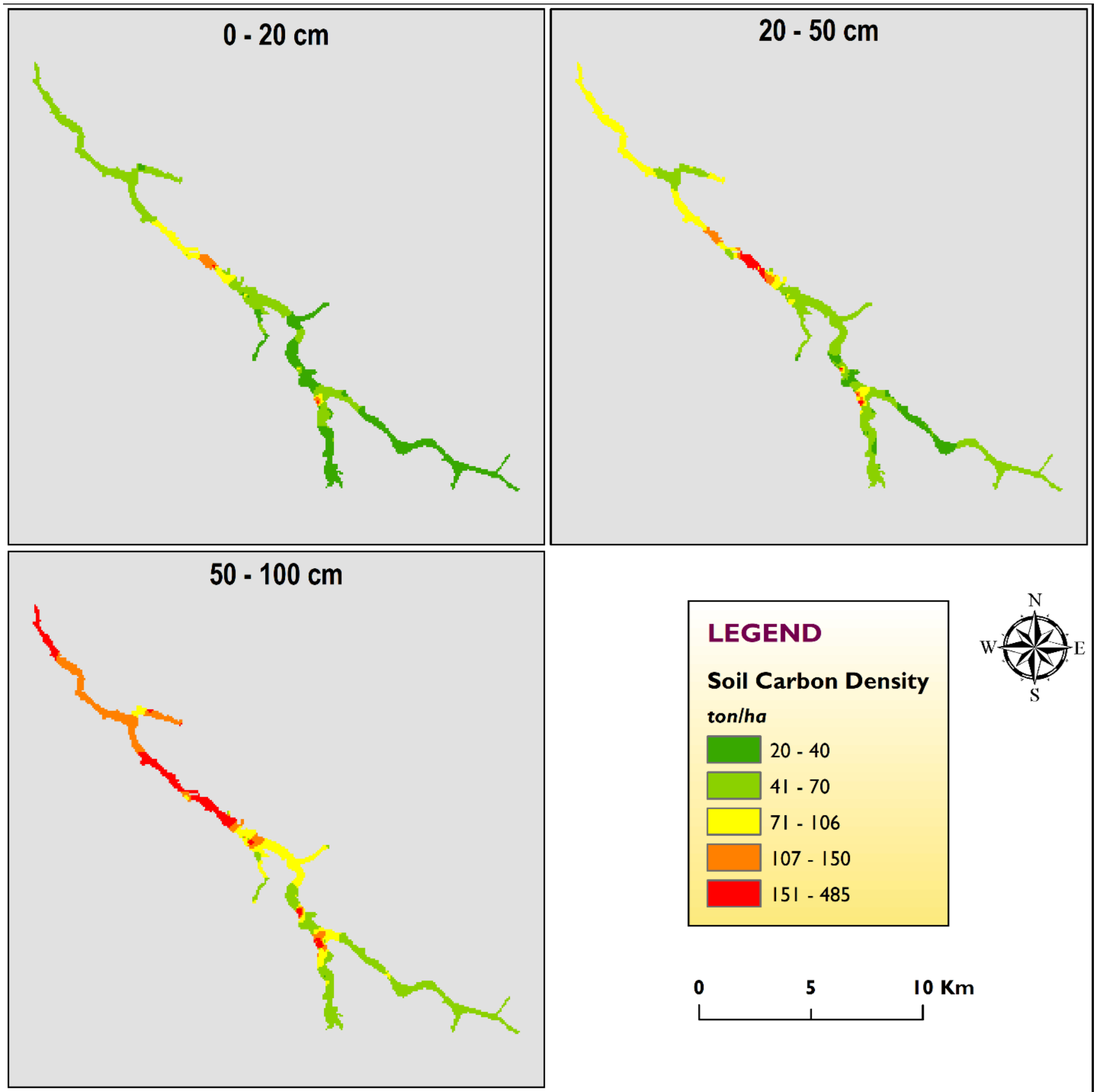


***Figure 4.4: Soil Carbon Density at Various Soil Depths in Kanyabaha Wetland***

Analysis of soil carbon density across the different soil types shows that soil carbon density increases with soil depth across the various soil types in Kanyabaha wetland. Soil carbon density was highest at the 50-100cm soil layer, implying that soil exposure to solar radiation and subsequent cultivation reduced soil carbon on the surface soil. Across the different soil depths, the highest soil carbon density was observed under peaty sands and clays while the lowest soil carbon density was associated with the reddish-brown clay loams (Figure 4.5).

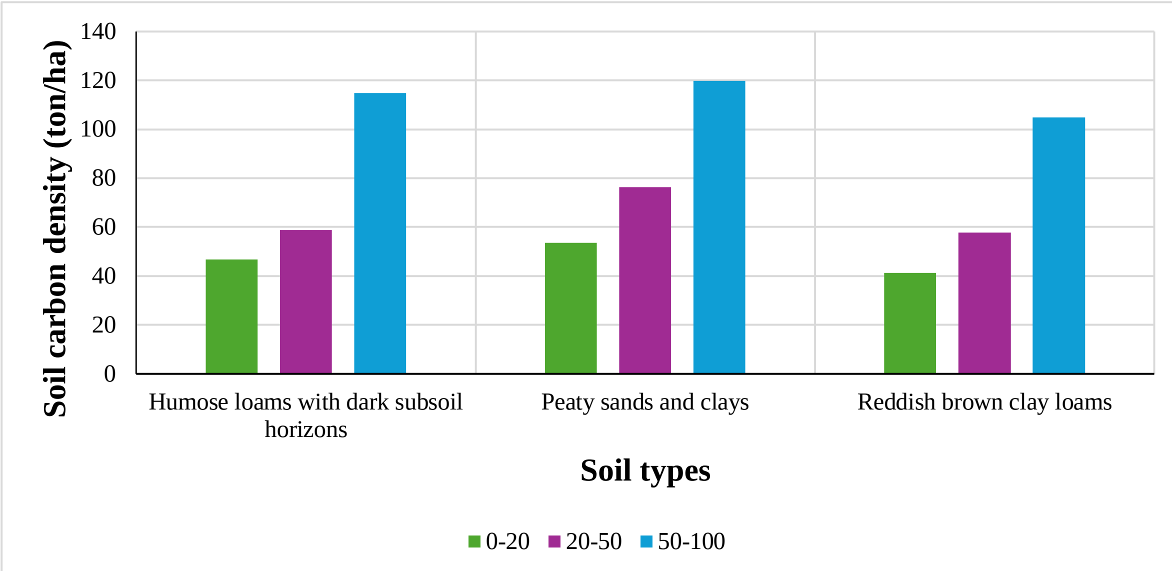


**Figure 4.5: Soil Carbon Density in the Different Soil Types in Kanyabaha Wetland**

The soil carbon density under built-up areas ranged between 20.3ton/ha and 866.5ton/ha. In grasslands, the soil carbon density ranged between 17.4ton/ha and 175.8ton/ha. The soil carbon density under the papyrus class ranged between 21.6ton/ha and 89.5ton/ha. In small-scale farmlands, soil carbon density ranged between 11.8ton/ha and 110.4ton/ha. The soil carbon density under tree plantations ranged between 26.6ton/ha and 429.4ton/ha. In woodlands, the soil carbon density ranged between 190.8ton/ha and 1,116.5ton/ha. Woodlands exhibited the highest mean soil carbon density (530.2±205.5), followed by built-up areas (107.7±28.8) and then tree plantations (98.3±12.5). The least mean soil carbon density was observed in grasslands (45.5±3.7) (Table 4.9).

**Table 4.9: Descriptive Statistics of Soil Carbon Density at the Different Land Use/Cover Types**

| Land Use/Cover Type | Mean soil carbon density (tons/ha) |
|---|---|
| Built-up | 107.7±28.8 |
| Grasslands | 45.5±3.7 |
| Papyrus | 47.2±4.5 |
| Small-scale Farming | 47.7±2.9 |
| Tree Plantations | 98.3±12.5 |
| Woodlands | 530.2±205.5 |

### 4.3.3: Aboveground, Belowground, and Total Carbon Stocks in Kanyabaha Wetland

The distribution of aboveground carbon density in Kanyabaha wetland is presented in Figure 4.6 below. The wetland is mostly dominated with aboveground carbon density that ranges between 7 ton/ha and 85 ton/ha. Most of the high aboveground carbon density is found in mid wetland and this ranges between 240.9 ton/ha and 396.6 ton/ha. The least aboveground carbon density was located in the western parts of the wetland, which were also downstream.

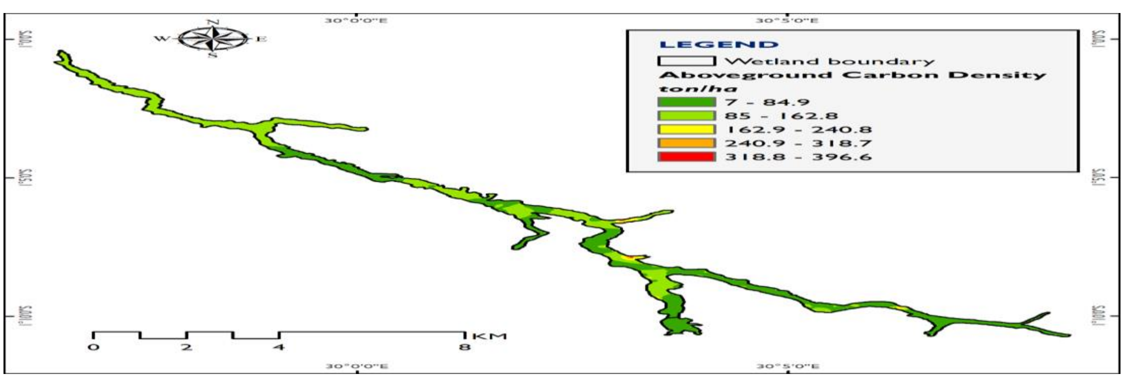


*Figure 4.6: Distribution of Aboveground Carbon Density in Kanyabaha Wetland for 2021*

The trend of aboveground carbon stocks for the different wetland use/cover types in Kanyabaha wetland between 1990 and 2021 is presented in Table 10. Between 1990 and 2021, the highest aboveground carbon stocks were observed under papyrus and the least aboveground carbon stocks were observed under built-up areas. Between 1990 and 2021, the aboveground carbon stocks for built-up areas and small-scale farmlands increased whereas that of grasslands and tree plantations decreased. The aboveground carbon stocks for papyrus and woodlands decreased between 1990 and 2011 and then increased between 2011 and 2021 (Table 10). There was a strong positive relationship between aboveground carbon stocks (AGCS) for built-up areas, grasslands, papyrus, farmlands, and tree plantations, and the changes between 1990 and 2021 (Figures 4.7-4.12). The changes in aboveground carbon stocks for woodlands between 1990 and 2021 were weak but positive (Figure 4.12).

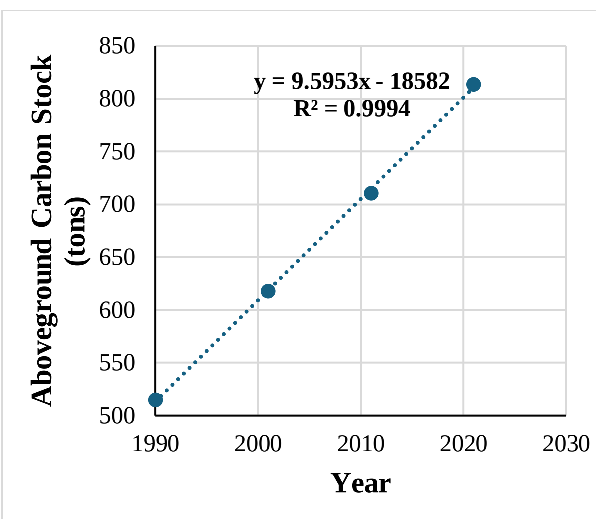


*Figure 4.7: AGCS for built-up areas between 1990 and 2021*

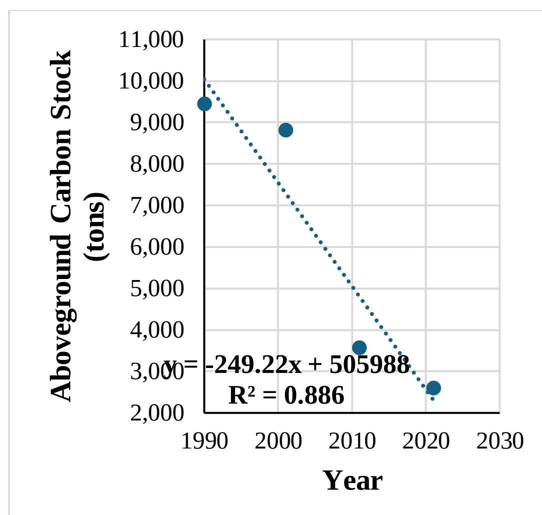


*Figure 4.8: AGCS for grasslands between 1990 and 2021*

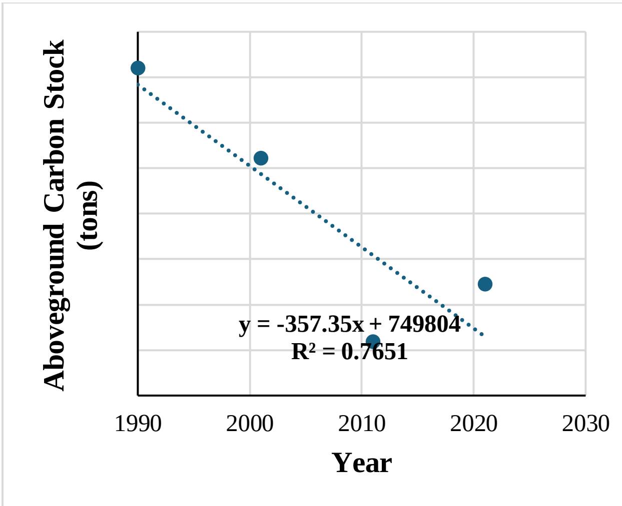


*Figure 4.9: AGCS for papyrus between 1990 and 2021*

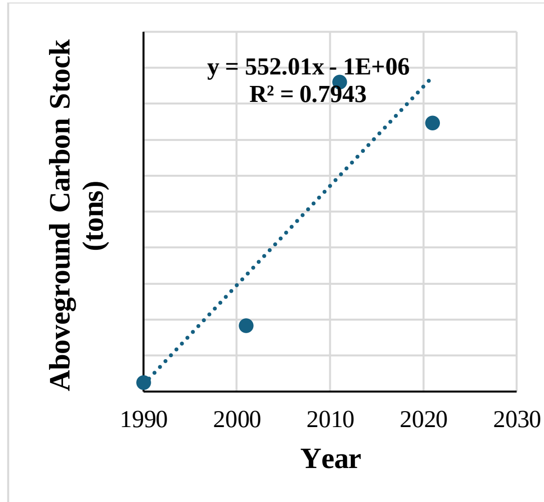


*Figure 4.10: AGCS for small-scale farmlands between 1990 and 2021*

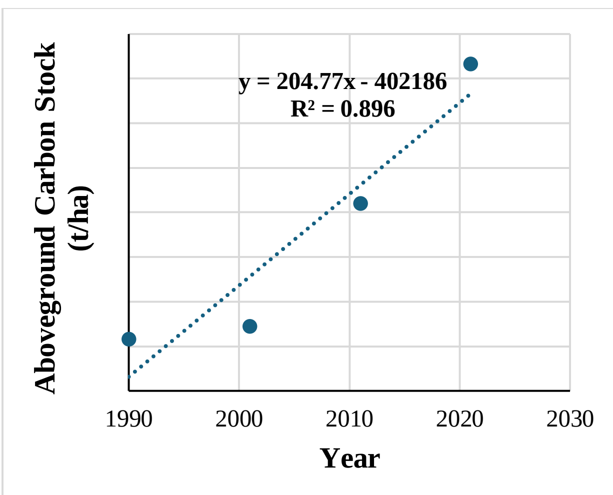


*Figure 4.11: AGCS for tree plantations between 1990 and 2021*

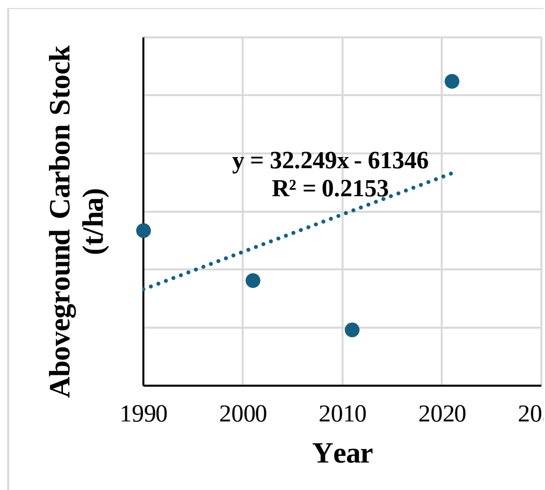


*Figure 4.12: AGCS for woodlands between 1990 and 2021*

**Table 4.10: Trend of Aboveground Carbon Stocks in 1990, 2001, 2011, and 2021**

| Land Use/Cover Type | 1990 | | 2001 | | 2011 | | 2021 | |
|---|---|---|---|---|---|---|---|---|
| | Carbon Stocks (tons) | % | Carbon Stocks (tons) | % | Carbon Stocks (tons ) | % | Carbon Stocks (tons ) | % |
| Built-up Areas | 0.81 | 0.80 | 0.98 | 1.0 | 1.13 | 1.00 | 1.29 | 1.10 |
| Grasslands | 14.56 | 14.40 | 13.57 | 13.5 | 5.51 | 4.90 | 4.02 | 3.40 |
| Papyrus | 65.47 | 64.50 | 58.88 | 58.6 | 45.46 | 40.50 | 49.67 | 41.4 |
| Small-scale Farmlands | 3.18 | 3.10 | 9.88 | 9.8 | 38.56 | 34.40 | 33.73 | 28.10 |
| Tree Plantations | 11.50 | 11.30 | 1.03 | 12.0 | 17.19 | 15.30 | 23.01 | 19.20 |
| Woodlands | 5.92 | 5.80 | 5.16 | 5.1 | 4.41 | 3.90 | 8.21 | 6.80 |
| Total | 101.46 | 100.00 | 100.52 | 100 | 112.25 | 100.00 | 119.91 | 100.00 |

The reported aboveground carbon (AGC) stocks from this study for tree plantations (majorly *Eucalyptus spp*) was 23.01 t C. This is lower than other reported tree C stocks from Masaka (28.6 t C) and higher than that reported from Soroti (12.7 t C $ha^{-1}$), Uganda (Hedman, 2019); Bushenyi District in southwestern Uganda (5.45-7.01 Mg ) (Nakakaawa *et al.*, 2010); as well as tree plantations from Rwanda (16.8 Mg C) (Mugabowindekwe *et al.*, 2023). However, the AGC value from this study is lower than total C stocks accumulated in *Eucalyptus netizens* (352 Mg C) and *Eucalyptus globulus* (254 Mg C) from Chile (Olmedo *et al.*, 2020) as well as *Eucalyptus* plantations from Southern Brazil (118.5 Mg C) (Viera & Rodríguez-Soalleiro, 2019). The variations in the aboveground C stocks for tree plantations could be attributed to the differences in stem density, stand age structure, tree species assessed, and the method used (Sharma *et al.*, 2011).

The aboveground C stocks for small-scale farmlands for this assessment (33.7 t C) varied greatly from C estimations of cultivated land in south western Uganda (6.6 t C ) (Langan *et* *al.,* 2019), coffee plantations in the Elgon region of Uganda (0.250-2.317 t C) (Justine *et al.,* 2019), and small-holder farms of western Kenya (0.6 ± 0.1 t C ) (Henry *et al.,* 2009). Hedman (2019) argued that cropland C stocks are expected to be the most unstable due to differences in land management, harvesting, ploughing, planting new seedlings, and whether the plantation is rain-fed or irrigated (Niang *et al.,* 2014). Henry *et al.,* (2009) suggested that to increase the accuracy of crop AGB C assessment, development of site-specific allometric equations and permission of plant harvesting are needed. Furthermore, the sampling of vegetation sampling should preferably be done before harvest periods to capture the biomass at peak growth state (Hedman, 2019).

The results of the total aboveground carbon stock with papyrus being the largest C stock as compared to woodlands deviates with previous studies (Hedman, 2019). Langan *et al.,* (2019) reported forest to have the highest aboveground biomass carbon, followed by reeds, papyrus, grasslands, and cultivated land in a wetland complex of southwestern Uganda. However, the total AGB C stocks for woodlands of 8.21 t C, are in comparison lower to regional woodland estimates for East Africa (221.9-236.5 t C) (Willcock *et al.,* 2012). This may be attributed to underestimation of the shrub vegetation, the dominant composition of woodlands in the tropics (Hedman, 2019). Therefore, it is worth noting the low value of AGB C stock for woodlands in Kanyabaha wetland could be attributed to the fact that trees were young and scattered.

Table 4.11 shows the trend of belowground carbon stocks in Kanyabaha wetland in 1990, 2001, 2011, and 2021. In all the years, belowground carbon stocks are highest under papyrus. In 1990, the least belowground carbon stock was observed under small-scale farmlands, however, in 2021, grasslands have the least belowground carbon stocks. Between 1990 and 2021, the belowground carbon stocks under tree plantations and built-up areas increased whereas that under grasslands decreased. The belowground carbon stocks under small-scale farmland increased between 1990 and 2011 and then decreased between 2011 and 2021. For papyrus and woodlands, their belowground carbon stocks decreased between 1990 and 2011 and then increased between 2011 and 2021. For all the years and wetland use/cover types, belowground carbon stocks were highest at the 50-100cm soil layer and least at the 0-20cm soil layer i.e., belowground carbon stocks increased with soil depth.

**Table 4.11: Trend in Belowground Carbon Stock in Kanyabaha Wetland in 1990, 2001, 2011, and 2021 (tons)**

| Year | 1990 | | | 2001 | | | 2011 | | | 2021 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil depth (cm) | 0-20 | 20-50 | 50-100 | 0-20 | 20-50 | 50-100 | 0-20 | 20-50 | 50-100 | 0-20 | 20-50 | 50-100 |
| Built-up areas | 3.02 | 425 | 9.27 | 3.62 | 5.10 | 11.13 | 4.17 | 5.86 | 12.79 | 4.77 | 6.71 | 14.64 |
| Grasslands | 17.05 | 21.19 | 33.99 | 15.89 | 19.74 | 31.69 | 6.45 | 8.01 | 12.85 | 4,71 | 5.85 | 9.38 |
| Papyrus | 27.74 | 34.02 | 52.69 | 24.95 | 30.60 | 47.38 | 19.26 | 23.62 | 36.58 | 21,04 | 25.80 | 39.96 |
| Small-scale farmlands | 1.53 | 1.99 | 307 | 4.76 | 6.17 | 9.55 | 18.59 | 24.09 | 37.23 | 16.25 | 21.07 | 32.58 |
| Tree plantations | 5.49 | 7.50 | 12.70 | 5.74 | 7.84 | 13.28 | 8.20 | 11.20 | 18.97 | 10.97 | 14.99 | 25.39 |
| Woodlands | 7.44 | 12.21 | 3153 | 6.49 | 10.64 | 27.49 | 5.53 | 9.08 | 23.44 | 10.30 | 16.91 | 43.65 |

The highest belowground carbon at 50-100 cm depth in Kanyabaha wetland was observed under woodlands (43.65 t C). This finding deviates from those of Hedman (2019) who found papyrus to have the highest BG C stock in Masaka District, Uganda (331.1 ± 437.8 t C). The high BGC stocks for woodlands are due to the high accumulation of organic matter in soils and a commonly deep organic soil profile that over time can build-up large reservoirs of C (Villa & Bernal, 2018). The woodlands in wetlands of Uganda have been associated with clay-rich soils, whose fine structured texture reduces the availability of oxygen and limits oxygen-required microorganisms involved in the decomposition processes (Langan *et al.,* 2019). In addition, clay has stronger binding of humus to clay particles with relatively large particle surface area, thus increasing the protection of the organic matter, hence higher carbon stocks in wetland soils (McCauley *et al.,* 2009).

In terms of temporal variability, papyrus exhibited the highest carbon stocks in Kanyabaha wetland between 1990 and 2021. These findings differ from those of Langan et al (2019) who found the forested wetlands in Kashambya wetland complex, Kabale District, Uganda, to have a higher mean carbon stocks than papyrus. Papyrus wetlands are significant sinks of carbon because large amounts of plant detritus can accumulate below the living mat of rhizomes and roots (Jones & Muthuri, 1997). In addition, papyrus plants utilize a $C_4$ photosynthetic pathway, which contributes to high rates of carbon assimilation and net productivity as $C_4$ plants tend to exhibit higher conversion efficiencies of solar radiation into dry matter than their $C_3$ counterparts (Saunders *et al.,* 2014). However, the conversion of papyrus to other land uses such as farmlands and built-up areas could have significant implications on the global carbon cycle through decomposition of SOM and carbon flux to the atmosphere, thereby contributing to climate change. There is already supporting evidence that conversion from natural habitats rapidly depletes the carbon stocks (Williams *et al.,* 2018).

**Belowground Carbon Stocks for the Different Land Use/Cover Types across the Same Soil Depth for a period 1990-2021**

The belowground carbon stocks were highest under papyrus and lowest under built-up areas as shown below (Figures 4.13a, 4.13b and 4.13c). The belowground carbon stocks for all the land use/cover types increased with soil depth. The belowground carbon stocks for built-up areas and tree plantations increased between 1990 and 2021. The belowground carbon stocks for grasslands decreased between 1990 and 2021. The belowground carbon stocks for papyrus and woodlands decreased between 1990 and 2011 and then increased between 2011 and 2021. The belowground carbon stocks for small-scale farmlands increased between 1990 and 2011, and then decreased between 2011 and 2021.

A. Soil depth (0-20cm)

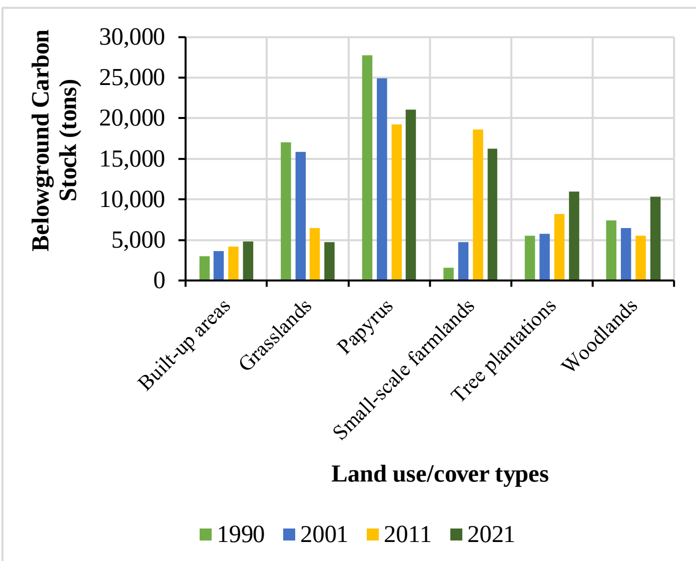


***Figure 4.13a: Belowground carbon stocks for the different land use/cover types at 0-20cm***

B. Soil depth (20-50cm)

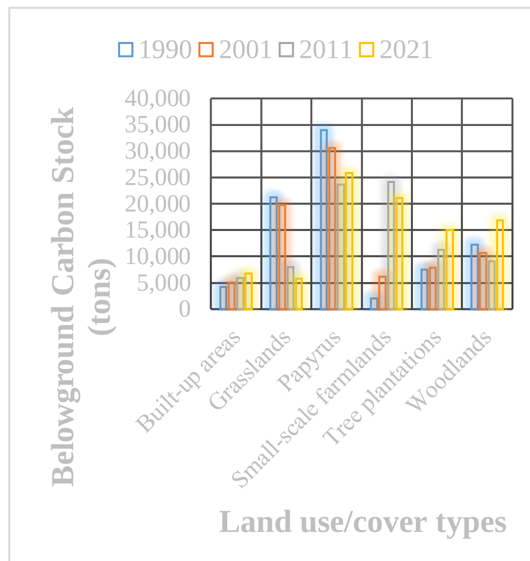


***Figure 4.13b: Belowground carbon stocks for the different land use/cover types at 20-50cm***

C. Soil depth (50-100cm)

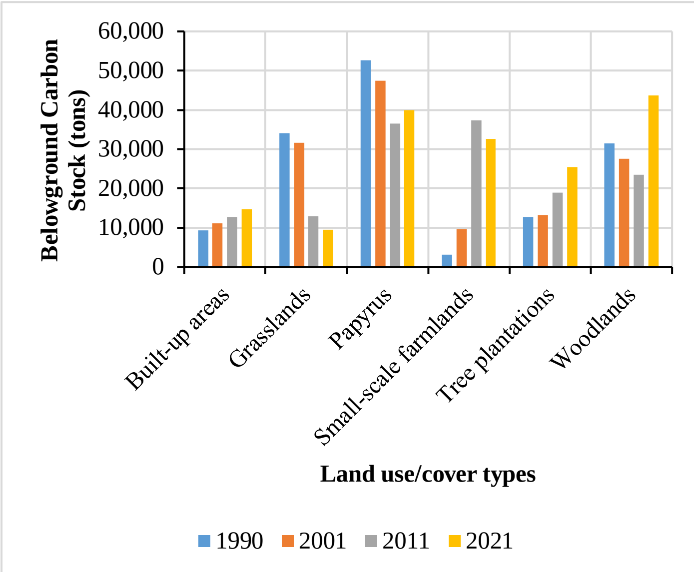


***Figure 4.13c: Belowground carbon stocks for the different land use/cover types at 50-100cm***

The assessment of total carbon stock in Kanyabaha wetland is presented in Figure 4.14. Between 1990 and 2021, total carbon stock is highest in the papyrus class. Small-scale farmlands had the least total carbon stock in 1990 whereas in 2021, grasslands had the least total carbon stock. Between 1990 and 2021, the total carbon stocks under tree plantations and built-up areas increased whereas that under grasslands decreased. The total carbon stocks under small-scale farmlands increased between 1990 and 2011 and then decreased between 2011 and 2021. The total carbon stocks for papyrus and woodlands decreased between 1990 and 2011 and then increased between 2011 and 2021 (Figure 4.14).

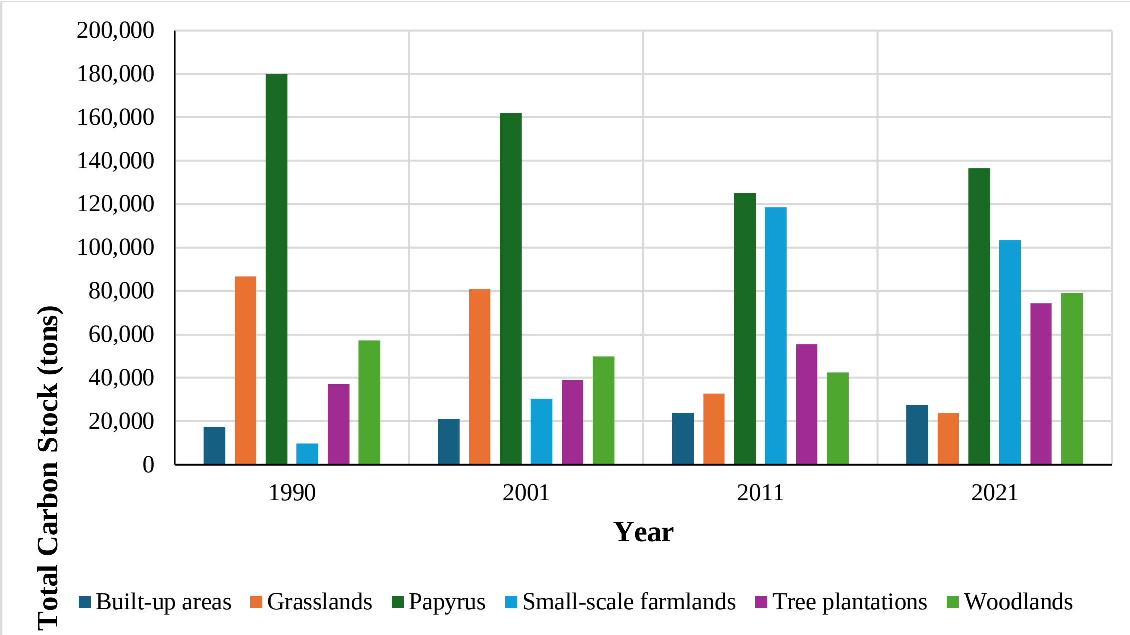


***Figure 4.14: Trend of total carbon stocks in Kanyabah wetland in 1990, 2001, 2011, 2021***

### 4.3.4 Bulk Density at Various Soil Depth and Land Use/Cover Types in Kanyabaha Wetland

At 0-20cm soil depth, bulk density ranged between 0.031ton/m$^3$ and 0.54 ton/m$^3$. At 20-50cm soil depth, bulk density ranged between 0.015 ton/m$^3$ and 0.59 ton/m$^3$. At 50-100cm soil depth, bulk density ranged between 0.014 ton/m$^3$ and 0.92 ton/m$^3$. Generally, the mean bulk density in Kanyabaha wetland was highest at the deepest soil layer considered (50-100cm), followed by the middle soil layer (20-50cm), and then the topsoil layer (0-20cm) (Table 4.12).

***Table 4.12: Descriptive Statistics of Bulk Density at Various Soil Depths in Kanyabaha Wetland***

| Soil Depth (cm) | Mean (ton/m$^3$) |
|---|---|
| 0-20 | 0.291±0.013 |
| 20-50 | 0.297±0.017 |
| 50-100 | 0.342±0.022 |

There are minimal noticeable differences in bulk density at various soil depth in Kanyabaha wetland (Figure 4.15). Lower amounts of bulk density can be found in the middle of the wetland, moderate amounts are located upstream, whereas higher amounts of bulk density can be found downstream of the wetland.

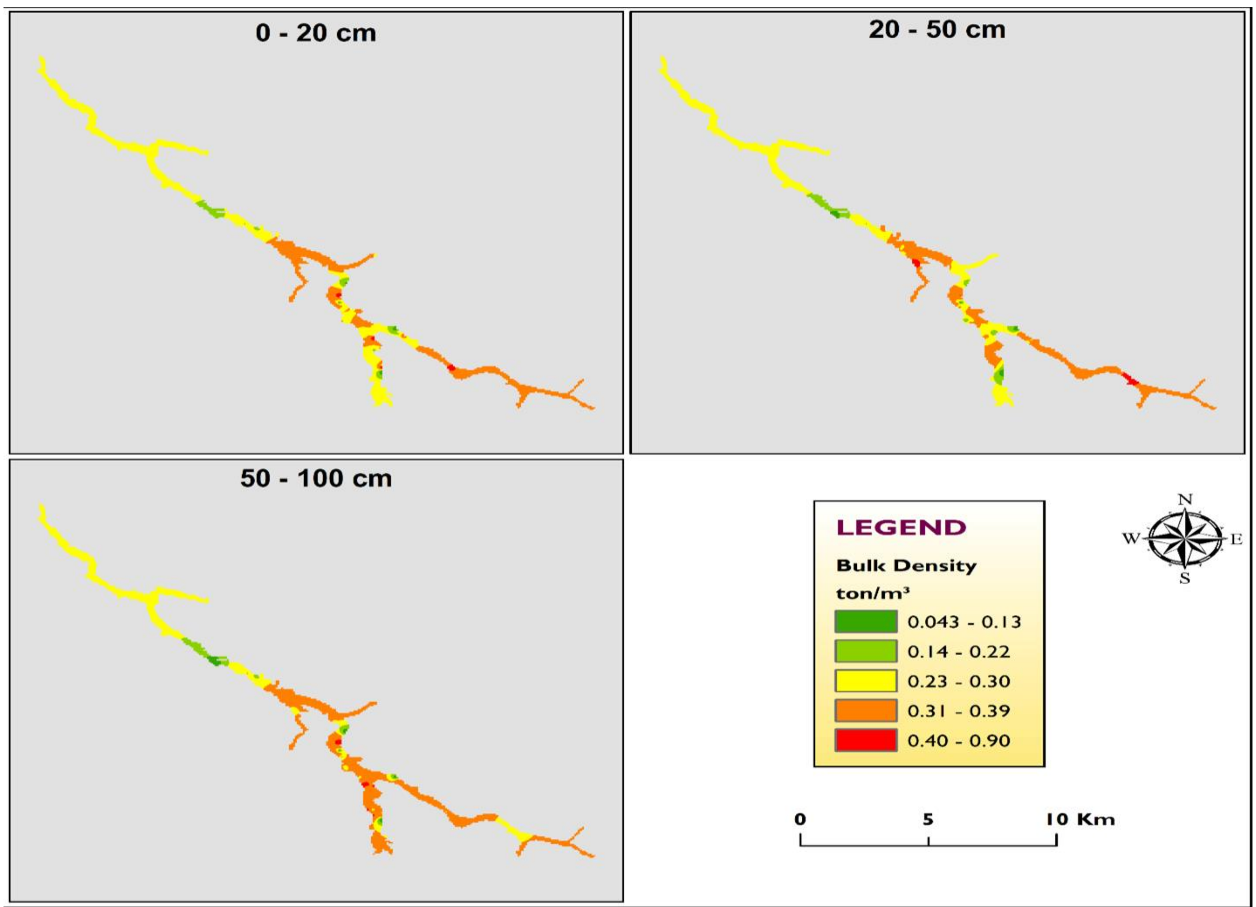


***Figure 4.15: Bulk density at various soil depth in Kanyabaha wetland in 2021***

The bulk density under built-up areas ranged between 0.062 ton/m$^3$ and 0.74 ton/m$^3$. In grasslands, bulk density ranged between 0.012 ton/m$^3$ and 0.53 ton/m$^3$. The bulk density under papyrus ranged between 0.034 ton/m$^3$ and 0.39 ton/m$^3$. In small-scale farmlands, bulk density ranged between 0.104 ton/m$^3$ and 0.54 ton/m$^3$. The bulk density under tree plantations ranged between 0.169 ton/m$^3$ and 0.63 ton/m$^3$. In woodlands, bulk density ranged between 0.067ton/m$^3$ and 0.92ton/m$^3$. Generally, woodlands exhibited the highest mean bulk density in Kanyabaha wetland (0.533 ton/m$^3$), followed by tree plantations and then small-scale farmlands. The least mean bulk density in Kanyabaha wetland was observed in grasslands (0.261 ton/m$^3$) (Table 4.1.3).

**Table 4.13: Bulk Density at Different Land Use/Cover Types in Kanyabaha Wetland**

| Land Use/Cover Type | Mean (ton/m$^3$) |
|---|---|
| Built-up | 0.324±0.039 |
| Grasslands | 0.261±0.020 |
| Papyrus | 0.278±0.026 |
| Small-scale Farming | 0.326±0.012 |
| Tree Plantations | 0.335±0.019 |
| Woodlands | 0.533±0.198 |

Slight variations were observed in soil bulk density at the various soil depths in Kanyabaha wetland. Similar findings have been also reported by Bae & Ryu (2015) who found the vertical distribution of soil bulk density not to differ significantly across the soil depth layers of wetland soils. The increasing soil bulk density with depth can be attributed to the continuous input of freshly dead plant biomass on the topsoil layers. The highest soil bulk density in Kanyabaha wetland was observed in woodlands and this can be due to soil compaction from grazing activities. The increase in population in southwestern Uganda has reduced rangelands available for grazing animals, and this has pushed communities to graze from wetlands (Byenkya *et al.,* 2014). This finding is consistent with previous studies that reported human activities to increase soil bulk density in topsoil layer (Beesley, 2012). Furthermore, the excessive soil compaction disrupts vertical root penetration, and this could reduce the movement of the SOC into the deep soil layers (Watson & Kelsey, 2006). This could account for the lowest SOC concentration (3.08%) that was observed under woodlands in Kanyabaha wetland.

## 4.4 Effect of Wetland Livelihood Activities on Carbon Stocks and Plant Species Diversity in Kanyabaha Wetland

### 4.4.1 Livelihood Activities and Associated Carbon Stocks

The wetland dependent livelihood activities that were observed in Kanyabaha wetland and have a direct bearing on carbon stocks included crop growing and tree planting. The carbon stocks for the different livelihood activities varied by soil depth. At 0-20cm, the carbon stocks for beans ranged between 22.3 tons and 23.4 tons. The carbon stocks for cabbages ranged between 20.4ton and 37.7 tons. For Irish potatoes, the carbon stocks ranged between 20.3tons and 26.9 tons. The carbon stocks for sweet potatoes ranged between 13.0 tons and 32.3 tons. For tobacco, the carbon stocks ranged between 35.6ton and 39.3ton. The carbon stocks for eucalyptus ranged between 18.9 tons and 210.5tons. The highest carbon stocks at the 0-20cm soil depth were observed under eucalyptus tree planting (74.0±16.8 tons) whereas the least was observed under beans (22.8±0.5 tons)

At 20-50cm, the carbon stocks for beans ranged between 31.2 tons and 32.6 tons. The carbon stocks for cabbages ranged between 30.3 tons and 46.1 tons. For Irish potatoes, the carbon stocks ranged between 39.0 tons and 63.5 tons. The carbon stocks for sweet potatoes ranged between 20.1tons and 80.1tons. For tobacco, the carbon stocks ranged between 49.1tons and 50.6 tons. The carbon stocks for eucalyptus ranged between 23.5 tons and 320.5 tons. The highest carbon stocks at the 20-50cm soil depth were observed under eucalyptus tree planting (113.4±25.8) whereas the least was observed under beans (31.9±0.7)

At 50-100cm, the carbon stocks for beans ranged between 48.1tons and 49.7 tons. The carbon stocks for cabbages ranged between 30.3 tons and 46.1tons. For Irish potatoes, the carbon stocks ranged between 39.0 tons and 63.5 tons. The carbon stocks for sweet potatoes ranged between 20.1tons and 80.1tons. For tobacco, the carbon stocks ranged between 49.1tons and 50.6 tons. The carbon stocks for eucalyptus ranged between 23.5tons and 320.5tons. The highest carbon stocks at the 50-100cm soil depth were observed under eucalyptus tree planting (196.7±42.2) whereas the least was observed under beans (48.9±0.8).

The total carbon stocks for beans ranged between 101.6 tons and 102.5 tons. The total carbon stocks for cabbages ranged between 103.4 tons and 147.2 tons. For Irish potatoes, the total carbon stocks ranged between 201.1tons and 209.7tons. The total carbon stocks for sweet potatoes ranged between 85.1 tons and 191.5tons. For tobacco, the total carbon stocks ranged between 181.8 tons and 190.3 tons. The total carbon stocks for eucalyptus ranged between 68.4tons and 1074.1tons. The highest total carbon stocks were observed under eucalyptus tree planting (372.5±81.1) whereas the least were observed under beans (101.6±0.4) (Table 4.14)

**Table 4.14: Mean (±SE) carbon Stocks (tons) for Various Livelihood Activities at the Various Soil Depths in Kanyabaha Wetland**

| Livelihood activities | Crops/trees grown | 0-20cm | 20-50cm | 50-100cm | Total |
|---|---|---|---|---|---|
| | Beans | 22.8±0.5 | 31.9±0.7 | 48.9±0.8 | 101.6±0.4 |
| Crop growing | Cabbages | 28.0±3.3 | 40.3±3.3 | 55.1±4.7 | 123.4±9.5 |
| | Irish potatoes | 23.6±3.3 | 51.3±12.8 | 130.5±13.3 | 205.5±4.3 |
| | Sweet potatoes | 23.2±3.6 | 43.1±9.9 | 68.9±6.8 | 135.2±18.0 |
| | Tobacco | 37.5±1.8 | 49.9±0.7 | 98.7±3.1 | 186.0±4.2 |
| Tree planting | Eucalyptus | 74.0±16.8 | 113.4±25.8 | 196.7±42.2 | 372.5±81.1 |

The belowground carbon stocks increased with soil depth for all the sampled wetland dependent livelihood activities (Figure 4.16). Generally, the belowground carbon stocks were highest under eucalyptus tree planting, followed by Irish potatoes, tobacco, sweet potatoes, cabbages, and beans in that order. There was significant variation in the carbon stocks for tree planting and that of crop growing (ANOVA F= 5.02, df = 180,186, p = 0.000).

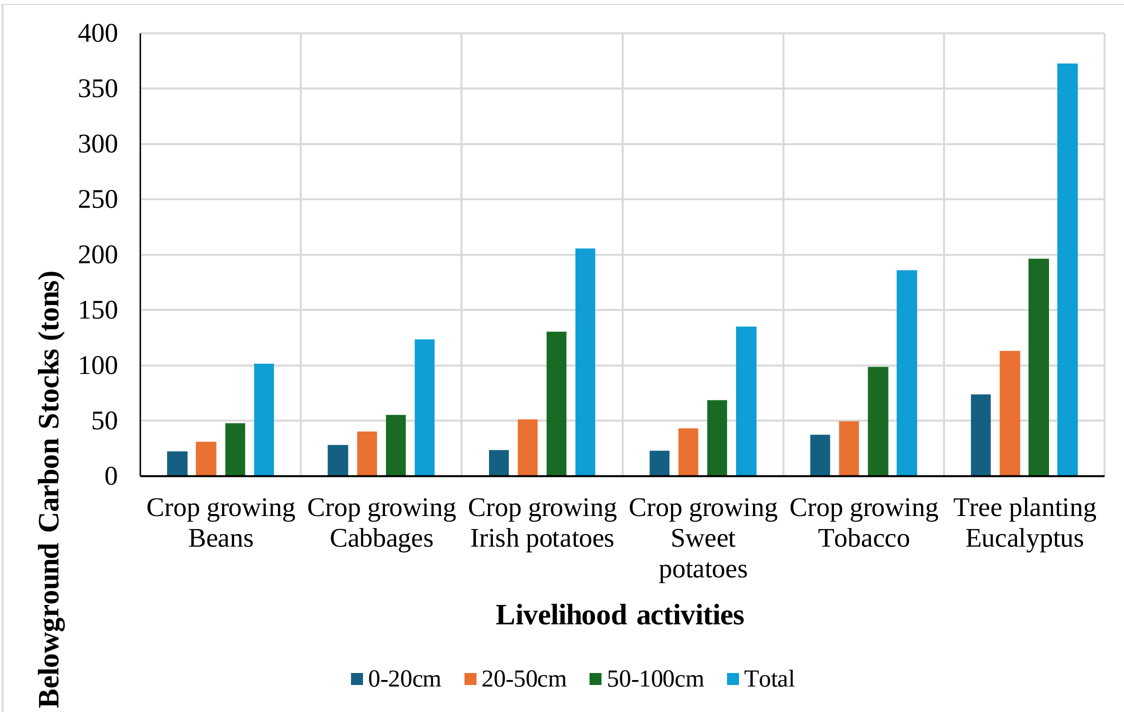


***Figure 4.16: Carbon stocks for the different wetland dependent livelihood activities at various soil depths***

The wetland dependent livelihood activities had a very significant impact on carbon stocks in Kanyabaha wetland (P<0.05) (4.15).

**Table 4.15: Analysis of Variance (ANOVA) for all Six Livelihood Activities and Carbon Stocks**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Livelihood | 6 | 613293 | 102215 | 5.02 | 0.000 |
| Error | 180 | 3663541 | 20353 | | |
| Total | 186 | 4276833 | | | |

The study conducted in Kanyabaha wetland explored the effect of wetland-dependent livelihood activities on carbon stocks, specifically focusing on crop growing and tree planting. The findings revealed variations in carbon stocks across different soil depths and types of activities.

At a depth of 0-20cm, it was observed that eucalyptus tree planting exhibited the highest carbon stocks compared to crop growing activities such as beans, cabbages, Irish potatoes, sweet potatoes, and tobacco. Similar trends were observed at greater depths (20-50cm and 50-100cm), where eucalyptus tree planting consistently showed higher carbon stocks compared to crop growing activities. This suggests that tree planting, particularly with eucalyptus, contributes significantly to carbon sequestration in the wetland.

These findings align with earlier studies that have highlighted the role of tree planting in enhancing carbon sequestration. For instance, Smith et al. (2015) emphasized the importance of afforestation and reforestation programs in mitigating climate change by sequestering carbon from the atmosphere. Similarly, Jones and Smith (2018) found that certain tree species, including *eucalyptus*, have high potential for carbon sequestration due to their rapid growth and dense biomass.

Moreover, the study indicated that belowground carbon stocks increased with soil depth for all sampled livelihood activities. This highlights the significance of considering soil depth when assessing carbon sequestration potential, as deeper soil layers may store a substantial amount of carbon. The significant variation in carbon stocks between tree planting and crop growing activities, as indicated by the ANOVA results, further emphasizes the importance of incorporating tree planting into wetland management strategies to enhance carbon sequestration.

In conclusion, the findings suggest that wetland-dependent livelihood activities have a notable impact on carbon stocks in Kanyabaha wetland, with tree planting, particularly eucalyptus, playing a crucial role in carbon sequestration. These results reinforce the importance of promoting sustainable land management practices that integrate tree planting to mitigate climate change and enhance carbon storage in wetland ecosystems.

### 4.4.2 Livelihood Activities and Plant Species Diversity

Wetlands are diverse ecosystems in their spatial patterning, hydrological conditions and plant species (Tan Z et. *al.*, 2016). Since so many anthropogenic activities take place in wetlands, ground truthing was necessary in Kanyabaha wetland to identify them. It was found out that the dominant land use cover in the study area was farming followed by agroforestry (Figure 4.17). This means that a significant portion of the wetland vegetation was removed to cultivate crops.

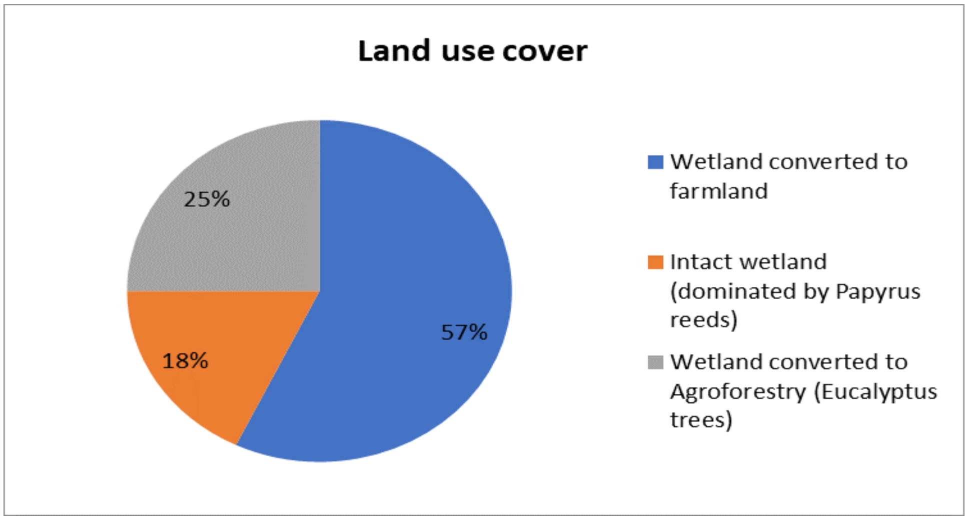


***Figure 4.17: Results showing Land use cover in Kanyabaha Wetland during Data Collection Period***

Wetlands provide a range of valuable ecosystem services, such as the provision of food, fresh water, soil erosion control, flood regulation, nutrient cycling among others (Burkhard and Maes, 2017). However, the value of these services is sometimes underestimated through draining and conversion of wetlands to farmland so as to increase food production for commercial purposes (Edmond, 2020). Wubie *et. al.*, (2016) further noted that an increased demand for agriculture, timber and construction material put severe pressure on uncultivated wetlands (to expand croplands), forests and shrub land by encroachers.

Land use change resulting from anthropogenic activities such as clearing the wetland for agriculture greatly affects food security and environmental sustainability (Popp *et. al.*, 2014). These activities, if not carefully monitored and regulated, can result into wetland deterioration.

A study done by Jeff Houlahan *et. al.,* (2006) also noted that landscape properties such as land use cover significantly predict species richness. This means that any activity that takes place in the wetland directly affects its plant communities.

Naibbi et.*al*., (2014) noted that changes in vegetation cover may be directed to land use change. So, it was necessary to take Landsat images into consideration. Carefully analyzed Landsat images derived from US. Geological survey topographic maps show changes in vegetation cover over time (Figure 4.18).

Results show that Kanyabaha wetland, agriculture and bare soils have been increasing over the years. Wood canopy has been decreasing over the years (Figure 4.18).

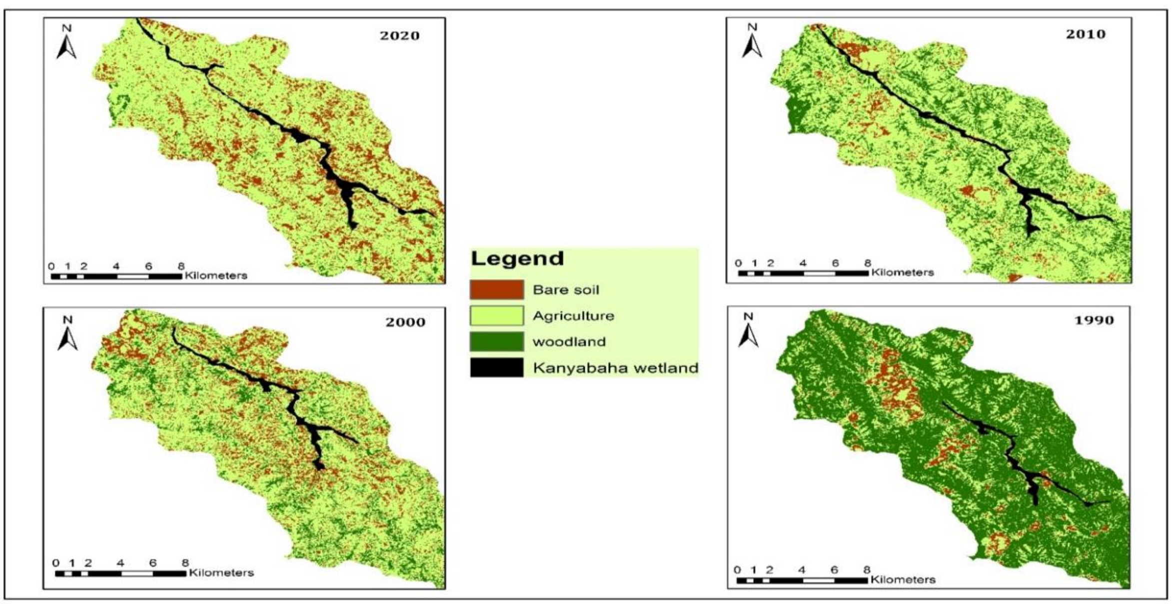


***Figure 4.18: Map showing Spatial Distribution of Agriculture, Woodland and Bare Soil in Rukiga District (from 1990 to 2020)***

An increase in Kanyabaha wetland over time could probably be due to the wetland restoration measures put up by the responsible authorities in Uganda. Another reason could be due to deforestation. A study done by Craig (2015) found out that this anthropogenic activity over time results into creation of new wetlands due to an increase in the amount of water flow into the wetlands (permanent, seasonal/temporal).

A decrease in woodland canopy over the years is a sign of deforestation. Deforestation is one of the global issues that have greatly altered the land cover resulting into exposing of the ground to direct sunlight. This explains why bare soil over the years has increased.

After clearing the land, activities such as agriculture usually follow. This could probably be the reason as to why agriculture has increased over the years.

#### ***4.4.2.1: Plant Species Composition***

A total of 31 plant species from 19 families were recorded in the Kanyabaha wetland (Table 4.16). These species encompassed a range of growth forms, including herbs (17), sedges (5), grasses (4), shrubs (4), trees (2), and a fern (1). Asteraceae and *Polygonaceae* were the most species-rich families, each contributing three species (9.7%), while the remaining 17 families accounted for 80.6% of species richness with one or two species each. In terms of abundance, vegetation was dominated by a few prolific species: Eucalyptus sp. (764 individuals), Cyperus papyrus (249), and *Vossia cuspidata* (200), which together comprised over 61% of the total plant count (1,213 out of 1,986).

**Table 4.16. Plant Species Composition in Kanabaha Wetland System. Values refer to number of individuals (abundance) of the species in each wetland.**

| No | Plant Species | Life Form | Family | Village (corresponds to respective wetland) | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Rutenje | Kitanga | Kitojo | Kyerero | Kandago | Burime | |
| 1 | *Eucalyptus* sp. | Tree | Myrtaceae | 161 | 424 | 149 | | | 30 | 764 |
| 2 | *Cyperus papyrus* L. | Sedge | Cyperaceae | 89 | 87 | 29 | 9 | 8 | 27 | 249 |
| 3 | Vossia cuspidata (Roxb.) Griff. | Grass | Poaceae | 71 | 69 | 23 | 7 | 6 | 24 | 200 |
| 4 | *Pycreus nitidus (Lam.)* J.Raynal | Sedge | Cyperaceae | 47 | | | 15 | 66 | | 128 |
| 5 | *Rumex abyssinicus* Jacq. | Herb | Polygonaceae | 113 | | | | | | 113 |
| 6 | *Crassocephalum montuosum* (S.Moore) Milne-Redh. | Herb | Asteraceae | 63 | | | 5 | | | 68 |
| 7 | *Impatiens burtonii* Hook.f. | Herb | Balsaminaceae | 54 | | | | | | 54 |
| 8 | *Cyperus dives* Del. | Sedge | Cyperaceae | 18 | 17 | 6 | 2 | 2 | 5 | 50 |
| 9 | *Persicaria setosula* (A.Rich.) K.L.Wilson | Herb | Polygonaceae | | | | 15 | 25 | | 40 |
| 10 | *Digitaria scalarum* (Schweinf.) Chiov. | Grass | Poaceae | 11 | 10 | 3 | 1 | 1 | 4 | 30 |
| 11 | *Miscanthidium violaceum* (K.Schum.) Robyns | Grass | Poaceae | 9 | 9 | 3 | 1 | 1 | 2 | 25 |
| 12 | *Pennisetum purpureum* Schumach. | Grass | Poaceae | 9 | 9 | 3 | 1 | 1 | 2 | 25 |
| 13 | *Spathodea campanulata* Buch.-Ham. ex DC. | Tree | Bignoniaceae | 2 | 8 | | 5 | 7 | | 22 |
| 14 | *Ludwigia abyssinica A.Rich.* | Herb | Onagraceae | 7 | 7 | 2 | 1 | 1 | 2 | 20 |
| 15 | *Melanthera scandens* (Schumach. & Thonn.) Brenan | Herb | Asteraceae | 7 | 7 | 2 | 1 | 1 | 2 | 20 |
| 16 | *Nymphaea lotus* L. | Herb | Nymphaeaceae | 7 | 7 | 2 | 1 | 1 | 2 | 20 |
| 17 | *Typha capensis* (Rohrb.) N.E.Br. | Herb | Typhaceae | 7 | 7 | 2 | 1 | 1 | 2 | 20 |
| 18 | *Carex congolensis Turrill* | Sedge | Cyperaceae | 7 | 7 | 2 | 1 | 1 | 2 | 20 |
| 19 | *Cladium mariscus (L.) Pohl* | Sedge | Cyperaceae | 7 | 7 | 2 | 1 | 1 | 2 | 20 |
| 20 | *Myrica kandtiana Engl.* | Shrub | Myricaceae | 5 | 5 | 2 | 1 | 1 | 1 | 15 |
| 21 | *Rubus rigidus Sm.* | Shrub | Rosaceae | 5 | 5 | 2 | 1 | 1 | 1 | 15 |
| 22 | *Acalypha psilostachya* Hochst. ex A.Rich. | Shrub | Euphorbiaceae | 4 | 4 | 1 | | | 1 | 10 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 23 | *Achyranthes aspera* L. | Herb | Amaranthaceae | 4 | 4 | 1 | | | 1 | 10 |
| 24 | *Persicaria senegalensis* (Meisn.) Soják | Herb | Polygonaceae | 4 | 4 | 1 | | | 1 | 10 |
| 25 | *Phytolacca dodecandra* L'Hér. | Shrub | Phytolaccaceae | 4 | 4 | 1 | | | 1 | 10 |
| 26 | *Polygonum senegalense* Meisn. | Herb | Polygonaceae | 4 | 4 | 1 | | | 1 | 10 |
| 27 | *Crassocephalum vitellinum* S.Moore | Herb | Asteraceae | | | | | | 5 | 5 |
| 28 | *Thelypteris confluens* (Thunb.) C.V.Morton | Fern | Thelypteridaceae | 2 | 2 | | | | 1 | 5 |
| 29 | *Acacia mearnsii* De Wild. | Tree | Fabaceae | 1 | | 2 | | | 1 | 4 |
| 30 | *Ocimum basilicum* L. | Herb | Lamiaceae | | | | | | 2 | 2 |
| 31 | *Hibiscus diversifolius* subsp. *rivularis* (Bremek. & Oberm.) Exell | Shrub | Malvaceae | 2 | | | | | | 2 |
| | **Total** | | | **724** | **707** | **239** | **69** | **125** | **122** | **1,986** |

*Values refer to number of individuals (abundance) of the species in each wetland.*

A total of 31 plant species belonging to 19 families were recorded across the six surveyed wetlands. Species richness varied among the sites. Rutenje and Burime wetlands, which are subject to moderate levels of human activity, recorded the highest richness with 18 and 17 species, respectively. In contrast, Kitojo, Kandago, and Kitanga wetlands exhibited the lowest richness, ranging from 10 to 12 species. These differences appear to reflect the intensity of human disturbance. Rutenje and Burime, with relatively intact sections alongside moderate human activities such as crop cultivation, settlements, fish farming, and selective harvesting of *Cyperus papyrus*, supported more diverse plant assemblages. In contrast, the higher levels of disturbance from agricultural expansion and settlement in Kitojo, Kandago, and Kitanga correspond with reduced species richness and simplified vegetation structure. These findings align with field-based assessments, which revealed that 57.1% of the surveyed wetlands had been converted into farmland, while 25.0% had been modified for agroforestry, primarily through the establishment of Eucalyptus plantations. Only 17.9% of the wetlands remained relatively intact, with papyrus-dominated stands. This spatial pattern highlights the rapid rate of wetland transformation and reinforces growing concerns over biodiversity loss in Uganda’s fragile wetland ecosystems (Gimbo et al., 2024; Matovu et al., 2024). Although these results support the commonly observed trend in which lower disturbance levels correlate with higher species richness, they differ from the findings of Takuwa et al. (2024), who reported greater species diversity in highly disturbed wetland sites. Similarly, Mulatu et al. (2014) observed higher richness in cultivated wetlands than in uncultivated sites in the South Bench District of southwest Ethiopia. Such discrepancies underscore the context-specific nature of disturbance-diversity relationships and highlight the need to account for multiple ecological and socio-economic variables.

The variation in plant composition among wetlands likely reflects species-specific ecological traits, disturbance intensity, and landscape context. For example, Bullock et al. (2017) emphasize the effective dispersal mechanisms of Asteraceae species, which facilitate their establishment in both disturbed and undisturbed areas. Likewise, Mamman et al. (2023) attribute the dominance of certain families to their efficient seed dispersal strategies, while the limited presence of others may result from poor regeneration capacity or sensitivity to human pressure. Suding et al. (2008) and Wang et al. (2022) further argue that the resilience of plant communities depends on both the type and intensity of disturbance and the recolonization capacity of individual species. Gojamme et al. (2024) also link wetland plant diversity to catchment-level variables such as hydrology, land-use patterns, and elevation.

These differences appear to reflect the intensity of human disturbance. Rutenje and Burime, with relatively intact sections alongside moderate human activities such as crop cultivation, settlements, fish farming, and selective harvesting of Cyperus papyrus, supported more diverse plant assemblages. In contrast, the higher levels of disturbance from agricultural expansion and settlement in Kitojo, Kandago, and Kitanga correspond with reduced species richness and simplified vegetation structure. It should be noted that the descriptors ‘highly disturbed’ and ‘less disturbed’ in this study are based on qualitative observations of human activity, land-use changes, and vegetation modification, rather than precise quantitative measurements. Consequently, these terms provide a general indication of anthropogenic influence, and interpretations regarding species richness, diversity, or dominance patterns should be made with caution. Future studies incorporating measurable disturbance metrics would strengthen understanding of the relationship between human activities and wetland plant communities. These findings align with field-based assessments, which revealed that 57.1% of the surveyed wetlands had been converted into farmland, while 25.0% had been modified for agroforestry, primarily through the establishment of Eucalyptus plantations. Floristically, the families Cyperaceae, Poaceae, Asteraceae, and Polygonaceae were the most represented across the study area. Among the species recorded, Eucalyptus sp., Cyperus papyrus, and Vossia cuspidata were the most abundant and widely distributed, though their dominance varied across sites. This variation in species composition reflects both ecological gradients and anthropogenic influence. The family-level patterns observed in this study are consistent with broader floristic trends in wetland ecosystems. Smith et al. (2022), for instance, reported the dominance of a few key families in various wetland types, while Yuan et al. (2025) documented the prevalence of Cyperaceae, Polygonaceae, and Poaceae in marsh wetlands along the lower Tumen River in northeastern China. In East Africa, Ruto et al. (2023) identified Asteraceae as a dominant family in the riparian zones of Kenya's Mau Forest Complex, while Odull and Byaruhanga (2009) noted the prevalence of Poaceae and Asteraceae in Ugandan wetlands. These patterns suggest that while some families such as Poaceae exhibit wide ecological amplitude, others are more indicative of local environmental conditions, hydrological dynamics, and disturbance regimes.

In summary, this study demonstrates that wetland plant composition is shaped by a combination of species-specific traits and human-induced pressures. Although moderate disturbance may support diverse assemblages in certain contexts, this relationship is not universal. Future research should explore how interactions among disturbance intensity, land-use history, and species traits affect the resilience and conservation status of wetland ecosystems. Such insights are essential for informing sustainable wetland management and biodiversity conservation in rapidly transforming landscapes.

#### *4.4.2.2 Plant Species Diversity*

The assessment of plant species diversity utilized three biodiversity indices: the Shannon-Wiener Diversity Index (H'), Simpson's Diversity Index (D), and Jaccard Similarity Index (J). The results of these indices are presented below, providing a comprehensive evaluation of species richness, evenness, and similarity across sites.

##### *4.4.2.2.1 Shannon-Wiener Diversity Index (H′)*

The overall Shannon-Wiener diversity index (H′) for all six wetland sites combined was 3.05. At the site level, diversity values ranged from 2.39 to 2.66. Kandago recorded the highest H′ value (2.66), followed by Burime (2.61), Kitojo (2.55), Kyerero (2.48), and Rutengye (2.46). Kitanga exhibited the lowest diversity value (H′ = 2.39). To assess whether the observed differences in diversity were statistically significant among the wetland sites, a one-way analysis of variance (ANOVA) was performed on plot-level Shannon indices. The results revealed a statistically significant effect of site on diversity ($F_{(5,\ 114)} = 12.88$, $p < 0.0001$), indicating that the diversity index varied meaningfully between sites. Post hoc comparisons using Tukey’s Honest Significant Difference (HSD) test further identified that Kandago’s mean plot-level H′ was significantly higher than those of Kitanga, Rutengye, and, to a lesser extent, Kyerero ($p < 0.05$).

##### *4.4.2.2.2 Pairwise Jaccard Similarity Index (J)*

Table 4.1.7 presents the pairwise Jaccard Similarity Index (J) values for plant species composition among the six wetland sites. The comparisons revealed clear patterns of floristic overlap and differentiation. Kandago showed the highest similarity with Burime and Kitojo (J > 0.75), indicating a strong overlap in species assemblages. In contrast, Kitanga consistently exhibited the lowest similarity across all pairings (J approximately = 0.58-0.62). To statistically assess differences in plant community composition, a permutational multivariate analysis of variance (PERMANOVA) was performed using Jaccard dissimilarity matrices derived from species presence-absence data. The analysis revealed a statistically significant effect of wetland site on floristic composition ($F = 3.97$, $p = 0.001$), confirming that community structure varied significantly across the six wetlands.

**Table 4.17 Pairwise Jaccard Similarity Index values between the Six Wetland Sites**

| Wetland | Burime | Kandago | Kitojo | Kyerero | Rutengye | Kitanga |
|---|---|---|---|---|---|---|
| **Burime** | * | 0.77 | 0.74 | 0.71 | 0.68 | 0.62 |
| **Kandago** | | * | 0.75 | 0.73 | 0.70 | 0.61 |
| **Kitojo** | | | * | 0.69 | 0.66 | 0.59 |
| **Kyerero** | | | | * | 0.67 | 0.60 |

#### 4.4.2.2.3 Simpson Diversity Index (1-D)

Simpson's Index of Diversity (1-D) ranged from 0.82 to 0.86 across the study sites (Figure 4.19), indicating moderate to high species diversity. Kandago exhibited the highest diversity (0.861), while Kitanga recorded the lowest (0.819). A one-way ANOVA confirmed that these differences were statistically significant ($F (5, 114) = 6.21$, $p < 0.001$), highlighting meaningful variation in community structure among the wetlands.

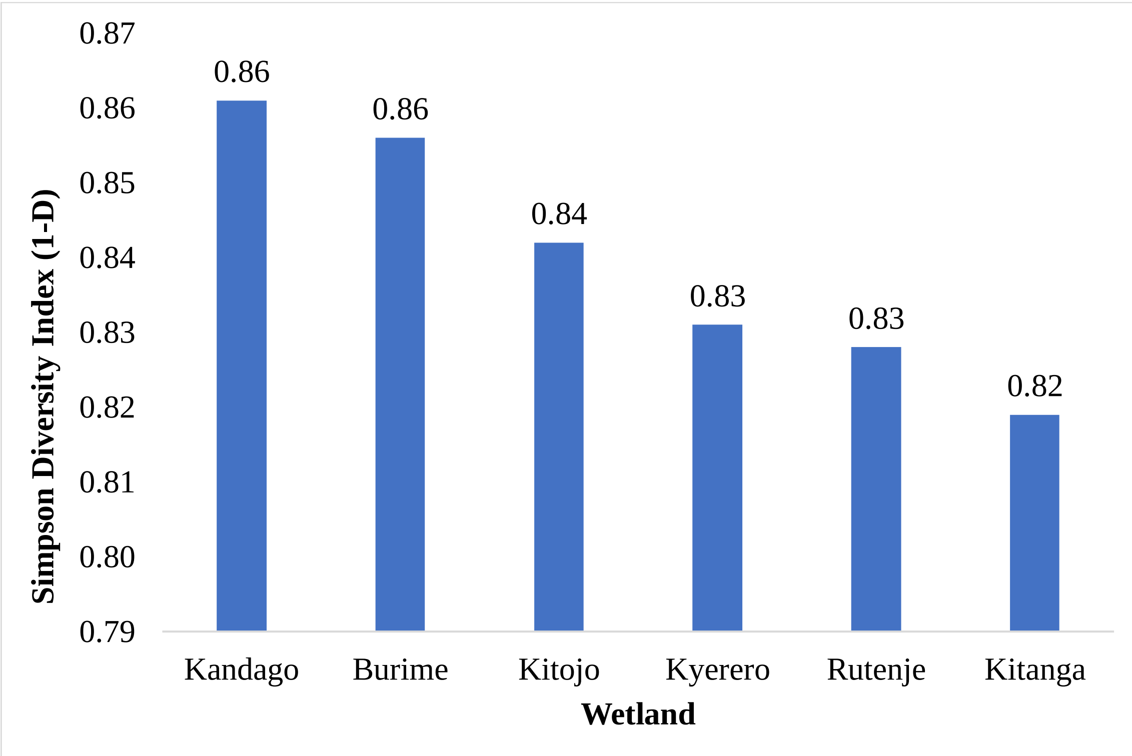


**Figure 4.19 Simpson Diversity Index (D) for the Plant Species in the Kanyabaha Wetland System**

Plant diversity plays a critical role in maintaining ecosystem stability and health (Wu et al., 2024), influencing primary productivity, nutrient cycling, and resilience to environmental changes (Yang et al., 2023). In this study, multiple indices, Shannon-Wiener (H′), Simpson's Index (1-D), and Jaccard Similarity Index (J) were employed to assess plant diversity in the Kanyabaha wetland system. Together, they provide a multidimensional understanding of species richness, evenness, and compositional similarity across sites. The diversity indices revealed meaningful differences in plant community structure among the wetlands. While sites like Rutenje and Burime showed higher species richness, diversity indices such as Shannon-Wiener and Simpson's Index highlighted that Kandago, a site experiencing significant human disturbance exhibited the highest overall diversity. This counterintuitive result underscores the importance of evenness and species distribution, not just richness, in understanding biodiversity patterns. However, this pattern should be interpreted cautiously. Kandago's high diversity indices likely reflect greater species evenness, where individuals are more evenly distributed among species despite low overall richness. Such high diversity does not necessarily indicate ecological integrity, particularly in wetlands dominated by disturbance-tolerant or invasive species. Further analysis of species composition and functional traits in Kandago would help clarify how disturbance and evenness interact to shape observed diversity patterns.

These findings align with studies by Mulatu et al. (2014) and Takuwa et al. (2024), who reported high species diversity in cultivated or disturbed wetland areas. Such patterns may be attributed to increased habitat heterogeneity and colonization opportunities for disturbance-tolerant or invasive species (DeBerry & Hunter, 2024; D'Aoust et al., 2024). The proliferation of species such as Eucalyptus in Kitanga, which exhibited both low richness and evenness, demonstrates how intense disturbance can simplify community structure and displace native flora, a trend also observed by Boru et al. (2024), Turyasingura et al. (2022), and Bentsi-Enchill et al. (2022).

The low floristic similarity observed between sites, as indicated by the Jaccard Index, further suggests spatial heterogeneity in species composition, likely influenced by site-specific land-use practices, hydrological conditions, and disturbance histories (Gojamme, 2024). Kitanga, in particular, emerged as ecologically distinct, potentially due to the dominance of exotic plantations and reduced understorey vegetation. From a conservation perspective, these findings highlight the dual role of disturbance in shaping plant communities. Moderate levels of disturbance may enhance diversity in the short term by creating niches for colonizers, but prolonged or intense disturbance especially through monoculture planting and wetland conversion can lead to biodiversity loss and functional degradation (Mulei et al., 2018; Raburu, 2020; Cao & Natuhara, 2020). While some diversity may persist under disturbed conditions, the risk of long-term ecological instability increases due to invasive species dominance and native species displacement. Therefore, the relatively high diversity recorded in sites such as Kandago should not be interpreted as an indicator of ecological integrity, but rather as a signal of transitional or disturbed community dynamics. As observed in other tropical wetland systems (Ambebe et al., 2025; Asongwe et al., 2022), floristic diversity must be interpreted in context, taking into account the processes driving it.

#### *4.4.2.2.4 Factors Influencing Plant Diversity*

The observed variation in diversity across the study wetlands is shaped by the interplay of ecological traits, human activities, and environmental gradients. Dominance by fast-growing, disturbance-tolerant species like Eucalyptus and Cyperus papyrus in degraded sites suppresses understorey growth and reduces species richness (Boru et al., 2024; Turyasingura et al., 2022). Conversely, disturbances such as drainage, vegetation clearing, and cultivation may create heterogeneous microhabitats that support a wider array of colonizing species (DeBerry & Hunter, 2024). However, this temporary boost in diversity is often unsustainable and comes at the expense of sensitive native species. Anthropogenic factors including agricultural encroachment, settlement, biomass extraction, and tree planting continue to exert pressure on Uganda’s wetlands, contributing to biodiversity decline (Gimbo et al., 2024; Matovu et al., 2024). Asongwe et al. (2022) further warn that land-use changes and pollution reduce species diversity by favoring a few dominant taxa. This study confirms these trends: while certain wetlands may appear diverse, their community structure reflects stress-tolerant, often invasive assemblages.

#### *4.4.2.3. Importance Value Index*

##### *4.4.2.3.1 Woody Species*

The woody plant community was dominated by *Eucalyptus* sp., with an IVI of 135.1 (Table 4.1.8). All other species had IVIs below 6, including *Spathodea campanulata* (5.1), *Myrica kandtiana*, and *Rubus rigidus* (3.6 each).

**Table 4.18. Importance Value Index for Woody Species**

| No. | Species | Relative Coverage | Relative Density | Relative Frequency | IVI |
|---|---|---|---|---|---|
| 1 | *Eucalyptus* sp. | 97.4 | 27.1 | 10.7 | 135.1 |
| 2 | *Spathodea campanulata* Buch.-Ham. ex DC. | 2.4 | 0.7 | 2 | 5.1 |
| 3 | *Myrica kandtiana* Engl. | 1.3 | 0.9 | 1.3 | 3.6 |
| 4 | *Rubus rigidus* Sm. | 1.3 | 0.9 | 1.3 | 3.6 |
| 5 | *Acalypha psilostachya* Hochst. ex A.Rich. | 1.3 | 0.6 | 0.9 | 2.8 |
| 6 | *Phytolacca dodecandra* L'Hér. | 1.3 | 0.6 | 0.9 | 2.8 |
| 7 | *Hibiscus diversifolius* subsp. rivularis (Bremek. & Oberm.) Exell | 1.3 | 0.1 | 0.2 | 1.6 |
| 8 | *Acacia mearnsii* De Wild. | 0.22 | 0.1 | 0.4 | 0.7 |

##### *4.4.2.3.2 Non-Woody Species*

The IVI results for non-woody species revealed an uneven distribution of ecological importance (Table 4.1.9). *Cyperus papyrus* had the highest IVI (45.4), followed by *Vossia cuspidata* (38.6) and *Pycreus nitidus* (28.5). *Rumex abyssinicus* (25.8) and *Crassocephalum* *montuosum* (15.5) demonstrated moderate ecological significance. The majority of remaining species recorded IVI values below 10.

**Table 4.19 Importance Value Index for Non-Woody Species**

| No. | Species | Relative Dominance | Relative Density | Relative Frequency | IVI |
|---|---|---|---|---|---|
| 1 | *Cyperus papyrus* L. | 19.7 | 15.0 | 10.7 | 45.4 |
| 2 | *Vossia cuspidata* (Roxb.) Griff. | 15.9 | 12.1 | 10.7 | 38.6 |
| 3 | *Pycreus nitidus* (Lam.) J.Raynal | 10.1 | 7.7 | 10.7 | 28.5 |
| 4 | *Rumex abyssinicus* Jacq. | 8.9 | 6.8 | 10.0 | 25.8 |
| 5 | *Crassocephalum montuosum* (S.Moore) Milne-Redh. | 5.3 | 4.1 | 6.0 | 15.5 |
| 6 | *Impatiens burtonii* Hook.f. | 4.0 | 3.3 | 4.8 | 12.1 |
| 7 | *Cyperus dives* Del. | 3.9 | 3.0 | 4.4 | 11.3 |
| 8 | *Persicaria setosula* (A.Rich.) K.L.Wilson | 3.2 | 2.4 | 3.6 | 9.2 |
| 9 | *Digitaria scalarum* (Schweinf.) Chiov. | 2.4 | 1.8 | 2.7 | 6.9 |
| 10 | *Miscanthidium violaceum* (K.Schum.) Robyns | 2.0 | 1.5 | 2.2 | 5.7 |
| 11 | *Pennisetum purpureum* Schumach. | 1.6 | 1.5 | 2.2 | 5.3 |
| 12 | *Ludwigia abyssinica* A.Rich. | 1.6 | 1.2 | 1.8 | 4.6 |
| 13 | *Melanthera scandens* (Schumach. & Thonn.) Brenan | 1.3 | 1.2 | 1.8 | 4.3 |
| 14 | *Nymphaea lotus* L. | 1.3 | 1.2 | 1.8 | 4.3 |
| 15 | *Typha capensis* (Rohrb.) N.E.Br. | 1.3 | 1.2 | 1.8 | 4.3 |
| 16 | *Carex congolensis* Turrill | 1.3 | 1.2 | 1.8 | 4.3 |
| 17 | *Cladium mariscus* (L.) Pohl | 1.3 | 1.2 | 1.8 | 4.3 |
| 18 | *Achyranthes aspera* L. | 1.3 | 0.6 | 0.9 | 2.8 |
| 19 | *Persicaria senegalensis* (Meisn.) Soják | 1.3 | 0.6 | 0.9 | 2.8 |
| 20 | *Polygonum senegalense* Meisn. | 1.3 | 0.6 | 0.9 | 2.8 |
| 21 | *Crassocephalum vitellinum* S.Moore | 1.3 | 0.3 | 0.4 | 2.1 |
| 22 | *Thelypteris confluens* (Thunb.) C.V.Morton | 1.3 | 0.3 | 0.4 | 2.1 |
| 23 | *Ocimum basilicum* L. | 1.3 | 0.1 | 0.2 | 1.6 |

The importance value index (IVI) measures the overall importance of a species in a given area, based on its relative dominance, density, and frequency. In this study, IVI values were computed separately for woody and non-woody plant species. The results showed considerable variation, with IVI scores ranging from 135.1 to 0.7 for woody species, and from 45.4 to 1.6 for non-woody species. Among the woody species, *Eucalyptus* sp. dominated the surveyed wetland areas, with a high IVI of 135.1. This dominance is primarily driven by its high relative coverage (97.4%), coupled with a high relative density (27.1%) and frequency (10.7%). These values indicate that *Eucalyptus* sp. is not only the most widespread but also the most frequently encountered and densely populated woody species in the area. Its ecological dominance may reflect deliberate planting for agroforestry and commercial purposes. In the context of this study, such commercial use is reflected in the predominant cultivation of *Eucalyptus* for construction poles and timber, highlighting its economic importance to local livelihoods. This local pattern of widespread cultivation and economic reliance on *Eucalyptus* is supported by Iglesias-Carrasco et al. (2025), who note that *Eucalyptus species* are among the most widely used trees in global forestry due to their rapid growth and high profitability. Their versatility extends to a range of uses, including paper production, timber, firewood, and as ingredients in medicinal and cosmetic products (Prajapati et al., 2024). Other woody species exhibited markedly lower IVI values, with Spathodea campanulata (IVI = 5.1), Myrica kandtiana, and Rubus rigidus (each at 3.6) occurring at low frequencies and densities. This skewed distribution suggests a simplified woody plant community structure, likely shaped by extensive land-use change and species introductions.

For non-woody plant species recorded, *Cyperus papyrus* emerged as the most ecologically significant, with an IVI of 45.4, attributed to relatively high dominance (19.7%), density (15.0%), and frequency (10.7%). *Vossia cuspidata* followed closely, with an IVI of 38.6, supported by strong dominance (15.9%) and density (12.1%). *Pycreus nitidus* ranked third, with a relatively lower IVI of 28.5, although it exhibited the same frequency (10.7%) as the top two species. These results suggest that *C. papyrus* and *V. cuspidata* are the most ecologically influential non-woody species in the surveyed wetlands. Consistent with Tijani et al. (2011), this study affirms that human-induced disturbances such as farming, brick-making, and vegetation clearance can drive shifts in wetland plant communities by displacing native species and facilitating the proliferation of secondary or ruderal vegetation. These processes likely explain the elevated IVIs of generalist species such as *Vossia cuspidata* and *Pycreus nitidus*, particularly in more disturbed wetland sites. Nyombi (2008) and Omagor & Barasa (2018) similarly observed that repeated cultivation in Uganda's Lubigi Wetland promoted the emergence of non-characteristic wetland weeds, including *V. cuspidata*, a species rarely dominant under undisturbed conditions. Blaser-Hart et al. (2025) further link the expansion of *V. cuspidata* to hydrological alterations such as fluctuating water levels and retention times, which create favorable microhabitats for colonization. Therefore, while high IVI scores may indicate ecological dominance, they should not be interpreted uncritically as markers of ecological integrity, especially when such dominance arises under anthropogenically altered conditions.

#### *4.4.2.4 Implications for Management and Policy*

This study highlights the need for integrated wetland management strategies informed by ecological data. Variation in species composition and dominance across Kanyabaha Wetland reflects differing levels of anthropogenic disturbance, with implications for biodiversity and ecosystem resilience. First, management interventions should go beyond species richness metrics and incorporate species dominance patterns, especially where exotic or disturbance-tolerant species (e.g., Eucalyptus, Vossia cuspidata) prevail. Restoration efforts should be site-specific, targeting areas where ecological integrity is compromised. Second, findings support the integration of biodiversity assessments into land-use planning and enforcement of wetland protection policies. The widespread conversion of wetland areas to farmland and settlements underscores the need for stronger governance and coordination among stakeholders. Third, community-based conservation should be prioritized. Sustainable use models, including incentives and alternative livelihoods, can reduce pressure on wetland ecosystems. Lastly, regular monitoring using ecological indices is essential to track changes and inform adaptive management. Aligning local actions with national wetland policies and international frameworks, such as the Ramsar Convention, will strengthen long-term conservation outcomes.

### 4.5 The Drivers of Utilization of Kanyabaha Wetland Resources in Rukiga District

Wetland degradation is becoming a major environmental problem in the world, moreover, with unsustainable utilization of limited natural resources, population increase, desertification, soil erosion and decline in agricultural land productivity (Reed & Stringer 2016). Through survey, FGDs and Key Informant Interviews, this study set out to identify the drivers of wetland utilization and encroachment in Rukiga. The findings from the qualitative survey are summarized in the figure 4.20 below:

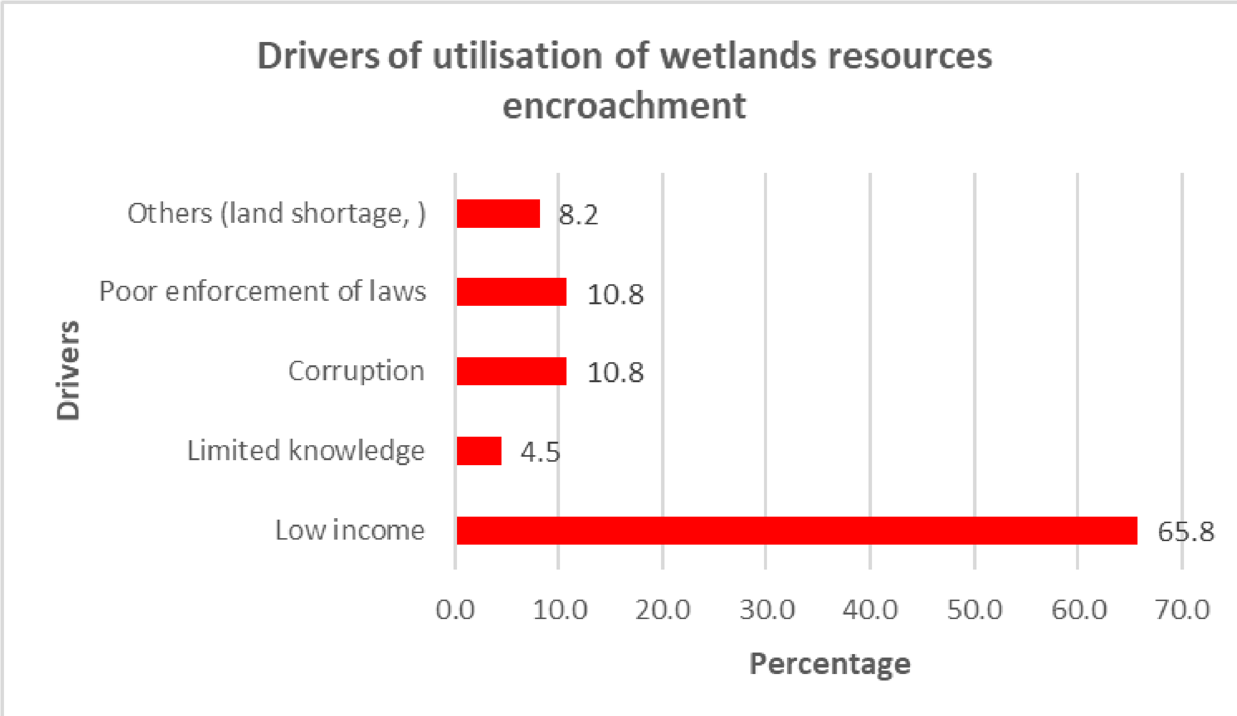


***Figure 4.20: Drivers of Wetland Encroachment***

### 4.5.1 Low Income as a Primary Driver

The study reveals that low income, with a staggering rate of 65.8%, serves as the main significant driver behind the exploitation of Kanyabaha wetlands in Rukiga District, Uganda. This alarming statistic underscores the profound impact of economic deprivation on environmental degradation. With the majority of the population living below the poverty line, communities are compelled to prioritize immediate economic needs over long-term environmental sustainability. Subsistence agriculture, practiced by many impoverished households, heavily relies on wetland resources for cultivation and sustenance. This reliance exacerbates the pressure on wetlands as communities strive to secure food and livelihoods amidst economic hardship. Interviews and FGDs with the community further show that limited income was a major driver of wetland encroachment as shown below:

According to an Environmental Officer in Rukiga District,

*"Low income is a significant factor driving the exploitation of Kanyabaha wetlands. Many families in the area rely on wetland resources for survival, especially during the dry seasons when other agricultural lands are not productive enough. This reliance on wetlands for subsistence agriculture exacerbates the degradation of these fragile ecosystems."*

During a focus group discussion with community members, a participant remarked,

*"We are aware of the importance of wetlands, but limited income forces us to prioritize immediate needs. Without adequate land for cultivation, we have no choice but to utilize the wetlands for farming and gathering resources. It's a matter of survival for us."*

A Local Leader in Rukiga District emphasized,

"*The low-income rate in our community drives people to exploit the wetlands without considering the long-term consequences. Despite efforts to raise awareness about wetland conservation, poverty remains a significant barrier to sustainable practices. We need comprehensive strategies to address both poverty and environmental degradation."*

Echoing similar sentiments, a youth representative stated,

*"Limited income levels push many young people in our community to engage in unsustainable activities like illegal fishing and farming in the wetlands. We need support from the government and NGOs to provide alternative livelihood opportunities that don't rely on wetland exploitation."*

These findings show that limited income is indeed a primary driver behind the exploitation of Kanyabaha wetlands in Rukiga District. They highlight the challenges faced by communities in balancing immediate economic needs with long-term environmental sustainability. Addressing limted income level through targeted interventions and providing alternative livelihood opportunities is crucial for promoting sustainable wetland management practices in the region.

### 4.5.2 Poor Enforcement of Laws

Inadequate enforcement of environmental laws, constituting 10.8% of the drivers, significantly exacerbates the challenges facing wetland conservation efforts in Rukiga District. Despite the presence of regulatory frameworks designed to safeguard wetlands, the enforcement mechanisms fall short of effectively deterring illegal activities. This lax enforcement creates a permissive environment wherein activities such as encroachment, illegal logging, and overharvesting continue unabated, further accelerating wetland degradation. These findings were reinforced by qualitative findings:

An Environmental Officer said,

*'The inadequate enforcement of environmental laws poses a significant challenge to wetland conservation efforts in Rukiga District. Despite the existence of regulatory frameworks aimed at protecting wetlands, the enforcement mechanisms are often ineffective. This lax enforcement allows illegal activities such as encroachment, illegal logging, and overharvesting to persist, undermining our conservation efforts and accelerating wetland degradation.'"*

A Community member noted:

*"From our observations, it's clear that the lack of enforcement of environmental laws contributes to the degradation of wetlands in our District. Despite knowing the regulations, some individuals continue to exploit wetlands for personal gain without fear of consequences. This impunity only emboldens others to follow suit, exacerbating the deterioration of these vital ecosystems."*

*"The inadequate enforcement of environmental laws is a pressing concern for wetland conservation in Rukiga District. Despite our advocacy efforts to raise awareness about the importance of wetlands and the need for compliance with regulations, the lack of enforcement undermines our progress. We urgently need stronger enforcement mechanisms and greater support from governmental authorities to protect our wetlands."*

Another respondent to the FGD mentioned:

*"The lax enforcement of environmental laws is a major obstacle to wetland conservation in our District. Many of us are aware of the regulations, but without effective enforcement, some individuals continue to exploit wetlands for short-term gain. This not only harms the environment but also jeopardizes our future and that of generations to come."*

The repercussions of inadequate enforcement extend beyond the mere violation of regulations; they directly contribute to the systematic exploitation of wetlands. Encroachment, in particular, poses a grave threat as it encroaches upon wetland ecosystems, disrupting natural processes and compromising their ecological integrity. Illegal logging compounds the issue by depleting valuable vegetation cover, which serves as habitat for diverse flora and fauna, and plays a crucial role in maintaining soil stability and water retention capacity within wetlands.

Moreover, overharvesting of wetland resources, facilitated by lax enforcement, results in the depletion of key species such as fish, medicinal plants, and reeds. This depletion not only diminishes biodiversity but also undermines the socio-economic resilience of local communities who rely on these resources for food security, traditional medicine, and livelihoods.

The lack of effective enforcement mechanisms not only hampers conservation efforts but also perpetuates a cycle of degradation wherein wetlands become increasingly vulnerable to exploitation and irreparable damage. Without robust enforcement of environmental laws, wetlands in Rukiga District remain vulnerable to exploitation, threatening their ecological functions and the livelihoods of local communities dependent on these vital ecosystems. Addressing this driver requires concerted efforts to strengthen enforcement capacity, enhance monitoring and surveillance, and ensure swift and impartial enforcement of regulations to deter illegal activities and promote sustainable wetland management practices.

### 4.5.3 Corruption as a Driver

The study reveals corruption constituting 10.8% as a distinct and pervasive driver behind the exploitation of Kanyabaha wetland in Rukiga District, Uganda. Corruption among environmental enforcement officers represents a significant barrier to effective wetland conservation, as reports indicate widespread bribery and unethical practices within regulatory bodies. This entrenched corruption undermines the enforcement of existing regulations aimed at protecting wetlands, creating an environment where illegal activities such as encroachment, illegal logging, and overharvesting can flourish unchecked.

"According to a Local Key Informant,

*'Corruption among environmental enforcement officers poses a significant barrier to effective wetland conservation in Rukiga District. Reports indicate widespread bribery and unethical practices within regulatory bodies, undermining the enforcement of existing regulations aimed at protecting wetlands. This entrenched corruption creates an environment where illegal activities such as encroachment, illegal logging, and overharvesting can flourish unchecked.'"*

"In a community focus group discussion, an elderly resident expressed concern, saying,

*'We've seen firsthand how corruption among environmental enforcement officers undermines wetland conservation efforts. Some officers turn a blind eye to illegal activities in exchange for bribes, allowing encroachment, illegal logging, and overharvesting to continue without*

*consequence. This corruption threatens the ecological health of our wetlands and undermines the well-being of our community.'"*

The detrimental effects of corruption on wetland conservation efforts are far-reaching. Not only does it compromise the integrity of regulatory institutions, but it also erodes public trust in governmental authorities responsible for environmental protection. When enforcement officers engage in corrupt practices, it sends a signal that adherence to environmental laws is negotiable, thereby perpetuating a culture of impunity and disregard for conservation efforts.

The prevalence of corruption, accounting for a substantial portion of the drivers at 8.2%, underscores the urgent need for anti-corruption measures and enhanced governance frameworks to combat illegal activities and promote sustainable wetland management practices. Addressing corruption requires multifaceted approaches, including the establishment of transparent and accountable governance structures, the enforcement of strict disciplinary measures for corrupt practices, and the promotion of ethical behavior among regulatory officials.

Moreover, combating corruption necessitates the involvement of various stakeholders, including government agencies, civil society organizations, and local communities. By fostering a culture of transparency, accountability, and integrity, stakeholders can work together to root out corrupt practices and promote sustainable wetland management practices that safeguard the ecological integrity of Kanyabaha wetland and protect the livelihoods of local communities dependent on these vital ecosystems.

### 4.5.4 Land Shortage

The study highlighted land scarcity as a critical driver contributing to wetland utilization and encroachment in Rukiga District, Uganda, constituting 8.2% of the identified factors. Rapid population growth, compounded by land fragmentation, has intensified the competition for land resources within the District. As a result, communities face increasingly limited alternatives for settlement and agricultural activities, driving them to seek out alternative spaces for livelihood activities. This was reinforced by qualitative findings:

A Local Government Official highlighted,

*Rapid population growth and land fragmentation have exacerbated the competition for land resources, leaving communities with limited alternatives for settlement and agriculture. This pressure on available land pushes communities to encroach upon wetlands in search of livelihood opportunities.'"*

During a community focus group discussion, a representative from the local farmers' group expressed,

*'We feel the effects of land scarcity firsthand. With rapid population growth and land fragmentation, finding suitable land for farming has become increasingly challenging. As a result, some of our members have resorted to utilizing wetlands for agriculture, despite the ecological consequences. We need support to address land scarcity and find sustainable land use solutions.'"*

An Environmental NGO representative emphasized,

*'Land scarcity is a pressing issue driving wetland utilization and encroachment in Rukiga District. The study's findings align with our organization's concerns about the impacts of rapid population growth and land fragmentation on land availability. To address this driver, we must promote sustainable land use practices and explore alternative livelihood options for communities affected by land scarcity.'"*

"During a discussion with members of the local women's group, one participant shared,

*'As women, we feel the effects of land scarcity acutely. With limited land available for farming and settlement, our options are increasingly constrained. Some women in our community have turned*

*to wetlands for agricultural activities, exacerbating environmental degradation. We need solutions that address both land scarcity and women's livelihood needs.'"*

The diminishing availability of suitable land options exacerbates the pressure on wetlands, compelling communities to encroach upon these fragile ecosystems for housing, cultivation, and other purposes. This encroachment not only threatens the ecological integrity of wetlands but also compromises their ability to provide essential ecosystem services, such as water purification, flood control, and habitat provision.

Furthermore, the scarcity of alternative land options creates a vicious cycle wherein the exploitation of wetlands becomes increasingly attractive as a means of addressing pressing socio-economic needs. As communities compete for limited land resources, the value of wetlands as potential sites for settlement and agriculture rises, further driving encroachment and degradation.

The consequences of land scarcity extend beyond the immediate ecological impacts, affecting the socio-economic well-being of local communities dependent on wetlands for their livelihoods. Encroachment on wetlands often leads to conflicts over land tenure and resource access, exacerbating social tensions and undermining community cohesion.

Addressing land scarcity requires holistic approaches that prioritize sustainable land management practices, equitable land distribution, and integrated land-use planning. Efforts to mitigate the drivers of wetland exploitation must include strategies aimed at addressing underlying issues such as population growth, land tenure insecurity, and inadequate land-use planning.

Moreover, promoting alternative livelihood options and providing incentives for sustainable land use can help alleviate the pressure on wetlands and reduce dependence on these fragile ecosystems. By addressing the root causes of land scarcity and promoting sustainable land management practices, stakeholders can work towards preserving the ecological integrity of wetlands in Rukiga District while ensuring the long-term well-being of local communities.

Community Limited knowledge about wetland conservation

Limited knowledge about wetland conservation within the community emerge as notable drivers of wetland degradation in Rukiga District, Uganda, constituting 4.5% of the factors influencing this phenomenon. The lack of awareness about the ecological importance of wetlands and the consequences of their degradation perpetuates destructive behaviors within communities. Many residents are unaware of the vital role wetlands play in maintaining biodiversity, regulating water cycles, and providing essential ecosystem services. Consequently, they may view wetlands as expendable resources rather than recognizing their intrinsic value and ecological significance.

An environmental officer highlighted the impact of limited knowledge about wetland conservation on wetland degradation, stating,

*'Limited knowledge about wetland* conservation *within the community is a significant driver of wetland degradation in Rukiga District. Many residents lack awareness about the ecological importance of wetlands and the consequences of their degradation. This limited understanding perpetuates destructive behaviors within communities, as some individuals view wetlands as expendable resources rather than recognizing their intrinsic value.'"*

In a community focus group discussion, an elderly resident shared insights on the challenges posed by limited knowledge about wetland conservation, saying,

*'We've noticed that many people in our community don't understand why wetlands are important. They don't realize that wetlands help maintain biodiversity, regulate water cycles, and provide essential ecosystem services. Without this knowledge, some community members engage in activities that harm wetlands, thinking they're just wastelands.'"*

"A local NGO representative emphasized the need for education and awareness-raising initiatives, stating,

*‘Limited knowledge about wetland* conservation *contributes to wetland degradation by hindering community understanding of wetland ecosystems. We need targeted education programs to raise awareness about the ecological importance of wetlands and the consequences of their degradation. By empowering communities with knowledge, we can promote sustainable behaviors and protect our wetlands for future generations.'"*

Limited knowledge about wetland conservation poses additional challenges to wetland conservation efforts in the region. Limited education levels hinder the dissemination of information on environmental conservation and sustainable land use practices. Without access to formal education or informational resources, community members may lack the knowledge and skills necessary to engage in environmentally friendly behaviors. This lack of awareness and understanding further exacerbates the threats facing wetlands, as individuals may inadvertently engage in activities that degrade these fragile ecosystems.

Efforts to engage communities in wetland conservation initiatives are impeded by Limited knowledge about wetland conservation. Community outreach programs and educational campaigns may struggle to effectively convey conservation messages to populations with limited literacy skills. As a result, opportunities for community participation and involvement in conservation efforts may be missed, hindering the implementation of sustainable management practices and exacerbating wetland degradation.

Addressing limited knowledge about wetland conservation requires targeted education and awareness-raising initiatives tailored to the needs of the local population. Community-based education programs can provide accessible information on the importance of wetlands, the threats they face, and the actions individuals can take to protect them. Additionally, promoting literacy and providing opportunities for skill development can empower community members to actively participate in conservation efforts and advocate for the sustainable management of wetlands in Rukiga District.

From the qualitative surveys, limited-income level and corruption were the major drivers to wetland utilization in Rukiga District. Under crop production as one of the livelihood activities, limited income rate scored the highest contributing 66% followed by corruption and poor enforcement with 27% and 25% respectively. Similarly, fishing farming was majorly driven by limited income level (80%)

**Table 4.20: Relationship between Drivers of Wetland Utilization/Encroachment and Land use/Livelihood Activities in Rukiga District**

| Land use / Livelihood activities | Drivers of Wetland Utilisation/Encroachment | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Limited income | | Limited knowledge | | Corruption | | Poor enforcement | | Others | | | | |
| | F | % | F | % | F | % | F | % | F | % | x2 | df | P values |
| Crop production | 167 | 66 | 13 | 5.1 | 27 | 10.7 | 25 | 9.9 | 21 | 8.3 | 6.515 | 4 | 0.164 |
| Fish farming | 8 | 80 | 0 | 0.0 | 0 | 0.0 | 1 | 10.0 | 1 | 10.0 | 2.241 | 4 | 0.692 |
| Livestock | 7 | 39 | 2 | 11.1 | 4 | 22.2 | 2 | 11.1 | 3 | 16.7 | 6.292 | 4 | 0.178 |
| Brick making | 4 | 50 | 0 | 0.0 | 2 | 25.0 | 1 | 12.5 | 1 | 12.5 | 1.913 | 4 | 0.752 |
| Agro-forestry | 3 | 38 | 0 | 0.0 | 4 | 50.0 | 0 | 0.0 | 1 | 12.5 | 12.112 | 4 | 0.017 |
| Beekeeping/Apiary | 2 | 40 | 0 | 0.0 | 0 | 0.0 | 3 | 60.0 | 0 | 0.0 | 12.726 | 4 | 0.013 |
| Others | 3 | 60 | 0 | 0.0 | 0 | 0.0 | 2 | 40.0 | 0 | 0.0 | 5.156 | 4 | 0.272 |

The results from the Chi-square test showed existence of a significant relationship between drivers of wetland utilization and livelihood activities particularly agroforestry ($x^2$=12.112, df=4, p=0.017) and Apiary ($x^2$=12.726, df=4, p=0.013). The existence of a significant relation between drivers of wetland encroachment and the livelihood activities implies that we reject the set hypothesis. These study results are consistent with regression results from a study conducted by

Niringiye *et al.,* (2010) investigating the poverty – environmental degradation nexus in Katonga Basin in Uganda showed that poverty is a major positive determinant of wetlands conversion. Participatory poverty assessments conducted in 14 developing countries of Asia, Africa, and Latin America, disclosed environmental quality as an important determinant for health, earning capacity, security, energy supplies and housing quality; and this was a common perception by the poor (Brocklesby and Hinshelwood, 2001). Not different from other scholars, Okwi *et al.,* (2006) also suggested that there exists a certain degree of association between rural poverty in central and Western Uganda rural stratum with a reasonable proportion of land reclaimed from wetlands under woodland, subsistence and commercial farming and other livelihood enterprises.

Similarly in China, a study conducted by study by Rozelle *et al.,* (1997) on the relationship between population, poverty and environmental degradation revealed that government policies have been ineffective in controlling rural wetland resources degradation primarily because of its limited resource and poorly trained personnel. Socioeconomic factors have long been attributed to the wetland changes across different scales. The findings of the current study are in agreement with findings by Akwetaireho & Getzner, (2010) who reported water supply, sand mining, fishing and agriculture as the key ecosystem services from Mabamba-Bay wetland in Uganda. Scholars such as Koehnken et al., (2020) have reported that such socioeconomic factors bear consequences on ecological and physical impacts on the wetlands including disturbances on the habitat and affecting species abundancy. In terms of the wetland utilization, Kakuru *et al.,* (2013) reported fish harvesting as the most important direct use value from the different wetlands of Uganda. In an investigation to assess goods and services obtained by the local community around Mabamba-Bay wetland, Akwetaireho & Getzner (2010) reported that water supply, sand mining, fishing and agriculture were reported as the most important ecosystem services from this wetland. Similarly, wetlands are also used for the production of other food crops such as vegetables, maize and yams by urban and peri-urban households in Uganda (Isunju & Kemp, 2016; James Gideon & Bernard, 2018). Therefore, this is why use-values such as fish, crop cultivation and domestic water provisioning are dominating g as the wetland direct use-values.

The economic value of domestic water supplies from wetlands within Uganda was estimated at US$ 34 million per year (Kakuru *et al.,* 2013). Wetlands across Uganda have been reported as important breeding grounds for both deep and shallow water fish (Bikangaga *et al.,* 2007; Kinyera & Doevenspeck, 2019). Earlier studies conducted in Uganda have also shown that local communities in Uganda perceive fish as the most affordable source of proteins compared to other animal sources such as chicken and beef (Akwetaireho & Getzner, 2010; Bikangaga *et al.,* 2007; Kakuru *et al.,* 2013). In terms of use values, water purification and climate regulation have been reported as the most critical aspects amongst the residents of Michgan state in the United States of America (Kaplowitz & Kerr 2003). These particular use-values are held in high regard by the local residents and make them desirous of ensuring the continuous conservation of the wetlands (Kaplowitz & Kerr, 2003). In Uganda, Kakuru *et al.,* (2013) estimated the economic value of flood control and water recharge by wetlands at US$ 1.7billions and 7million per hectare per year respectively. Indeed, wetlands such as Lubigi, Kinawataka and Nakivubo wetlands have been hailed for safeguarding many urban and peri-urban towns of Uganda from the havoc of floods by accommodating large volumes of storm runoff (Isunju & Kemp, 2016; Kakuba & Kanyamurwa, 2021; Kayima *et al.,* 2018). This signifies the salient services that the wetland offers the local communities within their vicinity, hence calling for the need to ensure their sustainable management.

Manuel (2003) reported that wildlife habitat and aesthetic beauty were found as wetland non-use values held in high regard by residents of Canada. Similar findings were reported by Kaplowitz & Kerr, (2003) who showed that altruistic and bequest wetland values accounted 82% and 75% amongst the residents of Michigan State in the United States of America. Turyahabwe *et al.*, (2017) argues that the possession of some degree of knowledge about unique wetland services such as biodiversity conservation, habitat provisioning, altruistic and bequest use by the local communities signifies the effort that has been made in raising awareness on the wise use of natural resources such as wetlands.

In sum, the findings show the multifaceted nature of the drivers behind wetland utilization and encroachment in Rukiga District. Addressing these challenges requires coordinated efforts to combat corruption, improve peoples' income, strengthen enforcement mechanisms, manage land resources sustainably, and enhance community education and awareness. By addressing the root causes outlined in this study, policymakers and stakeholders can develop targeted interventions to safeguard wetlands, preserve biodiversity, and support the livelihoods of communities dependent on these vital ecosystems.

The study sought to examine the drivers of utilization of Kanyabaha wetland resources in Rukiga District. The study first sought the drivers of utilization of wetland resources, results revealed that 65.8% households due to limited income are influenced to encroach on the wetlands for survival, this is coupled with shortage of land, limited knowledge about wetland conservation, corruption and poor enforcement of laws regarding environment conservation and management. This finding affirms study by Munishi *et al.,* (2014), the major reasons for utilization of wetland resources in many parts of Uganda are increasing human population, exploitation of wetland resources and conversion of wetlands into agricultural land. Research further, revealed that limited income level is the main contributor of environment degradation this partly attributed to the growing population which has put on added strain on the wetlands as the population continues to grow in Rukiga District. Also, the national wetland policy remains too large and inflexible to apply at the local government level which has intensified encroachment on the wetlands in the District.

Research further engaged on awareness of regulations for protecting wetlands in regards to utilization, results revealed that 78.2% of households are aware of the regulation though most of them do not follow them when utilizing wetlands, where 22.4% of households were undertaking activities to safeguard the Kanyabaha wetland in the District. This is in dispute with findings that rural communities consider wetlands to be important ecosystems which should be used wisely since they obtain essential services (Adekola *et al.,* 2008; Ndiweni and Gwate 2013). Research further investigated on the source of professional advise concerning wetland utilization and conservation and whether households do use the advised they attained, results indicate NEMA (77.4%) and District environment officers (16.1%) as the main source of professional advice on wetland utilization and conservation. Concerning applying the professional advice, 22.4% households were engaged in wetland conservation through regular tree planting (57.5%), use of better farming and fishing methods (26.4%) and building trenches and setting up river banks (16.1%). Therefore, lack of proper wetland management policies and strategies continue to threaten wetland areas in different parts of the world causing changes in the services and goods accrued from wetland resources (URT, 2007).

## 4.6 The Adaptation Strategies Adopted by Local Residents to Cope with Adverse Impacts of Changing Climate in Rukiga District

Local residents in Rukiga District, Uganda, have been confronting the challenges posed by climate change through a variety of adaptation strategies. These strategies, rooted in local knowledge and practices, aim to mitigate the adverse impacts of changing climatic conditions on livelihoods, agriculture, and natural resources. Through field observations, interviews, and participatory assessments, several adaptation measures were identified, showcasing the resilience and ingenuity of communities in Rukiga District. The following adaptation strategies have emerged from the findings of this study:

### 4.6.1 Diversification of Livelihoods

Local residents in Rukiga District diversified their livelihoods to reduce dependence on climate-sensitive sectors such as agriculture. Diversifying livelihoods is a prevalent adaptation strategy, with 16.1% of respondents opting for alternative income-generating activities. This includes engaging in alternative income-generating activities such as small-scale businesses, petty trading, and handicraft production. By diversifying their sources of income, households are better able to withstand climate-related shocks and disruptions to agricultural production. This strategy indicates a recognition of the need to reduce dependence on climate-sensitive sectors such as agriculture, thereby enhancing resilience to climate-related shocks.

During a focus group discussion (FGD), a local resident in Rukiga District expressed,

*"We've realized that relying solely on agriculture puts us at the mercy of unpredictable weather patterns. So, many of us have started exploring other ways to earn a living. Some of us have ventured into small-scale businesses, while others are into petty trading or handicraft production.*

*By diversifying our sources of income, we're not only reducing our vulnerability to climate-related shocks but also ensuring that we have a safety net during tough times. It's our way of acknowledging the need to adapt to the changing climate and build resilience in our community."*

### 4.6.2 Adoption of Climate-Resilient Agricultural Practices

Farmers in Rukiga District embraced climate-resilient agricultural practices to adapt to changing environmental conditions. The high percentage (20.7%) of respondents adopting climate-resilient agricultural practices highlights the importance of agriculture in local livelihoods and the recognition of the need to adapt farming systems to changing environmental conditions. This includes the use of drought-resistant crop varieties, conservation agriculture techniques, agroforestry, and soil conservation measures. By incorporating these practices into their farming systems, farmers are better equipped to cope with erratic rainfall, soil erosion, and other climate-related challenges.

During a focus group discussion (FGD), a farmer in Rukiga District shared,

*"We've had to change the way we farm because of the unpredictable weather. Many of us are now using drought-resistant crop varieties and practicing conservation agriculture. Some have even adopted agroforestry techniques. These changes are not easy, but they're necessary to survive in this changing climate. We've seen the benefits firsthand – our crops are more resilient to erratic rainfall, and our soils are healthier. It's a tough road ahead, but by embracing these climate-resilient agricultural practices, we're adapting to the new normal and securing our livelihoods for the future."*

### 4.6.3 Water Harvesting and Management

Given the variability in rainfall patterns, local residents implemented water harvesting and management techniques to ensure access to water for domestic use and agriculture. With 12.5% of respondents implementing water harvesting and management techniques, there is a clear acknowledgment of the importance of water resources in mitigating water scarcity during dry periods and supporting year-round agricultural production. This included the construction of rainwater harvesting systems, small-scale irrigation schemes, and community water storage facilities. These initiatives help to buffer against water scarcity during dry periods and support agricultural production year-round. During a focus group discussion (FGD), a community member in Rukiga District remarked,

*"We've seen how unpredictable the rainfall has become, especially during the dry seasons. To ensure we have enough water for our households and farms, many of us have started implementing water harvesting and management techniques. Some have built rainwater harvesting systems on their rooftops, while others have set up small-scale irrigation schemes or community water storage facilities. These initiatives are crucial for us to survive the dry spells and maintain agricultural production throughout the year. By managing our water resources effectively, we're taking proactive steps to address water scarcity and secure our livelihoods."*

### 4.6.4 Reforestation and Agroforestry

Recognizing the importance of forests in regulating local climate and providing ecosystem services, communities in Rukiga District undertook reforestation and agroforestry initiatives. Reforestation and agroforestry initiatives, embraced by 10.3% of respondents, demonstrates a commitment to enhancing ecosystem services, such as soil fertility, water retention, and carbon sequestration. This involves planting trees on farmland, communal lands, and degraded areas to enhance soil fertility, stabilize slopes, and conserve water resources. Reforestation efforts also contribute to carbon sequestration and biodiversity conservation. During a focus group discussion (FGD), a community leader in Rukiga District reflected, *"We've realized the crucial role that forests play in maintaining a stable climate and supporting our livelihoods. That's why many of us have come together to embark on reforestation and agroforestry initiatives. By planting trees on our farmlands, communal lands, and degraded areas, we're not just improving soil fertility and stabilizing slopes, but also conserving water resources for future generations. These efforts are more than just planting trees – they're a commitment to enhancing ecosystem services like carbon sequestration and biodiversity conservation. It's our way of ensuring a sustainable future for our community and the environment."*

Strengthening Social Networks and Community Resilience

Local residents reported leveraging social networks, traditional institutions, and community-based organizations to enhance resilience and adaptive capacity. The significant percentage (18.3%) of respondents who reported coping by strengthening social networks and community resilience highlights the importance of collective action and mutual support in building resilience to climate-related shocks. This included collective action for natural resource management, mutual support during times of hardship, and knowledge sharing on climate adaptation strategies. Strengthening social cohesion and solidarity enables communities to better withstand and recover from climate-related shocks and stresses. During a focus group discussion (FGD), a community member in Rukiga District expressed,

*"We've always known the value of coming together as a community, especially in times of need. With the changing climate, we've had to rely even more on our social networks and community bonds to navigate through tough times. Whether it's pooling resources for natural resource management or offering mutual support during hardships, we understand that we're stronger when we work together. Through collective action and knowledge sharing, we've been able to build resilience and adapt to the challenges posed by climate change. Strengthening our social cohesion*

*and solidarity isn't just about weathering the storms – it's about building a stronger, more resilient community for generations to come."*

### 4.6.5 Accessing Climate Information and Early Warning Systems

Improved access to climate information and early warning systems has enabled local residents to make informed decisions and take timely action in response to impending climate-related hazards. Improved access to climate information and early warning systems, mentioned by 13.3% of respondents, indicates a proactive approach to enhancing preparedness and risk awareness. This included the dissemination of weather forecasts, agro-meteorological advisories, and early warning messages through mobile phones, radio broadcasts, and community meetings. By enhancing preparedness and risk awareness, communities are better equipped to mitigate the impacts of extreme weather events. This strategy enables timely decision-making and response to climate-related hazards, thereby reducing vulnerability. During a focus group discussion (FGD), a local leader in Rukiga District remarked,

*"Access to timely and accurate climate information has been a game-changer for our community. With the help of improved early warning systems, we're able to stay ahead of climate-related hazards and make informed decisions to protect ourselves and our livelihoods. Whether it's receiving weather forecasts on our mobile phones, listening to agro-meteorological advisories on the radio, or participating in community meetings to discuss early warning messages, we're proactive in enhancing our preparedness and risk awareness. By staying informed and acting swiftly, we're better equipped to mitigate the impacts of extreme weather events and reduce our vulnerability to climate-related risks."*

### 4.6.7 Wetland Conservation and Restoration

Wetland conservation and restoration practices, embraced by 8.7% of local communities, represent a proactive approach to coping with climate change impacts. These practices involved various activities, including habitat restoration, re-vegetation of degraded areas, and invasive species management, all aimed at preserving and rehabilitating vital wetland ecosystems. By safeguarding wetlands, the communities harness their natural resilience to regulate local climate patterns, store carbon, and provide essential ecosystem services such as water filtration, flood control, and habitat provision. Additionally, these efforts contribute to biodiversity conservation, supporting a diverse array of plant and animal species crucial for ecosystem health. In essence, the adoption of wetland conservation and restoration practices by local communities serves as a strategic response to climate change challenges, emphasizing the recognition of wetlands as valuable assets for enhancing resilience and sustainability in the face of environmental threats. During a focus group discussion (FGD), a community member in Rukiga District reflected,

*"We've recognized the importance of our wetlands in mitigating the impacts of climate change. That's why some of us have taken proactive steps to conserve and restore these vital ecosystems. Through activities like habitat restoration, re-vegetation of degraded areas, and invasive species management, we're safeguarding our wetlands and ensuring they continue to provide essential services to our community. By preserving wetlands, we're tapping into their natural resilience to regulate local climate patterns, store carbon, and offer crucial ecosystem services like water filtration and flood control. Moreover, our efforts contribute to biodiversity conservation, supporting a diverse array of plant and animal species crucial for our ecosystem's health. These wetland conservation and restoration practices aren't just about protecting nature – they're about safeguarding our community's resilience and sustainability in the face of climate change."*

**Table 4.21: Climate Change Adaptation Strategy**

| Adaptation Strategy | Number of Respondents | Percentage (%) |
|---|---|---|
| Diversification of Livelihoods | 62 | 16.1 |
| Adoption of Climate-Resilient Agricultural Practices | 80 | 20.7 |
| Water Harvesting and Management | 46 | 12.5 |
| Reforestation and Agroforestry | 41 | 10.3 |
| Strengthening Social Networks and Community Resilience | 72 | 18.3 |
| Accessing Climate Information and Early Warning Systems | 53 | 13.3 |
| Wetland Conservation and Restoration | 34 | 8.7 |
| | 388 | 100 |

### 4.6.8 Factors Influencing Adoption of Climate Change Strategies

In studying climate change, it was revealed that there are factors that influence adoption and adaptation of climate change practices in different areas. According to Deressa *et al*, (2009), socio-demographic characteristics were shown to affect adoption of agricultural innovations; it's upon these findings that, it was hypothesized in this study that socio demographic factors (age, income, gender, education and residence ownership) have a significant influence on the adoption of climate change strategies by residents in Rukiga District.

#### *4.6.8.1 Age*

Adoption of climate change strategies among resident of Rukiga District was relatively high in adoption of climate resilient agricultural practices and reforestation and agroforestry; and the adoption of the practices were increasing with age as shown in Table 4.22 below. Only 12% of youths aged 21-30 years were using climate Information & early warning systems as opposed to 36% of those aged 41-50 years. However, Chi-square test results showed no significant influence of age on adoption of climate change strategies among residents in Rukiga District i.e. diversification of livelihoods ($x2$=5.167, df= 4, p = 0.271), adoption of climate resilient agricultural practices ($x2$=4.068, df=4, p= 0.397), water harvesting and management ($x2$=4.083, df= 4, p = 0.395), wetland conservation and restriction ($x2$=6.558, df=1, p= 0.161), among others.

**Table 4.22: Relationship between Age and Adoption of Climate Change adaptation Practices by Residents in Rukiga District.**

| | Age | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Climate Change adaptation Strategies | 15-20 | | 21-30 | | 31-40 | | 41-50 | | > 50 | | | | |
| | F | % | F | % | F | % | F | % | F | % | X2 | df | P values |
| Diversification of livelihoods | 1 | 2.1 | 11 | 22.9 | 18 | 37.5 | 15 | 31.3 | 3 | 6.3 | 5.167 | 4 | 0.271 |
| Adoption of climate resilient agricultural practices | 3 | 3.3 | 22 | 24.4 | 29 | 32.2 | 25 | 27.8 | 11 | 12.2 | 4.068 | 4 | 0.397 |
| Water harvesting and Management | 2 | 3.9 | 11 | 21.6 | 11 | 21.6 | 15 | 29.4 | 12 | 23.5 | 4.083 | 4 | 0.395 |
| Reforestation and agroforestry | 4 | 5.6 | 12 | 16.7 | 20 | 27.8 | 22 | 30.6 | 14 | 19.4 | 1.698 | 4 | 0.791 |
| Strengthening Social networks & community resilience | 0 | 0.0 | 7 | 16.7 | 16 | 38.1 | 11 | 26.2 | 8 | 19.1 | 3.390 | 4 | 0.495 |
| Access climate Information & early warning systems | 4 | 8.0 | 6 | 12.0 | 16 | 32.0 | 18 | 36.0 | 6 | 12.0 | 4.810 | 4 | 0.307 |
| Wetland conservation & restriction | 1 | 2.9 | 2 | 5.7 | 9 | 25.7 | 15 | 42.9 | 8 | 22.9 | 6.558 | 4 | 0.161 |

The findings were found to be inconsistent with a study by Deressa *et al*., (2009) where older people with time are expected to accumulate wealth, experience and resources, and therefore more likely to adopt climate smart practices. Likewise, the results were inconsistent with findings from Murage *et al.*, (2013) which argued that young people tend to be more educated, open minded and more likely to understand the advantages associated with innovations and therefore more likely to adopt the new technologies and innovation

### *4.6.8.2 Gender:*

Generally, there was a higher adoption of climate changes strategies by the male gender as compared to females. This was more evident in the adoption of climate resilient agricultural practices (69%) as well as reforestation and agroforestry (77%). The Chi-square test revealed a significant relationship between gender and adoption of climate change adaptation strategies specifically with only reforestation and agroforestry ($x^2$=3.915, df=1, p=0.048).

**Table 4.23: Relationship between Gender and Adoption of Climate Change Adaptation Practices by Residents in Rukiga District**

| Climate Change adaptation Strategies | Gender | | | | | | |
|---|---|---|---|---|---|---|---|
| | Male | | Female | | | | |
| | F | % | F | % | $X^2$ | df | P values |
| Diversification of livelihoods | 30 | 63 | 18 | 38 | 0.631 | 1 | 0.427 |
| Adoption of climate resilient agricultural practices | 63 | 69 | 28 | 31 | 0.158 | 1 | 0.691 |
| Water harvesting and Management | 32 | 63 | 19 | 37 | 0.612 | 1 | 0.434 |
| Reforestation and agroforestry | 55 | 77 | 16 | 23 | 3.915 | 1 | 0.048 |
| Strengthening Social networks & community resilience | 24 | 57 | 18 | 43 | 2.315 | 1 | 0.128 |
| Access climate Information & early warning systems | 35 | 70 | 15 | 30 | 0.16 | 1 | 0.689 |
| Wetland conservation & restriction | 23 | 66 | 12 | 34 | 0.058 | 1 | 0.81 |

Gender differences in adoption of climate change strategies like reforestation and agroforestry could be explained by variances in socioeconomic status and also land access opportunities where men by nature and cultural setting are much more privileged and aggressive to have access to land than women. However, there was no significant relationship between gender and adoption of some climate change strategies such as diversification of livelihoods ($x$2=0.631, df= 1, p = 0.427), adoption of climate resilient agricultural practices ($x^2$=0.158, df.=1 p= 0.691), strengthening social networks and community resilience ($x$2=2.315, df.=1, p= 0.128), among others (Table 4.23).

#### *4.6.8.3 Education Level:*

The hypothesis was based on the fact that education increases one's ability to understand and synthesize different forms of information thus influencing decision making. It is also evidenced that education influences attitude and acceptability of information coupled with people'e ability to assess and compare the advantages and disadvantages of a given option thus influencing adoption of a given strategy (Weir & Knight, 2000)

**Table 4.24: Relationship between Education and Adoption of Climate Change adaptation Practices by Residents in Rukiga District**

| Climate Change adaptation Strategies | Education | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | None | | Primary | | Secondary | | Tertially | | | | |
| | F | % | F | % | F | % | F | % | $X^2$ | df | P values |
| Diversification of livelihoods | 7 | 15 | 17 | 35 | 14 | 29 | 10 | 21 | 3.573 | 3 | 0.311 |
| Adoption of climate resilient agricultural practices | 6 | 7 | 43 | 47 | 28 | 31 | 14 | 15 | 1.398 | 3 | 0.706 |
| Water harvesting and Management | 6 | 12 | 23 | 45 | 17 | 33 | 5 | 10 | 1.592 | 3 | 0.661 |
| Reforestation and agroforestry | 3 | 4 | 33 | 46 | 25 | 35 | 10 | 14 | 3.681 | 3 | 0.298 |
| Strengthening Social networks & community resilience | 3 | 7 | 19 | 45 | 12 | 29 | 8 | 19 | 0.823 | 3 | 0.844 |
| Access climate Information & early warning systems | 7 | 14 | 23 | 46 | 13 | 26 | 7 | 14 | 1.394 | 3 | 0.707 |
| Wetland conservation & restriction | 6 | 17 | 17 | 49 | 7 | 20 | 5 | 14 | 3.506 | 3 | 0.320 |

The results from Table 4.24, however showed that education has no significant influence on the different climate change strategies adopted by the residents in Rukiga District. These results were inconsistent with the findings from various studies (Jones *et al.*, 2010; Rogers, 2003; Frank & Penrose, 2012) which clearly showed a significant influence that education has on adoption of climate change practices.

#### ***4.6.8.4 Residence Ownership:***

According to the study results, it was revealed that people who own homes within the District and the wetland catchment areas registered the highest adoption status for all the different climate change strategies as compared to their counterparts who are tenants and in other forms of residence as shown in table 4.25. Despite the fact that the results are as depicted in the table, residence ownership was found not to have any significant influence on the climate change strategy adopted by residents in Rukiga District.

**Table 4.25: Relationship between Residence Ownership and Adoption of Climate Change Adaptation Practices by Residents in Rukiga District**

| | Residence Ownership | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Climate Change adaptation Strategies | Tenant | | Owner | | Other | | | | |
| | F | % | F | % | F | % | X2 | df | P values |
| Diversification of livelihoods | 6 | 12.8 | 41 | 87.2 | 0 | 0 | 0.976 | 2 | 0.671 |
| Adoption of climate resilient agricultural practices | 8 | 9.3 | 77 | 89.5 | 1 | 1.2 | 0.87 | 2 | 0.647 |
| Water harvesting and Management | 2 | 4.0 | 48 | 96.0 | 0 | 0 | 2.55 | 2 | 0.279 |
| Reforestation and agroforestry | 9 | 12.9 | 61 | 87.1 | 0 | 0 | 1.328 | 2 | 0.515 |
| Strengthening Social networks & community resilience | 7 | 17.1 | 34 | 82.9 | 0 | 0 | 2.946 | 2 | 0.229 |
| Access climate Information & early warning systems | 3 | 6.1 | 45 | 91.8 | 1 | 2.0 | 3.237 | 2 | 0.199 |
| Wetland conservation & restriction | 2 | 5.9 | 32 | 94.1 | 0 | 0 | 0.87 | 2 | 0.647 |

#### *4.6.8.5 Income:*

Income earned had no significant influence on the different climate change strategies adopted by the residents in Rukiga District as shown in Table 4.26. These findings were inconsistent with a hypothesis in this study that the more the income earned by the resident the higher their capacity and the ability to respond to environmental disparities by adopting different climate change strategies to counter the effects of their activities in wetland areas. These results contradict with studies from Jones et al., (2013) and Gedikoglu & Parcel (2013) which postulate a positive impact that income has on adoption of different climate change mitigation and sustainable measures

**Table 4.2.6: Relationship between Income and Adoption of Climate Change Adaptation Practices by Residents in Rukiga District**

| Climate Change adaptation Strategies | Average Income | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | <250,000 | | 250,001 - 500000 | | 500001 - 750000 | | 750,001 - 100000 | | 1000001-1500000 | | 1500001-2000000 | | >2,000,00 | | | | |
| | F | % | F | % | F | % | F | % | F | % | F | % | F | % | X2 | df | P values |
| Diversification of livelihoods | 14 | 35.9 | 11 | 28.2 | 10 | 25.640 | 3 | 7.7 | 1 | 2.6 | 0 | 0.0 | 0 | 0.0 | 9.161 | 6 | 0.165 |
| Adoption of climate resilient agricultural practices | 25 | 32.9 | 18 | 23.7 | 11 | 14.5 | 14 | 18.4 | 4 | 5.3 | 4 | 5.3 | 0 | 0.0 | 3.134 | 6 | 0.792 |
| Water harvesting and Management | 13 | 38.2 | 6 | 17.7 | 4 | 11.8 | 6 | 17.7 | 3 | 8.8 | 2 | 5.9 | 0 | 0.0 | 2.576 | 6 | 0.86 |
| Reforestation and agroforestry | 16 | 28.1 | 11 | 19.3 | 10 | 17.5 | 13 | 22.8 | 2 | 3.5 | 4 | 7.0 | 1 | 1.8 | 4.130 | 6 | 0.659 |
| Strengthening Social networks & community resilience | 6 | 20.7 | 5 | 17.2 | 8 | 27.6 | 3 | 10.3 | 2 | 6.9 | 4 | 13.8 | 1 | 3.5 | 8.196 | 6 | 0.224 |
| Access climate Information & early warning systems | 16 | 44.4 | 8 | 22.2 | 5 | 13.9 | 2 | 5.6 | 3 | 8.3 | 2 | 5.6 | 0 | 0.0 | 5.603 | 6 | 0.469 |
| Wetland conservation & restriction | 8 | 33.3 | 2 | 8.3 | 3 | 12.5 | 4 | 16.7 | 1 | 4.2 | 5 | 20.8 | 1 | 4.2 | 11.834 | 6 | 0.066 |

In conclusion, among all the socio-economic factors, it was revealed that only gender has a significant relationship adoption of climate change adaptation strategies specifically with only reforestation and agroforestry ($x^2$=3.915, df=1, p=0.048). All the other socio-demographic factors i.e. age, education, residence ownership and income were found not to significantly influence climate change adoption strategies among residents in Rukiga District.

The findings from the study on adaptation strategies adopted by local residents in Rukiga District to cope with the adverse impacts of changing climate highlight several key observations and comparisons with earlier findings. Firstly, the diversification of livelihoods emerged as a prevalent adaptation strategy, with 16.1% of respondents opting for alternative income-generating activities. This reflects a recognition among local communities of the need to reduce dependence on climate-sensitive sectors such as agriculture, echoing earlier studies that emphasize the importance of livelihood diversification in building resilience to climate-related shocks (Ellis, 2000).

Secondly, the adoption of climate-resilient agricultural practices was reported by 20.7% of respondents, indicating a significant effort to adapt farming systems to changing environmental conditions. This aligns with previous research highlighting the importance of implementing climate-smart agriculture techniques to enhance agricultural resilience and productivity in the face of climate change (Lipper *et al.*, 2014).

Thirdly, water harvesting and management techniques were implemented by 12.5% of respondents, underscoring the importance of ensuring access to water for domestic use and agriculture in the context of variable rainfall patterns. This finding is consistent with earlier studies emphasizing the role of water management strategies in mitigating water scarcity and supporting agricultural production in water-stressed regions (Zou *et al.,* 2018).

Furthermore, reforestation and agroforestry initiatives were embraced by 10.3% of respondents, highlighting a commitment to enhancing ecosystem services and biodiversity conservation. This corresponds to previous research emphasizing the importance of restoring forest ecosystems and integrating trees into agricultural landscapes to mitigate climate change impacts and enhance ecosystem resilience (Baudron *et al.,* 2019).

Moreover, strengthening social networks and community resilience emerged as a significant adaptation strategy, with 18.3% of respondents leveraging social cohesion and collective action to build resilience to climate-related shocks. This finding aligns with earlier studies emphasizing the role of social capital and community-based approaches in enhancing adaptive capacity and fostering resilience in vulnerable communities (Adger *et al.,* 2005).

Lastly, improved access to climate information and early warning systems was reported by 13.3% of respondents, indicating a proactive approach to enhancing preparedness and risk awareness. This corresponds to previous research highlighting the importance of providing timely and accurate climate information to support adaptive decision-making and reduce vulnerability to climate-related hazards (Basher *et al.,* 2014). In summary, the findings from this study provide valuable insights into the adaptation strategies adopted by local residents in Rukiga District to cope with the adverse impacts of changing climate. These findings not only underscore the importance of community-based approaches and local knowledge in building resilience but also highlight the need for integrated and context-specific adaptation measures to address the multifaceted challenges of climate change.

# CHAPTER FIVE: CONCLUSIONS AND RECCOMENDATIONS

## 5.1 Introduction

Wetlands are invaluable ecosystems that provide essential services to both the environment and human societies. However, these vital habitats are increasingly threatened by human activities, including encroachment, overexploitation, and land use changes. Understanding the complex dynamics of wetlands, including their carbon storage capacity, the impact of livelihood activities, and the drivers of change, is essential for effective conservation and sustainable management.

This chapter presents the conclusions and recommendations of a comprehensive study conducted in Kanyabaha wetland, Rukiga District, Uganda. The study aimed to assess the existing carbon stocks, understand the effects of livelihood activities on carbon storage, and identify the drivers of wetland utilization and degradation. By addressing these objectives, the study provides valuable insights into the challenges facing wetland conservation and offers practical recommendations for mitigating threats and promoting sustainable practices.

## 5.2 Conclusions

### 5.2.1 The Existing Carbon Stocks in Kanyabaha Wetland in Rukiga District

The study aimed to assess the existing carbon stocks in Kanyabaha wetland, Rukiga District, with a focus on understanding carbon dynamics influenced by land use and cover changes. Notably, the primary sources of carbon in the wetland soil were identified as natural vegetation, particularly papyrus reeds, crops cultivated by farmers, grasses, and woody vegetation within the watershed. The accumulation of dead plant matter beneath the papyrus beds, coupled with organic matter transported from surrounding land via surface runoff, significantly contributed to carbon inputs in the wetland soils. Moreover, the study highlighted the profound impact of land use and cover changes on carbon stocks within the wetland ecosystem.

Analysis of organic carbon content across various soil depths and land use/cover types underscored notable disparities. Soil organic carbon exhibited considerable variability across different soil layers, with the deepest soil layer showing the highest average concentration, followed by the topsoil and subsoil layers. Additionally, variations in soil organic carbon content were observed among different land cover types, with grasslands exhibiting the highest mean soil organic carbon content, followed by built-up areas and papyrus, while woodlands recorded the lowest mean soil organic carbon content.

Furthermore, assessment of soil carbon density at different depths and soil types revealed intriguing patterns. Soil carbon density increased with soil depth across various soil types, with the highest density observed in the deepest soil layer. However, variations in carbon density were noted among different land use/cover types, with woodlands exhibiting the highest mean soil carbon density, followed by built-up areas and tree plantations, while grasslands displayed the lowest mean soil carbon density.

Moreover, the study investigated aboveground, belowground, and total carbon stocks in the wetland over time. Papyrus emerged as the land cover type with the highest aboveground carbon stock, while belowground carbon stocks were consistently highest under papyrus across all years assessed. Trends in aboveground carbon stocks varied among different land use/cover types over the years, with some experiencing increases while others exhibited decreases. Notably, belowground carbon stocks generally increased with soil depth, with the highest stocks observed in the deepest soil layer.

Additionally, the study examined bulk density at various soil depths and land use/cover types. Bulk density exhibited minimal differences across soil depths, with higher densities typically found downstream of the wetland. Among different land use/cover types, woodlands displayed the highest mean bulk density, followed by tree plantations and small-scale farmlands, while grasslands exhibited the lowest mean bulk density.

### 5.2.2 The Effect of Livelihood Activities on Carbon Stocks and Plant Species Diversity in Kanyabaha Wetland in Rukiga District

The findings regarding the effect of wetland livelihood activities on carbon stocks in Kanyabaha wetland yield powerful conclusions:

Wetland-dependent livelihood activities, including crop growing and tree planting, exert a significant influence on carbon stocks within the wetland ecosystem. The study reveals substantial variations in carbon stocks among different crops and tree species, indicating the diverse contributions of these activities to carbon sequestration.

Analysis of carbon stocks at different soil depths highlights the importance of belowground carbon storage, which generally increases with soil depth for all sampled livelihood activities. Eucalyptus tree planting stands out as the activity with the highest belowground carbon stocks across all soil depths, followed by Irish potatoes, tobacco, sweet potatoes, cabbages, and beans.

Statistical analysis confirms the significance of the relationship between livelihood activities and carbon stocks, with a notable variation observed between tree planting and crop growing activities. This underscores the distinct contributions of different activities to carbon sequestration dynamics in the wetland. Findings highlight the potential of wetland-dependent livelihood activities to contribute to carbon sequestration and storage. By recognizing the differential impacts of various crops and tree species on carbon stocks, policymakers and land managers can implement targeted strategies to promote sustainable land use practices that enhance carbon storage while supporting local livelihoods.

Human activities such as agriculture, settlement, and resource extraction may have led to a significant decline in plant species diversity in the Kanyabaha wetland system. This decline is marked by the dominance of a few resilient species and the disappearance of more sensitive and rare species. Additionally, the continuous pressure from human activities has altered the natural structure of plant communities in the wetland. There is a noticeable shift towards more of eucalyptus species, leading to a less diverse and more homogenized ecosystem. The reduction in plant species diversity and the alteration of community structure may result in the loss of critical ecological functions provided by the wetland, such as water purification, habitat provision, and carbon sequestration.

### 5.2.3 The Main Drivers of Wetland of Resources Utilization in Kanyabaha Wetland in Rukiga District

The findings regarding the drivers of wetland utilization and encroachment in Kanyabaha wetland, Rukiga District, reveal several critical conclusions:

Low emerges as the predominant driver behind the exploitation of Kanyabaha wetlands, with a staggering 65.8% of respondents citing economic deprivation as a significant factor. This highlights the urgent need to address poverty and provide alternative livelihood opportunities to alleviate the pressure on wetland resources driven by subsistence agriculture and immediate economic needs.

Inadequate enforcement of environmental laws significantly exacerbates wetland degradation, as 10.8% of respondents identify. Weak enforcement mechanisms create a permissive environment for illegal activities such as encroachment and overharvesting to persist, undermining conservation efforts and compromising wetland integrity.

Corruption within regulatory bodies represents a pervasive driver of wetland exploitation, accounting for 10.8% of the identified factors. Widespread bribery and unethical practices undermine the enforcement of existing regulations, fostering a culture of impunity that allows illegal activities to flourish unchecked.

Rapid population growth and land scarcity intensify competition for land resources, driving communities to encroach upon wetlands for settlement and agriculture. Land scarcity constitutes 8.2% of the identified drivers, highlighting the need for sustainable land management practices and equitable land distribution to alleviate pressure on wetlands.

Limited knowledge within the community emerges as a significant driver of wetland degradation, constituting 4.5% of the factors influencing this phenomenon. Limited awareness about the ecological importance of wetlands perpetuates destructive behaviors, hindering conservation efforts and exacerbating threats to wetland ecosystems.

The findings highlight the interconnected nature of drivers behind wetland utilization and encroachment, with poverty, poor enforcement, corruption, land shortage, and community limited knowledge contributing to a complex web of challenges. Addressing these drivers requires coordinated efforts to combat corruption, alleviate poverty, strengthen enforcement mechanisms, manage land sustainably, and enhance community education and awareness.

### 5.2.4 The Adaptation Strategies Adopted by Local Residents to Cope with Adverse Impacts of Changing Climate in Rukiga District

The findings from this study in Rukiga District, Uganda, highlight the proactive response of local communities to the challenges posed by climate change. Through a variety of adaptation strategies deeply rooted in local knowledge and practices, residents have demonstrated resilience and ingenuity in mitigating the adverse impacts of changing climatic conditions on their livelihoods, agriculture, and natural resources.

Firstly, the diversification of livelihoods emerged as a prevalent adaptation strategy, with 16.1% of respondents opting for alternative income-generating activities beyond agriculture. This shift reflects a recognition of the need to reduce dependence on climate-sensitive sectors, thus enhancing resilience to climate-related shocks.

Secondly, the adoption of climate-resilient agricultural practices was notable, with 20.7% of respondents embracing techniques such as drought-resistant crop varieties and conservation agriculture. This highlights the importance of adapting farming systems to changing environmental conditions and underscores the critical role of agriculture in local livelihoods.

Thirdly, water harvesting and management techniques were implemented by 12.5% of respondents, emphasizing the acknowledgment of water resources' significance in mitigating water scarcity during dry periods and supporting agricultural production year-round.

Moreover, reforestation and agroforestry initiatives, undertaken by 10.3% of respondents, demonstrated a commitment to enhancing ecosystem services, including soil fertility, water retention, and carbon sequestration, thus contributing to climate resilience. Additionally, strengthening social networks and community resilience emerged as a vital strategy, with 18.3% of respondents leveraging collective action and mutual support to withstand and recover from climate-related shocks and stresses. Furthermore, improved access to climate information and early warning systems was reported by 13.3% of respondents, enabling informed decision-making and timely action in response to impending climate-related hazards, thereby reducing vulnerability.

Lastly, wetland conservation and restoration practices, embraced by 8.7% of local communities, represented a proactive approach to coping with climate change impacts, safeguarding vital ecosystems and enhancing resilience and sustainability.

The findings from the study in Rukiga District, Uganda, shed light on the proactive and adaptive measures undertaken by local communities to address the challenges posed by climate change. Through a combination of diversification of livelihoods, adoption of climate-resilient agricultural practices, water harvesting and management, reforestation and agroforestry, strengthening social networks, accessing climate information, and wetland conservation and restoration, residents have demonstrated resilience and innovation in the face of changing environmental conditions.

These adaptation strategies, deeply rooted in local knowledge and practices, not only mitigate the adverse impacts of climate change on livelihoods, agriculture, and natural resources but also contribute to enhancing resilience and sustainability within the community. By recognizing the importance of reducing dependence on climate-sensitive sectors, adapting farming systems, managing water resources effectively, conserving ecosystems, leveraging social networks, accessing climate information, and safeguarding vital wetlands, communities in Rukiga District are taking proactive steps to address climate-related challenges and build a more resilient future.

The findings of this study highlight the importance of locally-tailored adaptation strategies and community-based approaches in climate change resilience-building efforts. By drawing on indigenous knowledge, leveraging social capital, and embracing innovative practices, local communities are better equipped to navigate the complexities of climate change and safeguard their livelihoods and ecosystems for future generations. However, continued research and investment are needed to support the scaling up and sustainability of these adaptation measures and ensure their long-term effectiveness in enhancing resilience to climate change impacts.

## 5.3 Recommendations

### 5.3.1 The Existing Carbon Stocks in Kanyabaha Wetland in Rukiga District

Based on the detailed analysis of carbon stock changes in Kanyabaha wetland, here are some practical recommendations:

**Promote Conservation of Natural Vegetation:** Encourage the preservation and restoration of natural vegetation, especially papyrus reeds, which are significant contributors to carbon stocks in the wetland soils. Implement measures to prevent the destruction of papyrus beds and protect other native vegetation.

**Implement Sustainable Land Use Practices:** Promote sustainable land use practices that minimize disturbances to soil organic carbon. This includes reducing deforestation, adopting agroforestry techniques, and practicing rotational grazing to maintain vegetation cover and prevent soil erosion.

**Enhance Soil Carbon Sequestration:** Implement strategies to enhance soil carbon sequestration, such as no-till farming, cover cropping, and organic soil amendments. These practices can help increase soil organic carbon content and mitigate carbon loss from the soil.

**Raise Awareness and Capacity Building:** Conduct awareness campaigns and capacity-building workshops to educate local communities, farmers, and stakeholders about the importance of carbon stocks in wetland ecosystems.

**Improve Monitoring and Enforcement:** Strengthen monitoring and enforcement mechanisms to prevent illegal activities such as deforestation, land degradation, and wetland encroachment. Implement strict penalties for offenders and ensure effective enforcement of environmental regulations.

**Promote Carbon-friendly Livelihood Activities:** Encourage livelihood activities that support carbon sequestration and storage, such as eco-tourism, agroforestry, and sustainable agriculture. Provide support and incentives for community-led initiatives that contribute to wetland conservation and carbon management.

**Facilitate Research and Knowledge Sharing:** Support research initiatives focused on understanding carbon dynamics in wetland ecosystems and disseminate findings to policymakers, land managers, and local communities. Foster collaboration between researchers, government agencies, and community organizations to develop evidence-based conservation strategies.

**Address Drivers of Wetland Degradation:** Tackle underlying drivers of wetland degradation, such as poverty, inadequate enforcement of environmental laws, corruption and rapid population growth.

### 5.3.2: The Effect of Livelihood Activities on Carbon Stocks and Plant Species Diversity in Kanyabaha Wetland in Rukiga District

Based on the findings regarding the effect of wetland livelihood activities on carbon stocks and plant species diversity in Kanyabaha wetland, here are some practical recommendations:

**Promote Agroforestry Practices:** Encourage the integration of tree planting within agricultural landscapes. Agroforestry systems can significantly enhance carbon stocks both above and below ground while also providing additional benefits such as improved soil fertility, biodiversity conservation, and diversified income sources for farmers.

**Diversify Crop Production:** Promote diversification of crop production by introducing and supporting the cultivation of crops with higher carbon sequestration potential. Diversification can help optimize carbon sequestration while reducing the risk of crop failure and enhancing food security.

**Adopt Conservation Agriculture:** Encourage the adoption of conservation agriculture practices among crop growers to minimize soil disturbance, improve soil organic carbon levels, and enhance overall soil health. Practices such as minimum tillage, cover cropping, and crop rotation can contribute to increased carbon stocks in agricultural soils.

**Provide Training and Technical Support:** Offer training programs and technical support to farmers on sustainable land management practices that promote carbon sequestration. This includes guidance on optimal tree planting techniques, crop selection, soil conservation measures, and nutrient management strategies tailored to local conditions.

**Monitor and Evaluate Impact:** Establish monitoring and evaluation systems to assess the impact of wetland livelihood activities on carbon stocks and plant species diversity over time. Regular monitoring allows for the identification of successful practices, areas for improvement, and emerging challenges, enabling adaptive management strategies to be implemented effectively.

**Integrate Carbon Considerations into Land-Use Planning:** Integrate considerations of carbon stocks and sequestration potential into land-use planning processes at the local level. Incorporating carbon considerations into land-use decision-making can help ensure the conservation and sustainable management of wetland ecosystems for future generations.

There is a need to establish a long-term monitoring program to assess changes in plant species diversity and wetland health. Further research needs to be conducted to understand the specific impacts of the different human activities to guide the development of targeted management strategies.

### 5.3.3 The Main Drivers of Wetland Resources Utilization in Kanyabaha Wetland in Rukiga District

The scope of projects subjected to Environmental Impact Assessment should be widened to cover small-scale activities which collectively have significant negative impact on the wetland environment.

Knowledge-based building through research should be encouraged and with effective information dissemination where the general population can be educated on wetland management and conservation issues.

Implement targeted poverty alleviation programs to uplift communities living below the poverty line, providing them with alternative livelihood opportunities.

Introduce sustainable income-generating activities that do not rely on wetland exploitation, such as eco-tourism, agroforestry, or vocational training programs.

Strengthen enforcement mechanisms and capacity-building efforts among regulatory bodies responsible for wetland protection.

Increase monitoring and surveillance activities to deter illegal activities such as encroachment, illegal logging, and overharvesting.

Implement strict penalties and disciplinary measures for offenders to create deterrence against environmental law violations.

Implement anti-corruption measures within environmental regulatory bodies, including transparency initiatives, whistleblower protections, and integrity training for enforcement officers.

Encourage community participation in monitoring and reporting corrupt practices to promote accountability and transparency.

Develop integrated land-use plans that prioritize conservation while accommodating the needs of growing populations.

Promote sustainable agricultural practices and land management techniques to maximize land productivity without encroaching on wetlands.

Launch targeted education and awareness campaigns to inform communities about the ecological importance of wetlands and the consequences of their degradation.

### 5.3.4 The Adaptation Strategies Adopted by Local Residents to Cope with Adverse Impacts of Changing Climate in Rukiga District

Based on the identified adaptation strategies in Rukiga District, Uganda, several recommendations can be drawn to support and enhance community resilience to climate change:

**Promote livelihood diversification:** Encourage and support initiatives that enable local residents to diversify their sources of income beyond agriculture. This could involve providing training, access to resources, and market linkages for alternative income-generating activities such as small-scale businesses, petty trading, and handicraft production.

**Scale up Adoption of Climate-Resilient Agricultural Practices:** Facilitate the dissemination of information and resources to enable farmers to adopt climate-resilient agricultural practices, including the use of drought-resistant crop varieties, conservation agriculture techniques, agroforestry, and soil conservation measures. Extension services and farmer cooperatives can play a vital role in promoting and supporting the adoption of these practices.

**Invest in Water Harvesting and Management:** Support community-led initiatives for water harvesting and management, including the construction of rainwater harvesting systems, small-scale irrigation schemes, and community water storage facilities. Provide technical assistance, funding, and capacity-building programs to enable communities to effectively manage their water resources and mitigate the impacts of water scarcity.

**Promote Reforestation and Agroforestry**: Encourage collaborative efforts among communities, government agencies, and non-governmental organizations to undertake reforestation and agroforestry initiatives. Provide incentives, technical support, and capacity-building programs to facilitate the planting of trees on farmlands, communal lands, and degraded areas, thereby enhancing ecosystem services and promoting biodiversity conservation.

**Strengthen Social Networks and Community Resilience:** Foster partnerships and collaboration among community-based organizations, traditional institutions, and local government agencies to strengthen social networks and build community resilience. Support initiatives that promote collective action, mutual support, and knowledge sharing on climate adaptation strategies, thereby enhancing community cohesion and solidarity in the face of climate-related challenges.

**Improve Access to Climate Information and Early Warning Systems:** Enhance access to timely and accurate climate information and early warning systems through mobile phones, radio broadcasts, and community meetings. Invest in the development of robust climate information systems and capacity-building programs to empower communities to make informed decisions and take timely action in response to impending climate-related hazards.

**Support Wetland Conservation and Restoration:** Provide resources and technical support for wetland conservation and restoration practices, including habitat restoration, re-vegetation of degraded areas, and invasive species management. Recognize the importance of wetlands in regulating local climate patterns, storing carbon, and providing essential ecosystem services, and promote their preservation as valuable assets for enhancing resilience and sustainability in the face of environmental threats.

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## APPENDICES

### Appendix I: Household Questionnaire

Dear Respondent,

My Name is PAUL WALAKIRA from Kenyatta University. I am conducting research on the **"IMPACT OF HUMAN ACTIVITIES ON CARBON STOCKS AND IMPLICATIONS ON SUSTAINABILITY OF COMMUNITY LIVELIHOODS IN KANYABAHA WETLAND IN RUKIGA DISTRICT, UGANDA".** This research is purely for academic purposes. I kindly request you to cooperate and fill out the questionnaire which seeks your views on this issue. The information that you give shall be treated confidentially and will only be used for academic reasons. I appreciate for taking your time to provide the response.

This questionnaire is designed to generate information on wetland dependent livelihood activities and their sustainability in Kanyabaha wetland in Uganda. It is used strictly for research purposes and the information gathered from the respondent will be kept confidential. We request for your time to answer some questions and thank you for the cooperation

District: …………………………….. Sub-county: ………………………

.Parish: …………………………….. Village: ……………………………

Date: ……………………………

GPS coordinates: …………………

Start time: ………………………… Finish time: ………………………………

SECTION A: Household Characteristics

| Q-No. | Question and Filters | Coding category (Circle appropriately) |
|---|---|---|
| 100 | Social demographic data | |
| 101 | Sex | Male ……………………………. 1<br>Female ……………………………2 |
| 102 | How old are you (in completed years)? | 15-20 ……………………………. 1<br>21-30 ………………………..….. 2<br>31-40 …………………………..... 3<br>41-50 ……………………………. 4<br>>50 ……………………………. .5 |
| 103 | What is your marital status? | Single ……………………………. 1<br>Married/cohabiting………………..2<br>Widowed …………………………3<br>Divorced/separated ………………. 4 |
| 104 | What is the last education level you attained? | None …………………………….. 1<br>P1-P4 ……………………………. 2<br>P5-P7 ……………………………..3<br>O-level ……………………………4<br>A-level ……………………………5<br>Tertially …………………………..6 |
| 105 | Ownership for home of residence? | Tenant ……………………….…...1<br>Owner ………………………...…..2<br>Other(specify) ……………………3 |
| 106 | Does your landlord reside at the same premises? | Yes ……………….………………1<br>No ………………..………………2 |
| 107 | How many people do you live with? | Children …………….…………...1<br>Adults …………….……………..2 |
| 108 | How long have you lived in this area (in years)? | Less than 1 ……………………...1<br>1 – 5 ……………………………..2<br>6 – 10 ……………….……………3<br>More than 10 ……………………4 |
| 109 | Why did you move to this place (current location/house)? | Nearer to my place of work………1<br>Nearer to the main road………..…2<br>Cheaper than other places ………..3<br>Closer to my family/friends………4<br>It was the only available option…..5<br>I consider it home ………………..6<br>I don't pay rent …………………..8<br>Other (specify) …………………..9 |
| 200 | Household Income | |
| | | Peasant/farmer……………….…….1<br>Casual labourer ………………..….2 |

| Q-No. | Question and Filters | Coding category (Circle appropriately) |
|---|---|---|
| 201 | What is your main occupation or source of income? | Professional (teacher, nurse, etc) …3<br>Self-employed (trader/business, mechanic, builder, etc) …………….4<br>Transport/ driver (taxi, lorry/truck, boda-boda, etc) ………….……..… 5<br>Remittance ……………..……….6<br>Other (specify) …………..……..7 |
| 202 | Do you have any other sources of income? | Yes……………………………….1<br>No ………………..……………...2 |
| 203 | How much do you earn on average per month? | < 250,000………………………....1<br>250,001-500,000………………….2<br>500,001-750,000…………….……3<br>750,001-1,000,000……….……..…4<br>>1,000,000………..……………..…5 |

| 300 | Property ownership along the wetland | | | | |
|---|---|---|---|---|---|
| 301 | What property do you own a along the wetland? | | *Bought* | *Inherited* | *Rent* |
| | | *Farm land* | | | |
| | | *Fishing gears* | | | |
| | | *Brick making site* | | | |
| | | *Mining site/assets* | | | |
| | | *Other1 (specify)* | | | |
| | | *Other2 (specify)* | | | |

SECTION B 400: Economic Activities that Lead to Wetland Degradation

| Q-No. | Question and Filters | Coding category (Circle appropriately) |
|---|---|---|
| 401a | In past 10 years, has the population in this area changed? | Yes………………………………….1<br>No …………………………………..2 |
| 401b | If yes, what has been the trend? | Increased …………………………...1<br>Decreased …………………………..2 |
| 405a | Does the population change leads to wetland degradation? | Yes………………………………….1<br>No …………………………………..2 |

| Q-No. | Question and Filters | Coding category (Circle appropriately) |
|---|---|---|
| 405b | If yes, how has the increase in population contributed to wetland degradation? | |
| 406a | In past 10 years has the amount of rainfall in the area changed? | Yes……………………………………..1<br>No ……………………………………..2 |
| 406b | If yes, what type of change has happened? | Increased ………………………………1<br>Decreased ……………………….…2 |
| 407 | Does the decrease in rainfall lead to wetland degradation? | Yes……………………………………....1<br>No ……………………………………..2 |
| 408 | Which activities do you use the wetland for? | Crop cultivation …………..………..1<br>Fishing ……………………………...2<br>Livestock/animal grazing……………...3<br>Brick making …………………………4<br>Sand mining …………………………...5<br>Agro-forestry …………………………6<br>Other (specify)....................................7 |
| 409a | What crops do you cultivate from the wetland area? | Maize …………………………………..1<br>Rice ……………….……………………...2<br>Beans……………………………………...3<br>Yams ……………………………………...4<br>Cassava ……………………………….…...5<br>Irish potatoes …………………………...6<br>Sweet potatoes ………………………….7<br>Vegetables ……………………….……8<br>Fruits …………………………………..9<br>Bananas ………………………………10<br>Other (specify)..................................11 |

<table>
<tr><th>Q-No.</th><th>Question and Filters</th><th colspan="2">Coding category (Circle appropriately)</th></tr>
<tr><td>409b</td><td>What livestock/animals do you rare from the wetland area?</td><td colspan="2">Cattle ……………………………………..1<br>Goats ……………………….……………2<br>Piggery..………………………………...3<br>Poultry.……………………….....……...4<br>Other (specify)......................................5</td></tr>
<tr><td>410a</td><td>Have your planting/cropping season changed over years?</td><td colspan="2">Yes.…………………………….……….1<br>No ……………………………….....…..2</td></tr>
<tr><td>410b</td><td>If yes, What do you think is the cause for the change?</td><td colspan="2"></td></tr>
<tr><td rowspan="7">411</td><td rowspan="7">In your understanding, which activity is the biggest threat to wetland health?<br>(Rank in order of severity of threat to wetlands starting with 1 as the biggest threat)</td><td>Activity</td><td>Rank</td></tr>
<tr><td>Crop cultivation</td><td></td></tr>
<tr><td>Fishing</td><td></td></tr>
<tr><td>Brick laying</td><td></td></tr>
<tr><td>Sand mining</td><td></td></tr>
<tr><td>Agro-forestry</td><td></td></tr>
<tr><td>Other……</td><td></td></tr>
</table>

| Q-No. | Question and Filters | Coding category (Circle appropriately) |
|---|---|---|
| 412 | Why are the activities mentioned above significantly affecting wetlands in Kabale (Rukiga) District? | Involve clearing of vegetation………...1<br>Eutrophication ………………………...2<br>Sedimentation ………………………....3<br>Draining ………………………………4<br>Other (specify)......................................5 |
| 413 | Why do people still practice the economic activities mentioned in 411 above despite their effects on wetlands? | Supplement HH incomes ……………1<br>Supplement HH food supply ………..2<br>Employment ………………………...3<br>Other (specify).....................................4 |
| 414 | In your opinion, comment on the amount of water available for use in the wetland? It has | Increased ………………………………1<br>Decrease ………….................. ……..2<br>Remained the same…………………...3 |

SECTION C 500: Livelihood Sources and Activities

| Q-No. | Question and Filters | Coding category (Circle appropriately) |
|---|---|---|
| 501 | How long have you been using the wetland? | ________Years |
| 502 | How big is your land in acres? | ________acres |
| 503 | Who owns the wetland you are currently using? | Myself ………………..……………...1<br>Family land …………..……………...2<br>Government …………..……………..3<br>Other/landlord …………..…………..4 |

| Q-No. | Question and Filters | Coding category (Circle appropriately) | |
|---|---|---|---|
| 504 | Do you possess a land title for the land you are now using? | Yes……………………….…………...1<br>No ……………………………...…..2 | |
| 505 | What do you use this land for? | Livestock …………….……..………...1<br>Crop production ……………….……......2<br>Beekeeping (Apiary) ………………....3<br>Fish farming ……………….…...……..4<br>Other (specify)..................................5 | |
| 506 | What are the major income generating sources from the activities done on the land mentioned above?<br>*(Rank in-order with 1 as the most important)* | *Activity* | *Rank* |
| | | *Crop cultivation* | |
| | | *Fish farming* | |
| | | *Livestock rearing* | |
| | | *Agro-forestry/Forestry* | |
| | | *Bee keeping/ Apiary* | |
| | | *Formal employment* | |
| | | *Wild animals* | |
| 507 | On average, how much income is earned from the enterprises mentioned in 506 above per annum?<br>*(Use the categories mentioned below)*<br>*< 250,000………………………….....1*<br>*250,001-500,000…………………….2* | *Activity* | *Income* |
| | | *Crop cultivation* | |
| | | *Fish farming* | |
| | | *Livestock rearing* | |
| | | *Agro-forestry/Forestry* | |
| | | *Bee keeping/ Apiary* | |

| Q-No. | Question and Filters | Coding category (Circle appropriately) | |
|---|---|---|---|
| | *500,001-750,000…………………….3*<br>*750,001-1,000,000……………………4*<br>*1,000,001-1,500,000………………5*<br>*1,500,001-2,000,000………………6*<br>*>2,000,000………………………….7* | *Formal employment* | |
| | | *Wild animals* | |

SECTION D 600: To Establish the Trends in Wetland Dependent Livelihood Activities and Their Sustainability in Kabale (Rukiga) District

To what extent do you agree with the following statements? *Use the given Likert scale (Strongly agree, Agree, undecided, Disagree, Strongly disagree)* by ticking appropriately the correct response.

| Qtn | Statements | Strongly agree | Agree | Undecided | Disagree | Strongly disagree |
|---|---|---|---|---|---|---|
| 601 | I do my farming activities 60 meters away from the wetland | | | | | |
| 602 | I do not clear vegetation along the wetland | | | | | |
| 603 | I use proper fishing methods | | | | | |
| 604 | I use both traditional and modern ways of preventing wetland degradation | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 605 | I teach others the proper methods of protecting wetlands | | | | | |
| 606 | The quantity of water available for domestic use has greatly been affected by wetland degradation | | | | | |
| 607 | The quality of water available for consumption has greatly been affected by wetland degradation | | | | | |
| 608 | The amount of income generated from using wetland has been affected by wetland degradation. How? | | | | | |

609. In your opinion, what do you think is likely to be the trend of the different climatic variables towards the future? (Tick appropriately to what applies)

| Climatic Variable | Increase | Decrease | Constant | Uncertain |
|---|---|---|---|---|
| Temperature | | | | |
| Rainfall | | | | |
| Floods | | | | |
| Droughts | | | | |

SECTION E 700: To Examine the Drivers of Resources Utilization of Wetland in Kabale (Rukiga) District

701. What do you think are the main drivers of wetland encroachment and degradation?

Poverty

Illiteracy

Corruption

Poor enforcement of laws and regulations

Others (specify)____________________________

702. Are you aware of any regulations for protecting wetlands?

Yes

No

703. Which activities are being done to safeguard the wetlands at household level?

....................................................................................................................................

....................................................................................................................................

704. Have you ever received any professional advice regarding sustainable wetland management?

Yes

No

705. What do you think can be done to preserve the wetlands in your area?

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Section F: 800: Adaptation Strategies to Changes in the Climate

How do you adapt to changes in climate within your community? (Multiple Responses Allowed)

| Adaptation Strategy | Yes | No |
|---|---|---|
| Diversification of Livelihoods | | |
| Adoption of Climate-Resilient Agricultural Practices | | |
| Water Harvesting and Management | | |
| Reforestation and Agroforestry | | |
| Strengthening Social Networks and Community Resilience | | |
| Accessing Climate Information and Early Warning Systems | | |
| Wetland Conservation and Restoration | | |
| Mention Any other….. | | |

END

****Thank you for taking time to participate in this exercise****

## Appendix II: Key Informant Interview (KII) Guide

Dear Sir/Madam,

This guide is designed to generate information on wetland impacts on climate change and sustainable livelihood in Uganda. It is used strictly for research purposes and the information gathered from the respondent will be kept confidential. We request for your time to answer some questions and thank you for the cooperation.

| | | | |
|---|---|---|---|
| Name of KI | | Organization | |
| Position | | Date Conducted | |
| Contact details | | Name of Interviewer | |

Could you please give me an overview and status of wetland environments in Uganda? In what condition are the wetlands in Kabale District?

What are the main reasons/drivers behind these current wetland conditions?

How is the current wetland status/condition influencing natural and social systems (livelihoods) in Kabale District?

What dangers are associated with wetland encroachment/degradation?

What opportunities exist in wetland areas?

What specific benefits and opportunities do people derive from the wetlands?

How are people adapting to minimize the dangers from wetland degradation/encroachment?

What is your role as a key stakeholder in regard to wetland and environment conservation?

What has been done about the wetland encroachment situation in your District?

What are some of the risk reduction strategies that stakeholders have implemented?

What are some of the major challenges encountered when dealing with issues to do with encroachment on wetlands?

Finally, what do you recommend as a workable solution to the current situation?

END

****Thank you taking time to participate in this exercise****

**Appendix III: Focus Group Discussion (FGD Guide)**

*Dear Sir/Madam*

This guide is designed to generate information on wetland impacts on climate change and sustainable livelihood in Uganda. It is used strictly for research purposes and the information gathered from the respondent will be kept confidential. We request for your time to answer some questions and thank you for the cooperation

| | | | |
|---|---|---|---|
| FGD Code | | Initials of interviewer | |
| Date Conducted | | Start/End time | |
| Parish | | Number of members | Male<br>Female |

How do you define a wetland and what do you know about them?

Of what benefit are wetlands to the community?

What specific benefits and opportunities do people derive from the wetlands?

What are some of the economic activities practiced in the wetlands within your community?

What are some of the dangers associated with wetland encroachment and degradation in Kabale?

Which of the mentioned economic activities have contributed to wetland encroachment and degradation in your environment? *Rank in order of importance*

What are the main reasons/drivers or factors influencing the activities that contribute to wetland encroachment and degradation?

How is the current wetland status/condition influencing natural and social systems (livelihoods) in Kabale District?

Please, could you mention some of the trainings and or sensitization opportunities that you have received on wetlands utilization and their protection?

What changes have you experienced or are likely to experience in weather patterns (temperature, rainfall, floods and drought), water access, quantity and quality as a result of wetland encroachment and degradation.

What adverse effects are they having or likely to have on productivity and livelihood?

What action have you taken to avert the wetland encroachment and degradation?

What are the drivers of Kanyabaha Wetland use in your community?

How do you adapt to climate change in the community?

END

****Thank you taking time to participate in this exercise****

This guide is designed to generate information on wetland impacts on climate change and sustainable livelihood in Uganda. It is used strictly for research purposes and the information gathered from the respondent will be kept confidential. We request for your time to answer some questions and thank you for the cooperation

| | | | |
|---|---|---|---|
| FGD Code | | Initials of interviewer | |
| Date Conducted | | Start/End time | |
| Parish | | Number of members | Male<br>Female |

How do you define a wetland and what do you know about them?

Of what benefit are wetlands to the community?

What specific benefits and opportunities do people derive from the wetlands?

What are some of the economic activities practiced in the wetlands within your community?

What are some of the dangers associated with wetland encroachment and degradation in Kabale?

Which of the mentioned economic activities have contributed to wetland encroachment and degradation in your environment? *Rank in order of importance*

What are the main reasons/drivers or factors influencing the activities that contribute to wetland encroachment and degradation?

How is the current wetland status/condition influencing natural and social systems (livelihoods) in Kabale District?

Please, could you mention some of the trainings and or sensitization opportunities that you have received on wetlands utilization and their protection?

What changes have you experienced or are likely to experience in weather patterns (temperature, rainfall, floods and drought), water access, quantity and quality as a result of wetland encroachment and degradation.

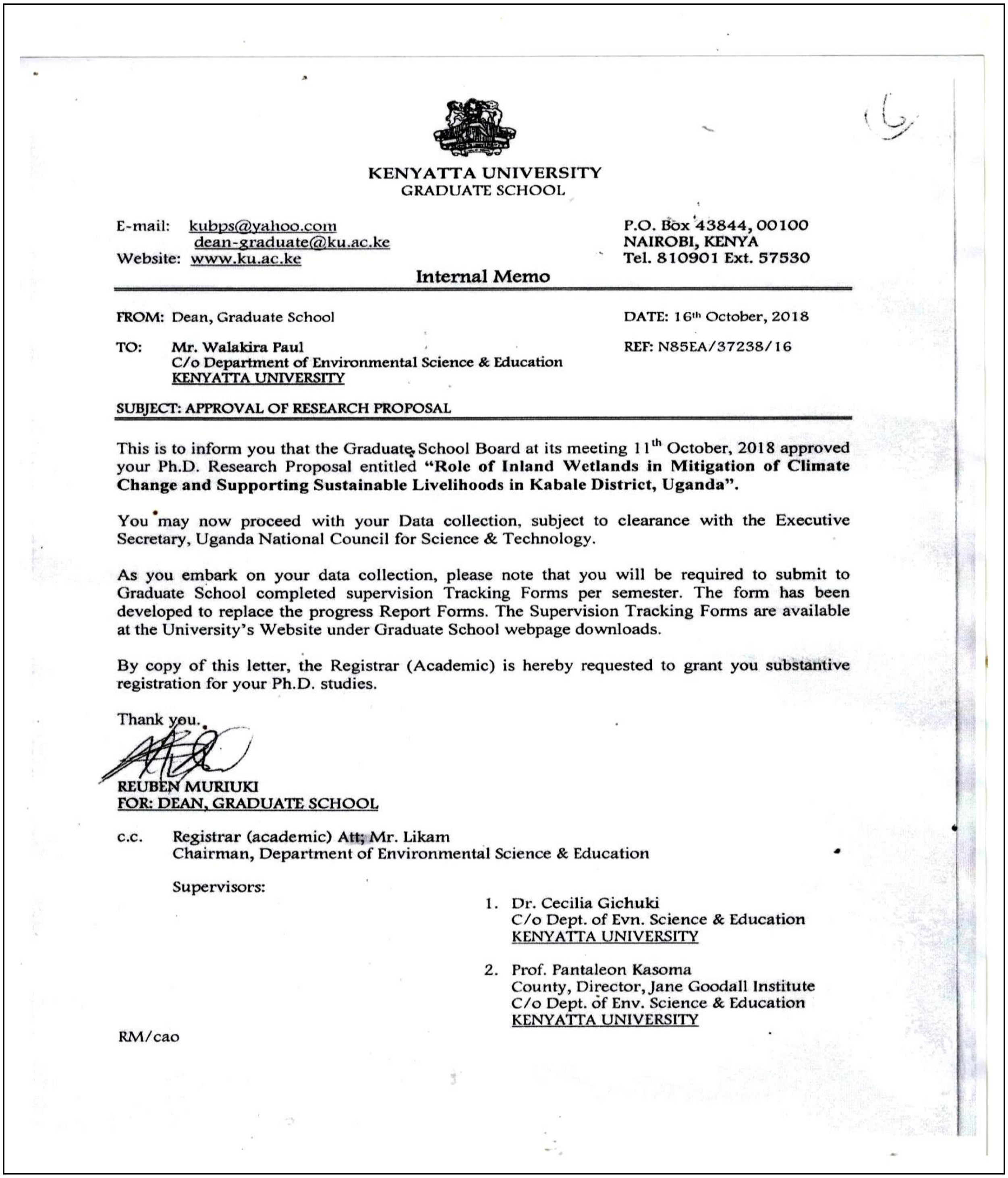
What adverse effects are they having or likely to have on productivity and livelihood?

What action have you taken to avert the wetland encroachment and degradation?

What are the drivers of Kanyabaha Wetland use in your community?

How do you adapt to climate change in the community?

## Appendix IV: Approval of Research Proposal Letter



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**Internal Memo**

**FROM:** Dean, Graduate School

DATE: 16th October, 2018

**TO:** **Mr. Walakira Paul**
**C/o Department of Environmental Science & Education**
**KENYATTA UNIVERSITY**

**REF:** N85EA/37238/16

**SUBJECT: APPROVAL OF RESEARCH PROPOSAL**

This is to inform you that the Graduate School Board at its meeting 11th October, 2018 approved your Ph.D. Research Proposal entitled **"Role of Inland Wetlands in Mitigation of Climate Change and Supporting Sustainable Livelihoods in Kabale District, Uganda".**

You may now proceed with your Data collection, subject to clearance with the Executive Secretary, Uganda National Council for Science & Technology.

As you embark on your data collection, please note that you will be required to submit to Graduate School completed supervision Tracking Forms per semester. The form has been developed to replace the progress Report Forms. The Supervision Tracking Forms are available at the University's Website under Graduate School webpage downloads.

By copy of this letter, the Registrar (Academic) is hereby requested to grant you substantive registration for your Ph.D. studies.

Thank you.

**REUBEN MURIUKI**
**FOR: DEAN, GRADUATE SCHOOL**

c.c. Registrar (academic) Att; Mr. Likam
Chairman, Department of Environmental Science & Education

Supervisors:

1. Dr. Cecilia Gichuki
   C/o Dept. of Evn. Science & Education
   KENYATTA UNIVERSITY
2. Prof. Pantaleon Kasoma
   County, Director, Jane Goodall Institute
   C/o Dept. of Env. Science & Education
   KENYATTA UNIVERSITY

RM/cao

## Appendix V: Permission to Conduct Research

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website: www.mwe.go.ug

In any correspondence on
this subject please quote Ref. No. DEA/59/168/01

FOR GOD AND MY COUNTRY
THE REPUBLIC OF UGANDA

**MINISTRY OF WATER AND ENVIRONMENT**
**P. O. BOX 20026**
**KAMPALA - UGANDA**

Thursday 23,October,2020

Mr. Paul Walakira
C/o Kyambogo University
P.O. Box 1 Kyambogo
Kampala, Uganda

**RE: PERMISSION TO CONDUCT RESEARCH AROUND LAKE BUNYONYI WETLANDS IN KABALE DISTRICT**

Following your application dated 2018-12-04 to carry out research on **"Role of inland wetlands in mitigation of climate change and supporting sustainable livelihoods in Kabale District, Uganda"**

I am pleased to inform you that you have been authorized to undertake research in Lake Bunyonyi wetland system (North Kiruruma and South Kiruruma), Kabale District.

You are advised to report to the Kabale District Administration before embarking on the research project. On completion of the research, you are expected to submit a copy of the research report/thesis to our office.



Yours faithfully,

Magara Nicholas

**For: PERMANENT SECRETARY**

**Copy to:**
The Chief Administrative Officer-Kabale District
The LCV Chairperson –Kabale District
The Resident District Commissioner –Kabale District
The District Environment Officer –Kabale District