THE EFFECTS OF WETLAND USE/COVER CHANGES ON SOIL ORGANIC CARBON IN MASESE WETLAND, JINJA CITY

BY

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DECLARATION

I, **PETER BAMEGE**, affirm that this dissertation, titled ***"THE EFFECTS OF CHANGES IN WETLAND USE/COVER ON SOIL ORGANIC CARBON IN MASESE WETLAND, JINJA CITY,"*** has not been submitted or presented to any university or institution of higher education for any other degree.

Signed……………………………… Date…………………………………

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APPROVAL

We certify that this dissertation titled ***“ASSESSING THE EFFECTS OF WETLAND USE/COVER CHANGES ON SOIL ORGANIC CARBON IN MASESE WETLAND, JINJA CITY”*** has been compiled under our guidance and supervision, and it is now ready for examination.

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ASSOCIATE PROFESSOR. WAMBEDE M. NABALEGWA

DEDICATION

I dedicate this dissertation to my parents, Bamege Peter Senior and Nakayima Kevin; my dear wife, Kifuko Jesca; and my children, Nakayima Noeline, Biribawa Rose Mary, and Bamege Nodrine Peter.

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LIST OF ABBREVIATIONS

AACS	Annual Agricultural Census Survey
ANOVA	Analysis of Variance
BMAU	Budget Monitoring and Accountability Unit
C	Carbon
CE	Common/Christian Era
CH4	Methane
CO_2	Carbondioxide
GEE	Google Earth Engine
GOU	Government of Uganda
GPS	Global Positioning System,
HRV	Hazard Risk and Vulnerability
LULC	Land Use/Land cover
MEA	Millennium Ecosystem Assessment
MSI	Multi-Spectral Instrument
MWE	Ministry of Water and Environment.
N_2O	Nitrous Oxide
NDP	National Development Programme
NEMA	National Environment Management Authority.
NSOER	National State of Environmental Report
OECD	Economic Co-operation and Development
OLI	Operational Land Imager
RGB	Red, Green and Blue
SDGs	Sustainable Development Goals
SOC	Soil Organic Carbon
TIRS	Thermal Infrared Sensor
TN	Total Nitrogen
UBOS	Uganda Bureau of Statistics

ABSTRACT

Human activities, particularly in rapidly urbanizing areas, are increasingly placing significant pressure on wetland ecosystems, compromising their ecological integrity and their role as carbon sinks. This study focused on the Masese wetland in Jinja City, Uganda, to evaluate land use/cover changes and soil organic carbon (SOC) across different wetland sections. The key objectives were to: (1) analyze spatial and temporal changes in wetland use/cover between 2014 and 2023; (2) examine the primary drivers of wetland use/cover changes; and (3) assess Soil Organic Carbon under various wetland use/cover types in Masese. The researcher adopted a mixed research design; cross cross-sectional research design; the quantitative and qualitative approach of data collection. The researcher used Landsat 8 (2014) and Sentinel-2A (2017, 2020, and 2023) satellite imagery for spatial-temporal analysis through the Google Earth Engine platform, collected social and economic data on wetland use/cover drivers from 276 households across five wards, administered questionnaires and conducted interviews with local stakeholders, analyzed soil samples from 15 sites using Walkley and Black’s rapid titration method and processed satellite imagery using maximum likelihood supervised classification, discriminant analysis, and change detection in ArcGIS 10.8.2. The researcher found a 3% reduction in permanent wetland areas between 2014 and 2023, driven by industrial development, economic growth, inadequate policy enforcement, and significant differences in soil properties like pH, phosphorus content, and sand/clay composition. The ANOVA results showed that there were no big differences ($p > 0.05$) in the SOC between the different types of wetland use. Therefore the study concludes that industrial and weak government policy and regulations have led to substantial wetland degradation in Masese wetland. However, the current land use practices have not yet caused significant depletion of SOC. The study recommends prioritization of vertical development instead of horizontal expansion practices to avoid encroaching on fragile ecosystems, particularly wetlands and strong policy enforcements related to land use planning and wetland protection, accompanied by community engagement to promote sustainable practices. Further research should examine the long-term impacts of land use changes on SOC and ecosystems, ensuring urban development considers ecological factors to preserve the wetland's role as a carbon sink.

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Wetlands are ecosystems that act as a bridge between land and water, defined by a shallow water table and either at or close to the surface, or by the presence of shallow water on the land. (Dar et al., 2020; Tooth & Waal, 2019; Vasumthi et al., 2023). They consist of various ecosystems, such as swamps, marshes, peatlands, and ferns, as well as marine regions with depths not greater than six meters at low tide, as defined by the Ramsar Convention. (An & Verhoeven, 2019; Dar et al., 2020). Even though they comprise only 6% of the Earth's terrestrial area, wetlands offer vital ecological services worldwide. (Dar et al., 2020). They are also distributed worldwide and classified into inland, man-made, and coastal/marine categories based on their characteristics and location (Vasumthi et al., 2023). Sarkar et al. (2020) observed that wetlands can be found in all climate zones, ranging from arid areas to high elevations, encompassing regions from the tropics to the polar zones, and including various types such as deltas, floodplains, flooded forests, lakes, mangroves, marshes, peatlands, rice fields, rivers, and swamps. Similarly, the Queensland government classifies wetlands including lacustrine, riverine, palustrine, estuarine, and modified or artificial (Adame et al., 2019) which also includes floodplain and valley bottoms (Mansur, 2021) while Bhattacharjee et al. (2021) noted that wetlands are categorized into seven distinct landscape types, which include: estuarine, open coast, floodplains, freshwater marshes, lakes, peatlands, and swamp forest.

Wetlands are known as the earth's kidneys (Meng & Dong, 2019; Zhang et al., 2021). They offer critical ecological benefits, such as managing floods, conserving water, and controlling greenhouse gas emissions. (Li et al., 2023a; Sui et al., 2021). They play a crucial role in the storage of carbon around the world, with freshwater sources holding about 33% of the terrestrial carbon inventory, surpassing the rates of carbon storage found in forests. (Treby et al., 2020; Were et al., 2020) and retain approximately one-third of the entire SOC reservoir in land-based systems. (Dai et al., 2023). Wetlands rank among the most productive ecosystems on the planet, serving a vital function in the global carbon cycle. They accumulate a substantial quantity of carbon in their soils, commonly known as soil organic carbon (SOC). These areas are important carbon sinks, absorbing carbon from the atmosphere, storing it in plant life, and hindering its emission into the atmosphere as carbon dioxide. (Sánchez-Espinosa & Schröder, 2019; Shao et al., 2022; Treby et al., 2020). Therefore, wetland carbon stock conservation is widely recognized as one of the most effective nature-based options for mitigating climate change (Magnan et al., 2023). Besides, Xiao et al. (2019), believe that wetlands are highly productive ecosystems that store a significant amount of carbon. Additionally, carbon storage in wetlands is essential for the global carbon cycle and supports the achievement of Sustainable Development Goal 13, which focuses on climate change mitigation. (Lorenz et al., 2019).

Wetlands are at risk because of alterations in land use caused by human actions like urban expansion, farming, and building projects, which have resulted in permanent changes. (Magnan et al., 2023). Wetlands are increasingly confronting environmental threats as a result of climate warming. (Shao et al., 2022). Over fifty percent of the planet's wetlands have suffered degradation, and the pace of this loss has risen considerably in the 21st century. (Chen et al., 2019; Xu et al., 2019; Anisha et al., 2020; Davidson, 2014; Ekumah et al., 2020; Mao et al., 2021; Zhang et al., 2021). Regional examples highlight significant wetland conversions, such as the depletion in Bangladesh, Indonesia, and China, and rapid wetland loss in East Africa and Uganda (Odeke Charles, 2019; NEMA, 2019; Sejati et al., 2020). The transformation of wetlands, particularly for agricultural or urban development, decreases soil organic carbon, which leads to increased greenhouse gas emissions, worsening climate change and endangering biodiversity. (Deng et al., 2022). Wetland degradation also impairs soil fertility, biodiversity, and the ecosystem’s ability to provide critical services such as water retention and climate regulation (Matovu et al., 2023; Nabiollahi et al., 2019; Sainepo et al., 2018; (Amanuel et al., 2018; Alikhani & Nummi, 2021). This puts at risk endeavours to achieve the SDGs, especially those connected to food security, health, climate, and land management. (Lorenz et al., 2019).

Different forms of wetland cover and use result in different soil organic carbon stocks. As an example, in Indonesia, Sejati et al., (2020) found that changes in land use and land cover (LULC) areas contributed considerably to a loss of more than 20% of blue carbon storage. Ma et al. (2016) and Meng & Dong (2019), a combination of climate change, artificial drainage, peat exploitation, and livestock grazing have caused the area of wetlands in China's Zoige Plateau to decrease by over 30% since the 1970s. These factors, along with the resulting change, are probably having a major impact on the SOC stock. In a similar vein, Meng and Dong.2019) contend that over 70% of wetlands in Bangladesh's Barind tract have been converted as a result of the growth of agricultural land, whereas within the past 30 years, China's wetland area has dropped by almost 33%. Korkanç et al. (2021) study looked at how land use change affected the Sultan marshes of Turkey's soil organic carbon and other soil characteristics. According to the study, rangelands, marshes, and shrublands had significantly higher SOC and carbon stocks than agricultural areas and drained lake regions. Xu et al. (2019) noted that SOC loss has been caused by the conversion of wetlands to croplands in northeastern China.

Because of North Africa's fast population expansion and migration, coastal wetlands are under a lot of stress, particularly from urban sprawl. (Aitali et al., 2022). Land degradation in Africa is largely caused by the loss of SOCS, which has detrimental effects on soil fertility, water retention capacity, and the provision of other crucial ecosystem services like climate control.(Willaarts et al., 2016). For instance, in Ethiopia's upper Blue Nile River Basin's Birr watershed, SOC tends to decrease with soil depth (Amanuel et al., 2018). Similarly, in Sub-Saharan Africa, there is no serious monitoring and protection of wetlands due to natural resources exploited by local communities leading to persistent degradation of swamps. For instance, Buraka et al., (2022) contended that in the Coka watershed in southern Nigeria, land use changes significantly impacted soil characteristics, especially SOCS, and that wetland health is deteriorating due to agricultural expansion, overgrazing, urbanization, and industrialization.

Wetlands in East Africa are seriously threatened by changing land use and population increases (Aitali et al., 2022). It is noted that agriculture has impaired soil fertility in East Africa in particular (Kabiri et al., 2022). Wetland use and cover change are environmental concerns in Uganda, specifically, wetlands face rapid depletion from drainage, pollution, and conversion for agricultural purposes (Odeke, 2019). The country has experienced a significant reduction in wetland coverage over the past decades, with the Eastern region particularly affected by rice farming and settlements (BMAU, 2022). Eastern Uganda has witnessed substantial wetland loss, with approximately 20% of wetlands already converted, highlighting the urgency of addressing wetland conservation (BMAU, 2022). NEMA (2019) reported a decline in wetland coverage from 15% to 13% of total land cover between 1994 and 2019, with a substantial portion being degraded or lost entirely (NEMA, 2019). These trends highlight the urgent need for comprehensive assessments of wetland dynamics and their impact on SOC (Wang et al., 2021). Studies on the Masese wetland in Jinja city, such as those by Hamid. (2023) underscore that urbanization and agricultural expansion have led to significant land use changes, affecting biodiversity and ecosystem services.

Tracking wetland changes and evaluating the effects of land use/land cover (LULC) on SOC and wetland health has been made possible by the use of remote sensing and GIS (Hailu et al., 2020) However, a research gap exists in integrating socio-economic factors and longitudinal studies on urbanization impacts on wetland ecosystems, In particular, soil organic carbon (SOC) is essential for successful conservation tactics. While land conversion typically reduces SOC, some urban wetlands show minimal SOC loss despite environmental degradation. Further research is needed to understand why SOC appears stable under urban expansion, as seen in Uganda’s wetlands (Odeke Charles, 2019; Wang et al., 2021). Studies indicate that policy, socio-economic pressures, and population dynamics significantly influence wetland conversion. However, further exploration of how these factors drive changes and how they vary across regions is necessary (Aitali et al., 2022).

1.2 Statement of the problem

The stability of ecosystems, agricultural productivity, and soil health all depend on soil organic carbon (Ngatia et al, 2021). However, the Masese wetland ecosystem in Jinja city is a host to numerous anthropogenic activities occasioned by long-term city/urban developments (Nabihamba., 2019) which present the potential for wetland change and associated soil organic carbon (SOC) losses. This precious ecosystem is rapidly deteriorating due to agricultural encroachment, industrial, rampant pollution, and urban expansion (Jinja City Council report, 2020; Nabihamba, 2019). These activities lead to significant changes that profoundly affect the Soil organic carbon within these ecosystems. The loss of SOC in wetlands not only releases stored carbon into the atmosphere, which fuels climate change, but it also jeopardizes the ecosystem's capacity to sustain biodiversity, control water quality and quantity, reduce the risk of erosion and flooding, and provide vital ecosystem services for human welfare (NEMA, 2019). The Masese wetland ecosystem has consistently lost SOC over time (Abaho, 2023). Furthermore, Masese Wetland has seen a 50% drop in SOC levels and a 30% decline in wetland areas, underscoring the critical need for conservation measures to preserve these essential ecosystems and their capacity to store carbon (Abaho, 2023; Hamid, 2023; Ministry of Lands, Housing & Urban Development report, 2022). Therefore, failure to address the situation could lead to the complete extinction of the Masese wetland system, which would lower SOC levels, impair soil productivity, reduce agricultural yields, and ultimately lead to food insecurity for the urban farmers who depend on these ecosystems. Previous studies conducted in the region have mostly examined how wetland degradation affects people's socioeconomic well-being (Hamid, 2023) and general wetland degradation (Wang et al., 2021). This calls for interventions based on scientific research to save the wetland system and the attendant ecosystem services that support urban livelihoods hence immediate action is essential to halt this decline, restore the health of the wetland and preserve it for the future. Against this backdrop, the researcher undertook this study to evaluate the effects of wetland use/cover changes on Soil organic carbon to inform sustainable wetland management strategies that can reverse wetland and SOC degradation, improve the supply of wetland ecosystem services, and support global initiatives aimed at carbon sequestration and climate change mitigation.

1.3 Objectives of the study

1.3.1 General Objective

The main goal of this study was to evaluate how changes in wetland cover and use affected the amount of organic carbon in the soil at the Masese wetland in Jinja City.

1.3.2 Specific Objectives

i. To quantify the spatial-temporal changes in wetland use/cover in the Masese wetland system between 2014 and 2023.
ii. To examine the drivers of wetland use/cover changes in the Masese wetland system.
iii. To assess the Soil organic carbon under different wetland use/cover changes in Masese wetland in Jinja City.

1.4 Research questions

i. What is the spatial-temporal extent of the changes in wetland use/cover Masese wetland system between 2014 and 2023?
ii. What are the drivers of wetland use/cover changes in the Masese wetland system?
iii. What are the differences in Soil organic carbon under different wetland use/cover changes in the Masese wetland system?

1.5 Significance of the Study

Wetland managers and policymakers should be made aware of the significance of wetland protection for climate change mitigation, biodiversity conservation, water resource management, sustainable land use planning, and economic development by using the effects of wetland uses and cover changes on SOC. This knowledge might guide policy decisions aimed at preserving and restoring wetlands to ensure their continued provision of ecosystem services. It also enables them to anticipate future challenges and develop proactive measures to address emerging threats to wetland ecosystems.

Secondly, this study provides valuable information for government decision-makers to develop and implement policies that conserve wetland ecosystems, mitigate climate change, and promote sustainable development.

This study's findings will assist land-use planning in Jinja City by informing effective physical and land-use plans. Understanding the relationship between wetland use/cover change and soil organic carbon (SOC) is crucial for guiding policymakers and conservationists toward sustainable practices that balance human needs with ecological preservation. Ultimately, this research will support better decision-making and enhance conservation efforts in wetland ecosystems. The study is crucial for environmental institutions, such as NEMA, to fulfil their mandate of protecting the environment and promoting sustainable development. It provides scientific evidence, guides regulatory decisions that value ecosystem services, informs policy development, and engages stakeholders in collaborative conservation efforts.

This study is essential for environmental institutions like NEMA to effectively carry out their mission of protecting the environment and promoting sustainable development. It offers scientific evidence, guides regulatory decisions that prioritize ecosystem services, informs policy development, and encourages stakeholder collaboration in conservation efforts.

1.6 Scope of the Study

The Masese Wetland in Jinja City served as the study site for the evaluation of particular improvements. Wards that bordered the Masese wetland system were the focus of the social-economic evaluation. Among these were Masese, Old Boma, Wanyama, and Budhumbuli East and West. The study region was selected based on its location inside a wetland catchment area and the increasing urbanization activities that are expected to affect the environment's diverse components, including wetlands.

The study focused on mapping wetland use/cover change using remote sensing and GIS to determine the trend and rate of wetland change, examine the drivers of wetland use/cover change, and quantify the Soil organic carbon under different wetland uses/cover change

Data on wetland use and cover was collected over nine years, from 2014 to 2023. This period is justified by the critical developments and changes in land use, particularly wetland encroachment that occurred within this timeframe. Reports emerged highlighting increasing encroachment of wetlands in Jinja by private developers constructing factories, disrupting the natural ecosystem. This occurred despite warnings from the National Environment Management Authority/NEMA. (2019) and the Jinja District Local Government. (2019).

1.7 Conceptual Framework

The study's conceptual framework (Figure 1.1) shows the connections between soil, wetland cover, and various land use patterns, as well as the variables influencing changes associated with wetland use activities. Wetland changes are predicted to be significantly influenced by activities including waste disposal, industrial growth, agricultural expansion, and settlement, which would change the wetland's geographical expanse and soil organic carbon (Ballut-Dajud et al., 2022; Newton, et al., 2020). These drivers are further exacerbated by climate change events such as droughts and floods (Brêda, et al., 2023; Clarke, et al., 2022). When the components of wetlands change, they can negatively impact the very activities such as agriculture and settlement that have led to those changes. Additionally, the frequency of climate change events is expected to increase, leading to further adverse effects on human activities.

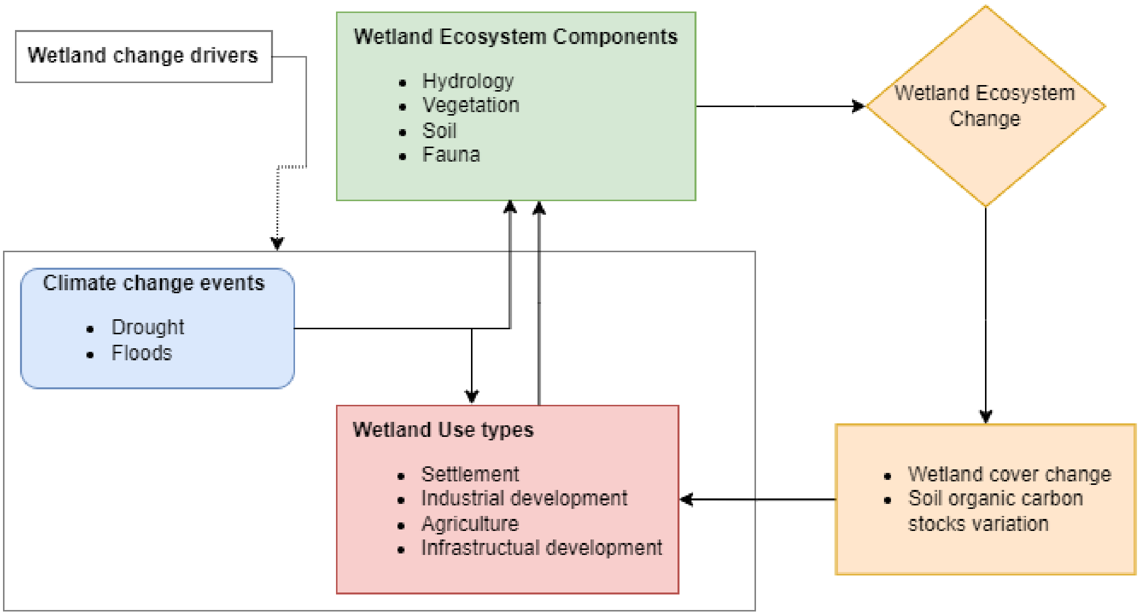

Figure 1. 1: Conceptual framework of the study

Anthropogenic pressures often result in the conversion of wetlands for agriculture, settlement, industrial, and infrastructure development leading to alterations in the structure of wetland systems which can be shown by spatial-temporal variations. These changes alter infiltration, and percolation processes thereby increasing environmental risks related to erosion and flooding. The loss of organic-rich topsoil due to increased erosion can have an impact on the soil's organic content. When wetlands are altered, their sediment storage capacity is reduced leading to increased sediments, and a reduction in the water table creating ideal conditions for methane production by certain micro-organisms and emission of GHGs. However, well-planned land use practices that consider wetland conservation and sustainable land management can help mitigate negative impacts on soil organic carbon. Implementing practices that minimize soil disturbance, maintain natural vegetation, and promote wetland health contribute to carbon preservation. In the study, SOC was treated as the dependent variable while wetland cover/use changes and drivers were envisaged as the independent variables.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter covers literature related to wetland change and Soil organic carbon. It concentrates specifically on the classification of wetland use/cover changes in the years 2014, 2017, 2020, and 2023, drivers of wetland use/cover changes, and Soil organic carbon under different wetland use/cover types.

2.2 Mapping Wetland Spatial Extents Using GIS/Remote Sensing

Accurate mapping of wetland spatial extents is crucial for understanding wetland dynamics, monitoring changes, and managing these ecosystems effectively (Muro et al., 2020; Wang et al., 2020). Remote sensing (RS) and geographic information systems (GIS) technology have transformed the field of wetland mapping by providing effective and affordable techniques for spatially explicit assessments (Drogkoula et al., 2023**)**; (Li et al., 2020). Utilize high-resolution satellite imagery (e.g., Landsat, Sentinel-2, World View) to capture wetland spatial extents and changes (Dong, et al., 2024; (Zhang et al., 2020). Field surveys that are expensive and time-consuming are no longer necessary thanks to satellite imagery and GIS analysis (Khallaf et al., 2020; (Li et al., 2020). geographical information system/remote sensing enables spatial and temporal analysis of wetland changes, informing effective management and conservation strategies (Dong, et al., 2024**;** (Zhang et al., 2020). The research provided a localized and context-specific understanding of wetland dynamics and SOC. The research focused on investigating the application of GIS/RS in monitoring wetland restoration and management effectiveness (Yohannes, 2021; Wang et al., (2020)

Wetlands change over time as well as in space. Time variations document changes in wetland use and cover over time, whereas spatial variations show variations in wetland use and cover across various landscapes (Peng et al., 2020). Unfortunately, wetlands have declined in both extent and quality across time and space (Garedew, 2023). The term "wetland use and cover changes" describes how wetland areas have changed and been used over time, frequently as a result of transportation, fishing, hunting, and agriculture and the abundant biodiversity and water supplies these ecosystems provide. Though estimates range from 30 to 90 percent of the world's wetlands have been destroyed or altered, little is known about how land use has changed within wetlands.

Chaikaew and Chavanich. (2017) report that one-third of the world's wetlands have been lost primarily due to land use change, revealing a critical research gap.

This study aims to fill that gap by employing advanced remote sensing techniques, such as satellite imagery, to develop detailed maps of land use changes. Wetlands are increasingly threatened by human habitation, which has historically developed alongside floodplains and wetlands, drawn by the availability of freshwater, food, and shelter (Courouble et al., 2021). Unfortunately, this has led to wetland destruction, as areas are drained, polluted, built on, or invaded by non-native species. In Australia, European settlers caused the loss of 57,300 km2 of coastal wetlands in the 19th century, and development pressures continue to degrade these ecosystems (Duarte de Paula Costa et al., 2021). Although significant wetland losses are documented globally, the impact of these changes on soil organic carbon (SOC) stocks remains understudied, representing a content gap that this research addresses. The goal is to support evidence-based policy and management practices to preserve wetlands and their ecosystem services.

Since 1700 CE, wetland extent has declined by 54-57%, with losses potentially reaching 87% (Davidson, 2014a). Wetland agricultural conversion has greatly surpassed conservation initiatives. In the past 150 years, activities like drainage and land reclamation have led to the loss or degradation of about half of the world's wetlands (Arya et al., 2016). The Global Wetlands Outlook (2018) and other reports highlight a 35% decline in global wetlands since 1970, reinforcing earlier estimates of significant wetland loss (Davidson, 2014a). The Ramsar Convention Secretariat also reported a 35% reduction in wetlands between 1970 and 2015, with 64% of the world's wetlands disappearing (Xu et al., 2019). This ongoing decline is accompanied by reduced environmental services that wetlands provide to society (Gardner, 2015). However, most of these studies were conducted outside Uganda, revealing a geographical gap in the literature.

Researchers like Darrah et al. (2019) indicate that the decline in coastal and marine wetlands (39%) is more severe than that of inland wetlands (35%) Population growth in coastal cities has driven urbanization and industrialization, negatively affecting coastal wetlands like those in Ghana (Ekumah et al., 2020). Between 1990 and 2000, China lost 30% of its natural wetlands (Zhang et al., 2021). Wetland areas in western Ethiopia also declined by 8.8%, with an annual drop of 4.2 km^2 (Moisa et al.,2023). The difficulties that urbanization, industry, and population increase present for wetlands are highlighted in these regional studies, highlighting the need for more focused, context-specific research.

The degradation of wetlands extends beyond Ghana, China, and Ethiopia. For instance, Kenya's wetland area decreased by over 48% between 2001 and 2018 (Mwangi, 2021). According to Ondiek et al. (2021), agricultural conversion and development caused the Anyiko wetland in Kenya to shrink by 55% between 1966 and 2018. Given that wetlands are still at risk from urbanization and agricultural runoff, these results show regional differences in wetland loss rates (Davidson et al., 2018; Ondiek et al., 2021). In China's Song-Liao Plain, 26,006 km² of wetlands were converted to grassland and urban areas (Xu et al., 2019). Wetland drainage for agricultural activities has also contributed to greenhouse gas emissions, with practices such as tillage, irrigation, and fertilizer use playing key roles (Tan et al., 2020).

Wetland ecosystems are still declining worldwide despite numerous conservation initiatives, and more regional studies are required to comprehend the connections between human activity and wetland degradation. In mapping these changes, identifying research needs, and creating management strategies to safeguard these crucial ecosystems, this work emphasizes the value of GIS and remote sensing

2.3 Drivers of Wetland change

2.3.1 Wetland as a driver of climate change

The degradation of wetlands contributes significantly to climate change by interfering with natural systems that control carbon emissions and storage. The transformation of wetlands releases stored carbon, leading to higher levels of carbon dioxide (CO2) and methane (CH). Climate change-induced changes in sea levels, precipitation patterns, and temperature modify hydrological cycles, which in turn affect the vegetation composition, water availability, and spatial distribution of wetland ecosystems. For example, Soleimani et al. (2017) demonstrated how variations in temperature, precipitation, and CO2 levels affect soil carbon dynamics, potentially shifting wetlands from carbon sinks to carbon sources. As decomposition rates accelerate, wetlands release significant quantities of CO_2 and CH_4, intensifying the greenhouse effect (Salimi et al., 2021). While the relationship between climate change and wetland dynamics is well-established affecting hydrology, vegetation, and wetland distribution. There remains a research gap regarding the specific impact on soil organic carbon (SOC). Wetlands are crucial for reducing climate change because they sequester carbon, and their disappearance could further upset the global climate system. Therefore, closing this gap is crucial. Wetland ecosystems' spatial distribution, water availability, and composition.

2.3.2 Wetland use types

Wetland change is mostly caused by activities like infrastructural construction, agricultural expansion, and urbanization. For example, in India, agriculture has reclaimed 24% of wetlands.(Khatun et al., 2021). Urban expansion often involves wetland conversion for residential, commercial, or industrial purposes, altering vegetation cover and hydrological patterns. Wetlands have long been used for hunting and fishing, as well as shifting cultivation such as rice farming, grazing, brick production, and extracting raw materials for house construction (Byamukama & Kiyawa, 2019). There is a need for comprehensive studies that quantitatively assess the specific impacts of different human activities on soil organic carbon (SOC) dynamics within wetland ecosystems hence creating a methodological gap.

In many cases, inadequate waste management leads to waste dumping and landfilling, particularly in areas with rapid development (Masese et al., 2023). This aligns with Matovu et al. (2023) who observed that backfilling resulted in a 75% loss in Kinawataka wetland cover by 2011. Relatedly, Vasumthi et al. (2023) indicated that nearly 80% of the world's wastewater is dumped into wetlands. Urbanization also encroaches on wetlands, with significant losses reported globally, especially in coastal areas (Ekumah et al., 2020; Li et al., 2018). Infrastructure projects like roads and highways disrupt wetland hydrology and structure (Li et al., 2023a), while poor governance and policy loopholes contribute to wetland degradation (Davidson et al., 2018). There is a need for empirical studies that examine the interactions between human-induced disturbances (such as waste dumping, urbanization, and infrastructure development) and SOC dynamics in wetland ecosystems which the research was intended.

More than 50% of coastal wetlands have been lost due to urbanization brought on by the rapidly expanding human population in coastal locations worldwide (Ekumah et al., 2020; Li et al., 2018) When wetlands are transformed into developed environments for urban development, wetland vegetation is lost and natural hydrological patterns are disturbed. As organic matter breaks down during construction, for example, wetland soil disturbance releases carbon, and the altered condition may decrease the wetland's capacity to sequester carbon. The National

State of Environmental Report for Uganda (2016) indicated that the pollution load is increased beyond what the wetlands can reasonably handle by the direct dumping of large volumes of wastewater. Wetlands are frequently filled up, drained, or developed for residential and commercial uses as metropolitan areas expand. There is a content gap because the study concentrated on how waste disposal impacts the SOC.

According to Tan et al. (2020), draining natural wetlands changes the water regime and nutrient availability. Between 2010 and 2017, the major driver of wetland loss and degradation in Western Sydney was urbanization (Gabites & Spencer, 2023). According to Li et al. (2023a), wetlands are also more irreversibly separated or encroached upon by urban growth. He added that humans had reclaimed a lot of good land in suburban and non-urban areas for aquaculture, agriculture, and animal husbandry, which had ruined the hydrological process and structure of wetlands and made it harder for them to survive. The growing likelihood of wetland invasion as people look for raw materials and land for habitation (NEMA, 2017). Furthermore, infilling, construction, extraction, and the production of raw materials for industry and agriculture are all contributing to the degradation of many wetlands, especially in metropolitan Uganda.(Kakuba & Kanyamurwa, 2021). While the literature identifies several key drivers of wetland loss and degradation, including urbanization, encroachment for settlement and resource extraction, and various anthropogenic activities such as infilling, construction, agriculture, and industrial production, there is limited research that directly investigates how these drivers influence SOC.

Agriculture land expansion is another major driver of wetland loss, with wetlands often being drained and converted into farmlands (Mao et al., 2018). Overgrazing and intensive agricultural practices further degrade wetland ecosystems (Matovu et al., 2023). Courouble et al. (2022). More than half of all internationally significant wetlands suffer from agricultural impacts. According to (Courouble et al. (2021a), agriculture's contribution to wetland loss has not been calculated internationally. Wetland contamination and eutrophication are made worse by the use of chemical pesticides and fertilizers, especially in Asia and Latin America. (Li et al., 2023a). All these studies were carried out outside Uganda creating a geographical gap.

Wetlands in tropical and subtropical regions have been increasingly damaged or disappeared since the 1950s due to agricultural conversion (Lorenz et al., 2019) for instance, the river Mpologoma catchment zone has a 5.52% yearly rate of wetland loss owing to cultivation

(Bunyangha et al., 2021). Around Bigodi wetlands, 72% of the wetland buffer zones have reportedly been converted to tea plantations and gardens, with 94% of the area being used for maize, 81% for bananas, 60% for beans, 53% for sweet potatoes, and 47% for cassava (Matovu et al., 2023). 73% of agricultural production in Wakiso was in the wetlands (Matovu et al., 2023). According to Valley et al. (2020) farmers carry out agriculture in the swamps due to the fertile soils which lead to high crop yields and also swamps provide extensive land for crop growing. In Tanzania, there are large expansions and intensifications of agriculture in the channelization which has led to low water table, habitat loss of aquatic biodiversity, and flooding of the valley areas. This investment in the Kilombero wetlands has aided regional food production and community livelihoods, as agriculture provides a living for more than 70% of Tanzania's rural population (Msofe et al., 2019). However, this study was conducted on the effects of agricultural development on wetland ecosystem services in Tanzania's Kilombero Valley, which produced a content gap that this study attempts to fill.

Industrial growth and development globally contribute significantly to wetland change and loss through pollution and habitat destruction (Tutal & Benzeyen, 2021). Wetlands are often perceived as undeveloped areas targeted for industrial use, leading to direct pollution and habitat loss (Byamukama & Kiyawa, 2019). Effluents from industrial activities are discharged directly into streams flowing into wetlands, ultimately reaching Lake Victoria's Murchison Bay, thereby exceeding the marsh's capacity to absorb pollutants and contributing to the eutrophication of Lake Victoria (NEMA, 2017). In urban areas, wetlands are considered prime sites for factories, transforming approximately 50% of Uganda's wetland regions into industrial, residential, and urban agricultural areas (Kabiri et al., 2022). Pollutants such as waste gas and wastewater released during industrial production cause wetland eutrophication and degrade wetland biodiversity, as noted by (Li et al., 2023b). According to field observations, improper waste disposal is the main cause of the rise in pollution, which accounts for 5% of the dangers, especially near wetlands in the Mayanja system (Matovu et al., 2023). The importance of industrial pollution in wetland degradation and biodiversity loss underscores the pressing need for studies to statistically evaluate the precise effects of industrial operations on soil organic carbon dynamics within wetland ecosystems. There is a need for empirical studies that specifically address the impacts of industrial activities on SOC dynamics within wetlands, bridging the knowledge gap between industrial pollution and its consequences on soil carbon storage and ecosystem functioning in wetland environments

Infrastructure developments such as roads, motorways, airports, and other infrastructure can disrupt wetlands and alter their hydrology thereby causing changes in their structure. Road construction encroaches on wetlands, destroying their integrity and leading to further wetland loss (Li et al., 2023a). For instance, the Kampala-Entebbe Expressway and the Kampala Northern Bypass Highway have damaged the city's main drainage systems by encroaching on the Nsooba, Lubigi, and Nakivubo wetland ecosystems. (NEMA, 2017). Wetlands were isolated and degraded as a result of road construction, especially road network construction, which also decreased the amount of land available for wetland growth. While it is acknowledged that infrastructure development disrupts wetlands and alters their hydrology, leading to changes in wetland structure and integrity.

The destruction and deterioration of wetlands in urban areas is a result of political causes. (Courouble et al., 2021). Even though wetlands are lawfully assigned to the Central Government or Local Government for the benefit of all Ugandans, local administrations have recently violated this constitutional obligation in cases of wetland abuse. Wetland degradation is largely caused by insufficient land use planning and weak policy frameworks (Davidson et al., 2018). The absence of strict regulations allows unchecked development in wetland areas, and policy loopholes combined with a lack of enforcement mechanisms fail to protect wetland ecosystems, resulting in their gradual deterioration(Liu & Wang, 2011). Bunyangha et al. (2021) discovered that ineffective land management practices caused the Mayanja catchment region's built-up area to increase by 55.5%, indicating that several political factors, such as the undervaluation of the benefits of urban wetlands, their exclusion from planning processes, and their disorganized governance, are responsible for the continuous loss and degradation of wetlands in urban settings. (Courouble et al., 2021).

Furthermore, the Kinawataka wetland in Kampala City Council's Industrial Area gazetted in 1972, has fallen victim to detrimental government policies that allocated wetlands for industrial development. The entire marsh has been subdivided into parcels, and road networks have been constructed. Surrounding developments have resulted in paved surfaces, reduced wetland retention capacity and infiltration rates, and disrupted the natural flow patterns of rivers (GOU, 2016b). Similarly, Omagor and Barasa. (2018) emphasized the lack of coordination and efficacy in governance, as well as the insufficient implementation of wetland legislation and political meddling. (Courouble et al., 2021). In Kampala, the number of industries has grown exponentially, leading to wetland infilling with murram, decreased vegetation cover, and increased pollution from industrial wastewater discharge (GOU, 2016b). Future research could focus on quantifying the extent of wetland loss and degradation in urban settings over time. This might entail tracking changes in wetland areas and quality using remote sensing and GIS techniques, which would yield useful information for conservation and policymaking.

Land use changes have been impacted by corruption and poor management in several areas. Changes in land usage might result from uncertain property rights over certain natural resources and insecure land ownership. For example, historically, wetland resources have been viewed as a public resource that is vulnerable to "open access" pressures. Since they do not have legal property rights, they can be depleted without any restrictions (Msofe et al., 2019). The National Environment Act of 1995 explicitly states that wetlands cannot be legally owned by individuals. Nevertheless, many individuals claim ownership of wetlands, resulting in conflicts as documented in the Uganda Wetland Atlas, Volume One (GOU, 2016b). Sarkar et al. (2020) note that ineffective government policies and management strategies are significant factors influencing the long-term conservation of tropical wetlands. The development of capacity and sustainable wetland management are impeded in the absence of a working institutional structure and wetland management strategy (Iaip & Site, 2017; S. Li et al., 2023a). There is a need for an in-depth investigation into the impact of corruption, mismanagement, and insecure land ownership on wetland conservation and management hence creating a content gap.

The transformation of wetlands is often linked to widespread public ignorance regarding the ecological benefits they provide. There is a common misconception that wetlands are useless areas that can be filled and repurposed for other activities, including dumping sites for garbage. (Davidson et al., 2018; Finlayson et al., 2018). For instance, wetlands in Ethiopia are facing significant strain and degradation because their true value is not fully appreciated (Nesre et al., 2022). Instead of acknowledging the importance of wetlands, people often perceive them merely as breeding grounds for mosquitoes, carriers of diseases, and sources of risk. Consequently, early settlers and governments historically attempted to reclaim large portions of wetlands to exploit their full potential (Xu et al., 2019). These studies were conducted outside Uganda, highlighting a geographical gap in research

In the past, some wetlands have been drained and destroyed because they were recognized as a source of water-borne parasite diseases. For example, industrial mosquito control was carried out in North America.(Courouble et al., 2021). Wetlands have historically been considered "wastelands," meaning that "such obvious waste can only be put to good use if it is reclaimed for agriculture or human settlement." When not regarded as "wastelands," wetlands are frequently seen as having little value in contrast to other uses of their property that can result in more immediate, noticeable, and significant financial gains (Ondiek et al., 2021). Similarly, Phethi et al. (2017) claimed that because they are viewed as wastelands, most of South Africa's wetlands are under danger. A content gap was caused by research that looked at how these views impacted land use planning, policy frameworks, and the efficacy of wetland conservation initiatives.

The degradation of certain wetlands is often attributed to the introduction of alien plant species. When non-native plants and animals are introduced into wetland ecosystems, they can cause a cascade of ecological problems. Invasive species can outcompete native species, alter habitat structures, and disrupt nutrient cycling processes. For instance, the commercial planting of pine and eucalyptus trees has caused the loss of important wetland soils in the riparian and wetland zones along the Mpologoma River (Bunyangha et al., 2021).

Similarly, through mechanisms such as predation, resource competition, and disease transmission, non-native species can become invasive and pose a threat to indigenous species (Masese et al., 2023). Eucalyptus tree growth along water bodies like the Lubigi River has been a major factor in the change in wetland cover in places like Wakiso and Kampala, where wetland area has decreased from 96.3% in 2002 to 80.6% in 2018 (Omagor and Barasa, 2018) According to a 2019 National Environment Management Authority (NEMA) assessment, commercial eucalyptus tree farming has also been recognized as a new source of wetland degradation, contributing 0.9% of the damaged wetland area. This chain of events highlights the critical importance of addressing invasive species management to safeguard wetland ecosystems and their biodiversity which the study intended to address. Findings from this study are essential for creating strategies that can effectively reduce wetland degradation, encourage sustainable land-use, and safeguard ecological services in Uganda.

2.4 Soil organic carbon under different wetland uses/cover change

The amount of carbon stored in wetlands can vary based on different wetland uses and management practices. Here are the differences in carbon storage under different wetland uses: Changes in wetland habitats due to human activities like drainage, urbanization, and agriculture might affect the distribution of SOC. Understanding these anthropogenic influences is crucial for sustainable wetland management.

A study by Bekele (2019) noted that farming practices like tillage eventually lead to a decrease in soil productivity since they physically remove topsoil, reduce rooting depth, remove plant nutrients, and water.. Under no-tillage, SOC rises in the upper soil layers (0–15 or 0–20 cm), but generally has a low to non-significant effect on SOC over depths beyond 30 cm, according to global meta-analyses and reviews (Nwaogu et al., 2018). Depending on the types of land use, some writers have reported significant SOC concentrations in the topsoil, while others have observed higher concentrations in the subsurface layer. Human activities that lower soil carbon in the topsoil, plant species, and moisture content could all be responsible for this variation (Nabiollahi et al., 2019). However, these studies were conducted outside Uganda creating a geographical gap that the research intended to address.

According to research done in India by Bhunia et al. (2016), SOC varied greatly depending on the land usage, peaking at 0–19 cm deep and decreasing as depth increased. SOC was highest (0.69%) in the topsoil (0-19 cm in the forest soils) and lowest (0.41%) on fallow land. Similar findings were made by Akodi et al. (2016) who discovered that SOC was higher in the top 30 cm of soil than in the deeper layers (30-60 cm and 60-90 cm) and that it varied significantly between land use regimes. Other researchers like Cardinael et al. (2015) looked into how land use affected SOC and found out that, because of their steep slopes and little cultivation, forests had higher SOC naturally than cultivation. Cultivation exposes organic matter to decomposition, accelerating SOC loss (Amanuel et al., 2018). All these studies were done outside Uganda hence creating a geographical gap.

Sodango et al. (2020) used remotely sensed predictors to model the spatial distribution of SOC in Fuzhou City, China. They discovered that the spatial distribution is significantly impacted by land use, lithology, and landscape factors, especially those caused by intensive human activities like urbanization and industrialization processes. Similarly, in Wafangdian, Liaoning province, Amanuel et al. (2018) found higher SOC concentrations on a mountainous coastline landscape. Additionally, the distribution of SOC is significantly influenced by environmental factors such as climate, slope gradient, parent material, vegetation species, and human activities (Nguemezi et al., 2021). Although most studies concentrate on environmental factors that affect the spatial distribution of SOC, this study identified a content gap by examining changes in wetland usage and cover.

Studies conducted by Odeke (2019) on wetland degradation and carbon sequestration potential in Lubigi wetland highlighted that wetlands with thick vegetation exhibited significantly higher plant and soil organic carbon (SOC) content compared to other land use categories. The above-ground plant carbon varied between 28 grams per square meter in thick vegetation wetlands to 191.8 grams/m^2 in cultivated wetlands. Osinuga and Oyegoke. (2019) conducted a study on wetland degradation assessment under various land uses in Ogun State, Nigeria, revealing that most cultivated wetlands exhibited high levels of degradation compared to reference (fallow) soils, which showed slight degradation. They also highlighted differences in particle size distribution among wetlands, indicating varied textural compositions that reflect intrinsic soil properties. However, the study was not carried out in Uganda creating a geographical gap.

In addition, Korkanç et al. (2022) investigated how land use change affected SOC and certain soil characteristics in the Sultan marshes in Turkey. They found that carbon stocks and SOC were low in agricultural and drained lake areas and high in rangelands, marshes, and shrublands. The studies were based on the influence of topography on SOC but this study focused on assessing the impact of wetland use and cover changes on SOC creating a knowledge gap.

The Naigombwa wetland in Iganga, Uganda, was the subject of a study by Were et al. (2020). The estimate was made because a significant portion of the freshwater wetland is being converted into rice fields. Carbon sequestration was found to be higher in the natural wetland than in the converted region, and it was advised that other locations be used for rice production rather than the wetlands (Ballut-Dajud et al., 2022). In a similar vein, the replacement of rice fields for wetland vegetation has led to a decline in wetland function and biodiversity (Businge, 2017). However, these studies emphasized the effect of cultivation on chemical properties. The study assessed SOC in line with wetland use and wetland cover change hence creating a content gap.

Drained or degraded wetlands lose their carbon storage capacity as organic material decomposes rapidly when exposed to air (Nascimento et al., 2021) asserted that overgrazing destroys the protective ground cover, and wind and water erosion endangers adjacent arable land in certain climatic zones. .According to Businge (2017) , fire was mostly used historically to clear land for hunting, farming, and grazing. Due to the extensive loss of their natural carbon reserves, agricultural soils have a large ability to absorb CO2 (Hairiah et al., 2020). By causing erosion and compaction, livestock grazing frequently reduces soil fertility and microbial activity, biodiversity, nutrient availability, and climate regulation (Treby et al., 2020).

Agricultural intensification in wetlands, characterized by monoculture cropping, excessive tillage, and heavy fertilizer use, further exacerbates SOC depletion through soil disturbance and nutrient leaching (Yu et al., 2024). Land use conversion to agricultural systems can change the biotic or abiotic processes involved in the carbon cycle, such as the size distribution of SOC at different profile depths, which can have an impact on soil carbon storage in terrestrial ecosystems. Nearly 26 percent of the world's peatlands and riparian wetlands have been drained for agricultural purposes since 1985 (Tan et al., 2020). Stored carbon may be released into the atmosphere as a result of drainage for construction or cultivation. For instance, conventional tillage agriculture and wetland draining have been connected to higher CO2 emissions and microbial breakdown of soil organic carbon (SOC), both of which exacerbate global climate change (Tangen & Bansal, 2020). In addition, Wang et al. (2012) observed that following cultivation, the amounts of total nitrogen (TN) and soil organic carbon (SOC) in each soil layer dropped significantly. The growing demand for agricultural land to meet the demands of the expanding population is predicted to accelerate the rate of carbon leakage (Sanderman et al., 2017). Numerous researchers have attempted to examine the connection between cultivation and physical-chemical soil characteristics, as can be seen from the literature above. However, because none of the studies were conducted from a Ugandan perspective, contextual and empirical gaps arose.

Mairghany et al. (2019), who examined the effects of rotary tillage on a few specific physical characteristics of fine-textured soil in Malaysian wetland rice cultivation, claim that the cumulative effect of tillage operations on soils causes soil loosening and a decrease in soil organic carbon because of increased oxygen exposure, which speeds up the breakdown of organic matter. In contrast, there is typically less total pore space before tillage operations, with more fine pores and less air-filled pores. According to a different study by Mulatu et al. (2014) which examined the effects of wetland farming on soil fertility and plant diversity in the south Bench district of southwest Ethiopia, the transformation of wetlands into agricultural land may result in changes to the physico-chemical characteristics of the soil. The removal of biomass and replacement of dominating plants transformed a CO_2 sink into a potent carbon source (Tan et al., 2020). Tillage is thought to promote SOC mineralization because it breaks up soil aggregates mechanically and by precipitation, which releases CO2 (Ngatia et al, 2021). However, the study on the effects of wetland uses on Soil organic carbon has not been conducted on Masese wetlands is still limited.

Wetland clearing for agriculture, including paddy rice, has resulted in soil erosion, a reduction in soil fertility, wetland siltation, and a loss of biodiversity, according to GOU (2016b) in the Uganda Wetland Atlas Volume 2. 80% of rice farming is done by small-scale farmers, who also manage water resources poorly. As a result, the wetlands are drained by rice farming. Wetland functions have declined and biodiversity has decreased as a result of rice crops replacing wetland plants. There is also poor water management by mostly small-scale rice farmers who account for 80% of rice farming. Thus, rice cultivation ends up draining the wetlands. The replacement of wetland vegetation with rice fields has led to biodiversity loss and decline in wetland functions (Businge, 2017). Tobore et al. (2021) used geospatial methodologies in the Nigerian city of Ibadan to study the geospatial assessment of wetland soils for rice cultivation in Ajibode. The investigated soils' morphological characteristics differed in terms of colour, texture, structure, and boundary. This study created a content gap by using extensive soil sampling.

2.4.1 Settlement/urbanization and wetland SOC

The conversion of wetlands for urban development or infrastructure projects results in the loss of natural vegetation and wetland soils. Urbanization can lead to soil compaction, increased impervious surfaces, and changes in hydrology, all of which can reduce soil organic carbon content for instance Chinese researchers Liu et al. (2020) and Wang et al. (2018) have repeatedly shown that urbanization causes wetland loss and degradation, which lowers SOC significantly. They also assert that the conversion of wetlands to impervious surfaces disrupts the hydrological processes and reduces organic matter inputs. Research by (Chen et al., 2019) highlighted that Urbanization-induced SOC loss: 10-30% of global SOC (approx. 2.2-6.6 GtC) while urban wetlands may act as carbon sources rather than sinks, as they release stored carbon due to soil disturbance and reduced vegetation cover. The study occurred in China causing a geographical gap

2.4.2 Industrialization and Wetland SOC

Industrial expansion results in more paved surfaces, which diminishes wetlands' ability to retain water and slows the infiltration rate, disrupting natural river flow patterns (GOU, 2016b; Omagor and Barasa, 2018). (Byamukama & Kiyawa. (2019) noted that the annual Soil Organic Carbon loss rate at 1-2%. In Kampala, for instance, the rapid increase in enterprises has led to wetland infilling with murram, causing vegetation loss and escalating pollution from industrial wastewater discharge (GOU, 2016a). Due to excessive pollution and drainage for infrastructure expansion, businesses significantly strain wetlands. High pollutant levels and runoff from infrastructural development are two further ways that industries affect wetlands. Furthermore, for financial reasons, a large number of wetlands, notably the Namanve swamp in Central Kampala, have recently been given to investors (Byamukama & Kiyawa, 2019). The effluent enters streams directly, which nourish the wetland before arriving at Murchison Bay in Lake Victoria.(NEMA, 2016). This direct discharge exceeds the wetland's capacity to absorb pollution, contributing to eutrophication in Lake Victoria (NEMA, 2017). GOU (2016c) and Omagor and Barasa (2018) emphasize that industrial expansion increases paved surfaces, reducing wetlands' retention capacity and infiltration rates, which impacts natural river flow patterns.

2.4.3 Invasive Species in Wetlands and Spatial Disruption

Invasive plant species that humans bring into wetlands have the potential to displace native plants and change the composition and functionality of the wetland ecosystem. SOC loss rate per year: 0.5–1.5% as a result of invading species (Chen et al., 2019). Non-native species' invasion of wetlands can change the amount and calibre of organic matter inputs, which may have an impact on SOC. The rate at which invasive plants decompose their litter may differ from that of native species. SOC decomposition rates are altered by invasive species by 15–40% (Liu et al., 2020)

2.4.4 Conservation and Restoration Strategies

Restored wetlands are areas previously drained or degraded that have been brought back to their natural state. As organic matter builds up in the soil after restoration, these wetlands can gradually regain their ability to store carbon. By raising a wetland's water table, the natural process of sequestering and storing carbon in the soil can be restored (Limpert et al., 2021).

Wetland restoration is proposed as a method to partially mitigate losses in soil organic carbon (SOC) by discontinuing CO2-producing land-use practices, capturing CO2 in plant biomass, and replenishing SOC (Tangen & Bansal, 2020). Restoring wetlands is becoming more widely acknowledged as a sustainable strategy to address climate change (Treby et al., 2020).

Restored wetlands actively sequester carbon as vegetation regrows and organic matter accumulates in the soil. Proper restoration techniques can enhance carbon sequestration rates. After restoration, GHG emissions would decline while soil and aboveground plant carbon stocks would gradually increase (Treby et al., 2020). In controlled wetlands, like rice paddies, carbon is stored as soil organic matter. But soil disturbance, water management, and agricultural practices can also affect storage capacity. With the right soil and water management techniques, managed wetlands can store carbon. In rice fields, for instance, techniques like alternate soaking and drying can improve carbon sequestration by encouraging the aerobic breakdown of organic waste. By adding organic matter to the soil, properly managed livestock dung can raise the soil's carbon level. The degree of carbon buildup, however, is determined by management techniques; excessive organic input and overfeeding can accelerate mineralization rates and result in SOC losses (Rahman et al., 2016).

Wu et al. (2022) investigated how land-use conversion affected the composition and functionality of the soil microbial community in North-Eastern China's urban wetlands. They found that the reduction of wetland areas due to their conversion to farmland, artificial woodland, and various land-use types had long-lasting effects on soil structure. In the end, this has led to risks to the ecological stability and function of wetlands. Raising the carbon content of the soil. However, management techniques determine how much carbon accumulates; excessive organic intake and overfeeding result in higher rates of mineralization and possible SOC losses.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter defines the framework within which the research was conducted. It presents the research design, data collection, and analysis methods. It begins by describing the study area in terms of location, geomorphology and topography, geology and soils, climate, vegetation, drainage, and economic and land use activities.

3.2 Description of the study area

This section covers geomorphology and topography, geology and soils, climate, vegetation, drainage, population and ethnicity, and land use and economic activities.

3.2.1 Location

The Masese wetland system in Jinja City (Figure 3.1), which is located between coordinates 0.47^0 N and 33.25^0 E, was the site of the study. The region is located on Lake Victoria's northern shoreline, northeast of the Napoleon Gulf, and comprises Kikenyi, Masese-Budhumbuli, and Kirinya wetlands. Kirinya wetland is two kilometres away (Naigaga et al., 2011). This wetland is used for open dumping of waste materials in Jinja city. It receives urban effluents and stormwater runs (Naigaga et al., 2011). Masese wetland catchment covers approximately 110 km^2 (Koller and Kunz, 1997). This ecosystem is characterized by stands of Cyprus papyrus, palms and thickets, bushlands, and grasslands.

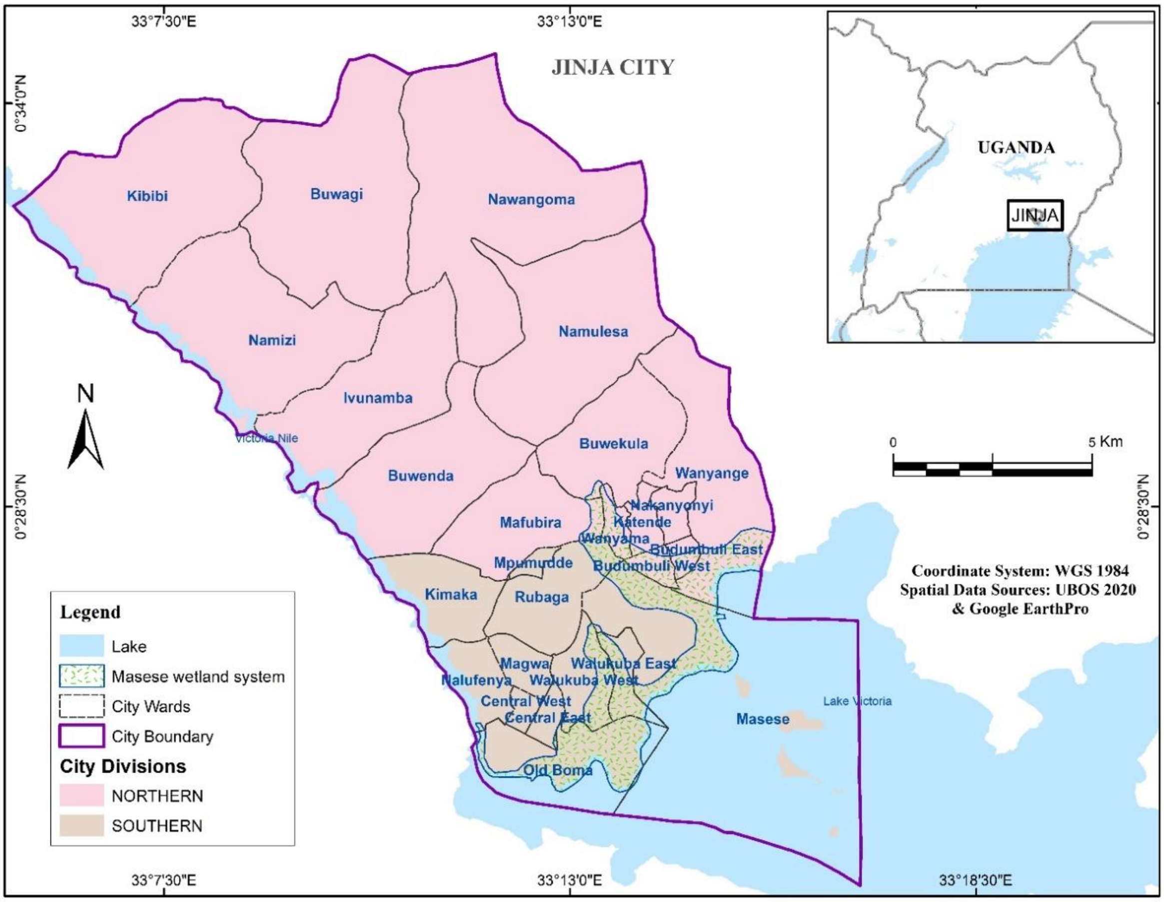

Figure 3. 1: Location of the study area

3.2.2 Geomorphology and Topography

In the Masese wetland catchment area, the highest point of the tapering plateau is about 1,230 meters above sea level (Jinja City Council report, 2022) and a series of several flat-topped hills and wide interlocking valleys break up the low hills (National Environment Management Authority [NEMA], 1997). The landscape is generally rolling and undulating with vertical gully heads and flat valley bottom swamps. The wetland types in the area are mainly characterized by papyrus, palms and thickets, bushland, grassland (MWE, 2009)

3.2.3 Geology and Soils

According to Kayendeke (2018), the soil types in the central region are clay loam, and the swampy lowland is sandy loam (Hamid, 2023). Masese wetland is underlain by metamorphic rocks of the Precambrian age. With a few notable exceptions, the majority of the geological formation is made up of the earliest system, the basement complex, which is covered by a series of sedimentary strata that have experienced varying degrees of transformation.

Lake Victoria's shorelines are primarily hydromorphic. These are linked to the Kabira catena and Buganda surface, which are both marked by low to medium fertility. The remaining portion is filled by lake sand and granitic rocks, while the northern and eastern regions are primarily composed of quartzite and laterites whose parent rock is Buganda catena (Jinja City Council report, (2022). Different locations have different soil textures, ranging from deep red or brown loam clay soils that are highly productive to red lateritic soils. These soil types are known as the "fertile crescent region of Uganda" because of their mature soils, distinct soil profiles, stable structure, minimal erodibility, and high fertility (Sengendo et al., 2012). Some soils are over a meter deep, or as deep as 15 cm. With a well-defined course and shallow alluvium in beds, some valleys typically have a range of clay, light soils, and sandy loamy soils. On basic rocks, ferrisol soil, sometimes known as red soil, is present (Jinja City Council report, 2022)

3.2.4 Climate

The Masese wetland area experiences year-round tropical conditions with very little seasonal variation in wind, humidity, and temperature (Jinja District Hazard Report, 2016). The annual climatic cycle is divided into four seasons-March to May is the rainy period with April receiving the highest rains. The September-November period constitutes the second rainy season, while December-February and June-August are the dry periods (Jinja City Council report, 2022). The area receives heavy annual rainfall between 1250mm to 1500mm. The average rainfall is about 112.5 centimetres (Jinja City Council report, 2022). The average annual maximum temperature does not exceed 30^0C and the minimum annual temperature is not below 12.5^0C. The hottest temperatures are experienced in March and the coldest temperature is in July. It has almost had an equal length of day and night throughout the year with mean annual evaporation of between 1450mm to 1600mm (Sengendo et al., 2012). The area received a total precipitation of 2123 millimetres in 2019. The highest amount of rainfall (355.8 mm) was received in December while the lowest was received in March with 41.5 mm (Uganda Bureau of Statistics 2020 Statistical Abstract, 2020)

3.2.5 Vegetation

The vegetation of Masese wetland like the rest of Uganda, has suffered from pressure created by the rapid population growth and the demand for fuel and space for man’s activities. The vegetation in the area has minor variations, for areas bordering Lake Victoria have Savannah vegetation while the central part has forest/savannah mosaic. There are a few isolated patches of forest left in some of the valleys, mid and lower slopes. There are grasses such as Pennisetum purpureus and Hparuhemia rufa dominate (Jinja District Hazard, Risk and Vulnerability Profile Report, 2016 and Jinja District Development Plan Report, 2015). Additionally, there are some tropical rainforests on the islands of Kisima and Rwabitoke in Lake Victoria, as well as along the Nile River to the west. Along the banks of Lake Victoria and the Nile River, permanent marsh vegetation can be found at Kirinya, Budhumbuli, Walukuba, and Kikenyi. Although it is essentially undifferentiated, Miscanthus violaceous and Cyprus papyrus cover it most of the time (Sengendo et al., 2012).

3.2.6 Drainage

The drainage network in in Masese catchment area in Jinja City is characterized by lakes, rivers, and wetlands. It is drained by Lake Vitoria in the south, river Nile in the west, and major wetlands of Kirinya, Walukuba, Masese, Budumburi, and Kikenyi. This study targeted wetlands in the Masese catchment due to higher vulnerability to changes related to anthropogenic pressures.

3.2.7 Population and Ethnicity

According to the National Population and Housing Census (2014), Jinja City's total population is currently 247,074 after Bugembe, Budondo, and Mafubira were annexed. From 2002 to 2020, the population grew from 71,200 to 269,900 people (Jinja City Council report (2022). Today, migrants born outside Jinja or Uganda make up over half of the city’s population.

3.2.8 Economic and Land Use Activities

Public services employ 25% of the working population, agricultural services employ 18%, manufacturing employs 13%, and financial institutions employ 8% (Jinja District Hazard Report, 2016) The processing and manufacturing sector of Jinja City is small currently estimated at 18%, however, the city's potential for industrial growth is very high. The Masese wetland comprises primarily urban centre development projects such as hotels, factories, industries, fuel depots, homesteads, sewage treatment ponds, untreated domestic and industrial effluent drainage systems, and planted agricultural landscapes. herefore, before the effluent empties into Lake Victoria, this wetland receives storm water and industrial and domestic effluent from point and non-point sources, including small-scale workshops, waste oil from parking lots, and auto repair shops. This waste material may contain pollutants (Naigaga et al., 2011). In the Masese wetland catchment region, the majority of agricultural operations are carried out on tiny plots of land per household. Cane, coffee, rice, maize, cassava, sweet potatoes, g-nuts, tomatoes, cabbages, greens, onions, beans, and trees that are currently harvested are among the common crops planted. Another high-value activity that is popular in the area is fishing, which contributes about 60% of the total revenue from all land uses (Jinja City Council report (2022).

3.3 Study Approach

This study utilised a mixed research design; cross cross-sectional research design; the quantitative and qualitative approach of data collection where Landsat 8 OLI (Operational Land Imager) & TIRS (Thermal Infrared Sensor) images for 2014, and sentinel 2 MSI (Multispectral Instrument) images for 2017, 2020, and 2023. These were subjected to unsupervised and supervised classification to determine the spatial components of wetland cover and use extent over time. Data on the main drivers of wetland change was obtained by administering a questionnaire to households living in the cells bordering the wetland. At the same time, Key Informant Interviews were also undertaken by City resource officers, City environment officers, and LC 1 Environment representatives. Soil Organic Carbon (SOC) content data was collected by taking deep soil sampling using soil auger from pits dug in the sites of three main wetland use/cover strata and then taken to the laboratory for analysis. The total carbon stock was obtained by establishing ABG and added to SOC stock then statistical analysis. Because of its economic nature, speed of data collection, and capacity to comprehend a population by employing a subset of the population, the cross-sectional design was chosen for this study (Amin, 2005; (Martins & Romeiro, 2017). Qualitative research design was used to uncover hidden or underrepresented issues that quantitative methods may overlook, providing a voice to marginalized groups and contributing to social change (Abrams, et al., 2022). The combination of the two approaches was undertaken since the study involved numerical aspects and opinions of individuals. The socio-economic and Soil Organic Carbon data components were handled in a cross-sectional design format. The two components followed a quantitative approach. The research design and approach are well adopted since the key variables were measured on a continuous scale.

3.4 Methods of data collection and analysis

Both primary and secondary sources provided the study's data. To evaluate the spatial-temporal changes in wetland cover and uses, secondary sources mostly comprised remotely sensed data from satellite pictures, both published and unpublished. The field was used to gather primary data regarding ground-truthing for the various forms of wetland cover and use. By using primary data sourcing methodologies, socioeconomic and SOC data were also gathered from the field.

3.4.1 Determining the spatial-temporal changes in wetland use/cover in the Masese wetland system in Jinja City between 2014 and 2023

3.4.1.1 Data sets

The study classified and monitored the land cover in the Masese wetland using Sentinel-2 MSI (Multispectral Instrument) images and Landsat 8 OLI and TIRS imagery. Using cloud-based remotely sensed data archives in Google Earth Engine (GEE), satellite imagery representing remotely sensed data covering the research area from 2014 to 2023 (with 3-year intervals) was retrieved. According to Gorelick et al. (2017), GEE simplifies remote sensing analysis by providing easy access to historical and current imagery, which allows the study to perform multi-year analyses without the limitations of local storage and processing capacity. The online platform provides access to a collection of free high-resolution satellite data such as Landsat series, Sentinel, MODIS, and SRTM among others with a collection of historical images of spatial resolutions of up to less than 10 meters for some cases. Landsat 8 OLI & TIRS bands were downloaded and used for wetland cover/use the spatial extent of 2014, whilst bands of sentinel 2 MSI were downloaded for 2017, 2020, and 2023. Landsat bands came in 30*30 meters while sentinel 2 MSI bands came with the RGB bands in 10*10 meters making them ideal for observation and analysis of landscape changes. Landsat 8 data was used because of longer-term availability (2014) while Sentinel was preferred for spatial and spectral resolution. To confirm the classification results. Additionally, GPS data was gathered during field surveys to determine the primary land cover and uses in the research region, which served as the basis for categorization and as a means of validating classification results.

Data from ground truthing were utilized to confirm land use changes relative to the satellite maps. To ensure the accuracy of the remote sensing analysis, GPS data was collected during field surveys, enabling the study to validate the land cover classifications derived from satellite imagery. Ground truthing involved visiting selected areas within the Masese wetland to match observed land use and cover with the classified outputs. This validation process ensured that the classifications aligned with actual conditions, enhancing both the reliability and the accuracy of the study’s findings.

3.4.1.2 Satellite Image Preprocessing

The study area shape file was uploaded onto assets in Google Earth engine software. The shape file was then imported into Google Earth engine code editor and used together with Landsat and Sentinel collections scripts for the targeted dates (2014, 2017, 2020, and 2023). The images were then exported onto Google Drive in tiff format and downloaded onto the desktop for processing using ArcGIS 10.82 software. To harmonize the difference in the spatial resolutions of the Landsat and Sentinel data, the Landsat data image was resampled to the resolution of Sentinel to ensure consistency and data quality (Amani et al., 2020; Matarira, et al., 2022). Within the image collection and download scripts in the code editor, commands for cloud masking and clipping of the target images were embedded as part of the pre-processing.

3.4.1.3 Processing

The image classification was based on wetland use/cover change changes in the study area. The classification scheme employed in the study is a hybrid/robust approach, combining both unsupervised and supervised techniques to identify six wetland use types. This scheme integrated both unsupervised and supervised classification techniques to identify the six wetland use types. The unsupervised classification involved the application of an iso-clustering classification algorithm to initially categorize the satellite data into broad clusters and was meant to guide the supervised classification procedure. Supervised classification involved the creation of a signature file that contained the maximum likelihood model training data for the wetland cover/use types data. Maximum likelihood classification relies on user-defined classes assigned to a sample of pixels in an image. From the training data set, 20% of the data was reserved for model validation for each of the classes. This robust classification scheme enables accurate identification and monitoring of wetland use/cover changes, informing conservation and management efforts. Six types of wetland uses were identified and used in this study: (1) open water, (2) built-up areas, (3) crop farming, (4) grassland, (5) tree plantations, and (6) wetland). Table 4:1 shows the overall changes in wetland usage and cover from 2014 to 2023, along with the increases and decreases in each category.

3.4.1.4 Description of Emerging Classes: Wetland Use/Cover Types

Six separate use types were identified in the Masese wetland research area; each has its characteristics, ecological roles, and distributions. The following are the six land classes that were identified:

Built-up Areas

These are areas with settlements such as urban settlements, infrastructure, and developed lands, including residential, commercial, and industrial areas. These areas are usually characterized by impermeable surfaces like concrete and asphalt, which reduce soil permeability and increase runoff. While built-up areas generally offer limited ecological functions compared to natural landscapes, they can impact wetland ecosystems by introducing pollutants and altering natural water flows, especially if located near wetland buffers. In Masese, built-up areas are commonly found in regions adjacent to transportation routes or urban centres, where human settlement and concentrated in areas with high population density.

Open Water

This class represents permanent water bodies, including rivers, ponds, and lakes, typically with minimal vegetation and high water reflectance values. Open water is critical for the wetland ecosystem, serving as a habitat for various aquatic species and supporting biodiversity. Additionally, they are essential for sediment transport and hydrological management. In the Masese wetland area, open water bodies are distributed throughout the wetland and often interconnect with surrounding marshes, contributing to the water flow and maintaining wetland hydrodynamics.

Crop Cultivation

This involves agricultural lands used for cropping, including annual and perennial crops. It is characterized by Rectangular or irregular cultivated fields, irrigation infrastructure, and farm roads. These areas are often modified with soil tillage, irrigation, and fertilization. While essential for food production, crop cultivation within wetlands can lead to habitat loss, soil degradation, and nutrient runoff, which may contribute to eutrophication in nearby water bodies. In Masese, crop cultivation is usually concentrated on the periphery of the wetland where the soil is fertile, but it sometimes extends into the wetland zones, reflecting the anthropogenic influence on land use patterns.

Grassland

Grasslands are open areas primarily covered by grasses and other low-growing vegetation, which can be either seasonal or perennial. Grasslands located within wetlands are vital as they provide habitat for birds, insects, and small mammals. They also help stabilize soil, reduce erosion, and contribute to nutrient cycling. In Masese, grasslands are found scattered throughout the wetland, often situated in areas that transition between open water and denser vegetation zones. These grasslands are occasionally used for grazing or other low-intensity land uses.

Tree Plantation

These areas mainly consist of planted trees, typically non-native or commercial species like eucalyptus or pine, which are grown for timber or other resources. While tree plantations can provide economic benefits, they may also change the soil composition, affect water availability, and disrupt the natural flora and fauna of the wetland area. Additionally, if the species used are high-water-demand types, they can reduce groundwater recharge. In Masese, tree plantations are often found around the edges of the wetland, allowing for easier harvesting without significantly impacting the wetland's core.

Papyrus Wetland

Wetlands are characterized by papyrus vegetation, which includes marshes, swamps, and floodplains. These areas are marked by the dominance of papyrus, waterlogged soils, and unique microhabitats. Consequently, papyrus wetlands are vital for maintaining biodiversity, controlling water flow, and delivering vital ecosystem services. Natural vegetation is mostly found around Lake Victoria's northern coasts, especially in the Napoleon Gulf, in the Masese wetland area. In a ground-truthing operation, the classified photos from 2014, 2017, 2020, and 2023 were validated by gathering geographic coordinates for each type of vegetation using GPS technology.

3.4.1.5 Post classification

Post-wetland cover/use classification involved the calculation of class areas for the different years and conducting a discriminate analysis. Post-classification covered change detection and accuracy assessment. Change detection not only investigates changes that have occurred, but it also defines their type and determines their spatial breadth and pattern. The purpose of transition analysis was to compare the classes for several years, namely 2014, 2017, 2020, and 2023, to identify any changes in wetland cover and the ultimate conversion to or from class. The evaluation of classification accuracy comprised the computation of Kappa statistics, overall accuracy, and a confusion matrix. The confusion matrix shows how many guesses were right and wrong in relation to the actual classes on the ground or reference map (Rwanga & Ndambuki, 2017). Overall accuracy is calculated using the confusion matrix which gives the proportion of the total predictions to all predictions made. Conversely, the Kappa coefficient quantifies the extent to which various rasters consistently classify the same things (Rwanga & Ndambuki, 2017). The confusion matrix, overall accuracy, and Kappa statistics are shown in formulae 1, 2, & 3 below;

$C[i][j] = \sum_{k=1}^{m} I(yk = i \cap yk = j)$ Equation (1)

Where;

$C[i][j]$ is the element at row *i* and column *j* of the confusion matrix.

I is an indicator function that returns 1 if the condition inside is true, and 0 otherwise.

yh is the true label of the *k-th* sample

yk is the predicated label of the *k-th* sample

Overall Accuracy $\frac{\sum_{i=1}^{k} C[i][i]}{N}$ equation (2)

Where;

$C[i][i]$ *is the number of samples correctly classified for class I and N is the total number of samples.*

Kappa accuracy $K = \frac{\text{Observed}-\text{Expected}}{1-\text{Expected}}$……………………….Equation (3)

3.5 Examining the drivers of wetland use/cover changes in Masese wetland in Jinja City

3.5.1 Study population and sample size selection

Data was collected in the Masese wetland area in Jinja City, specifically targeting the southern and part of the northern division wards that border the wetland. These include Budhumbuli West, Budhumbuli East, Wanyama, Masese, and Old Boma. These areas were chosen due to their close proximity to the Masese wetland system. Within these wards, specific cells contain wetlands, including Loco in Old Boma, Masese 1 and 2 in Masese, Kalina Zone and Church Zone in Budhumbuli East, School Zone and Commercial Zone in Budhumbuli West, and Katamba cell in Wanyama (see Figure 3.2). It is from these that the target sample/households were selected. The Jinja City Development Plan III-2020/21 indicates that the five aforementioned wards have a total population of 50,955 persons and 13,726 households. Since the study targets households as respondents, the study population is deduced from the 13,726 households. The study population comes from the seven cells/zones selected out of the 20 cells making up five divisions. Because of their closeness to Jinja municipal's Masese wetland system, the municipal wards and cells were chosen. Given that the total number of households was 13,726 for the 20 cells, the number of households per cell was estimated by dividing the total number of households by the total number of cells (i.e., 13726/20), giving 686 households per cell. Therefore, the study population was obtained by multiplying the number of selected cells by the number of households per cell (i.e., 7*686), giving 4,802 households. The study population was thus 4802 households in seven cells. From these, the sample size was derived using proportionate sampling procedures (Fielding et al., 1993)using the formula;

$$n = \frac{N}{1+N(e^2)}$$ Equation (4)

Where;

n is the sample size,

N is the total population which is 4802,

e is the level of precision which is 0.05%

$$n = \frac{4802}{1+4802(0.05)^2}$$

$$n = \frac{4802}{1+4802\ (0.0025)}$$

$$n = 369.242$$

$$n \cong 369 \text{ households}$$

The sample size for the study was thus 369 households.

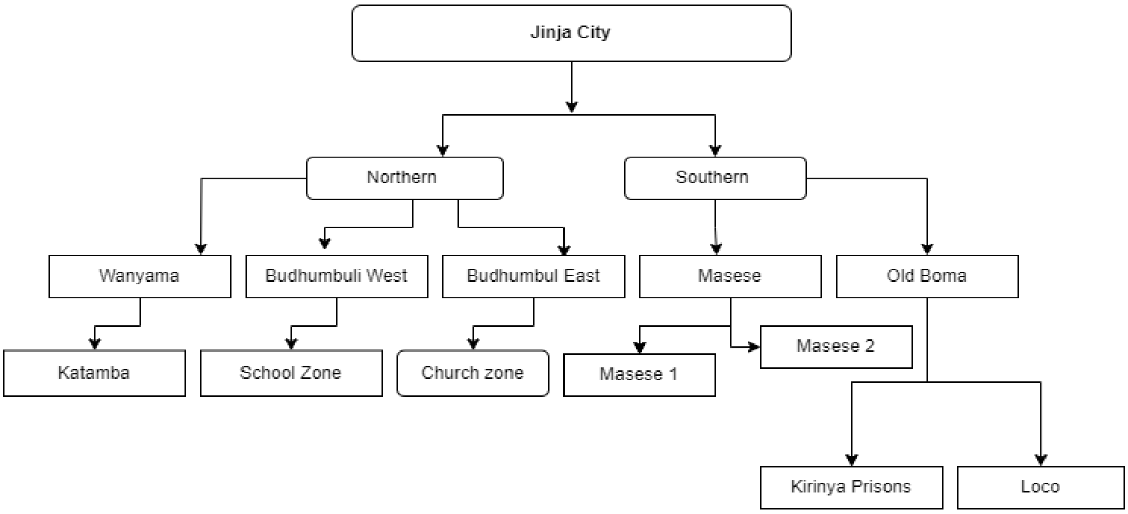

Figure 3. 2: Area sampling framework

3.5.2 Data collection

To investigate the important factor influencing wetland alteration in Masese wetlands at the local level, socioeconomic data on the subject was gathered. This data was collected from households in the wards of Jinja City adjacent to the wetland sections of Kikenyi, Budhumbuli, Masese, and Kirinya. The specific Jinja City wards of Wanyama, Budhumbuli East, Budhumbuli West, Masese, and Old Boma formed the basis for household sampling. The households were proportionately and systematically sampled based on population data achieved in UBOS reports. Socioeconomic data was gathered from these using a structured questionnaire (Appendix 1). The research assistants interpreted the survey questionnaires in the Lusoga language. The questionnaires were directly administered through one-on-one interviews to minimize peer influence and for purposes of ensuring good quality of data.

The questionnaire comprised a set of questions that required the respondents to rate/grade and rank the significant drivers of wetland change in the area. Section A collected respondents' bio-data, section B collected study location data, section 1 collected wetlands presence, status, and benefits data, while section 2 collected data on drivers of wetland change, impacts of change, wetland conservation measures, and their effectiveness. Key informants at the city, division, ward, and cell levels were also interviewed. These included City/Division Environmental Officers, Natural Resource Officer, Wetlands management committee chairperson, and members. The key informants were specifically chosen because of their involvement in wetland management initiatives and with the communities surrounding wetlands. For this, an interview guide customized to the study's objectives (Appendix 2) was employed.

3.5.3 Validity and reliability

The validity and reliability of the structured questionnaire were ensured through pilot testing, expert reviews, and statistical analysis of the responses.

A pilot test of the questionnaire was conducted with six wetland environmental officers from the Masese wetland catchment area. This pilot phase aimed to identify potential issues related to question clarity, consistency, and the overall effectiveness of the questions in gathering reliable data. Feedback from the pilot test was used to refine the questions, ensuring they were well understood by the target respondents and aligned with the study's objectives.

The questionnaire items were reviewed by a panel of experts with experience in wetland studies, environmental management, and survey methodology. The experts evaluated each item based on its relevance and ability to measure the study variables. Each item was rated on a scale of 1 (relevant) to 2 (not relevant), and only those rated as relevant were retained. This process helped refine the instrument, ensuring the questions were both comprehensive and focused on the key constructs of the study. To assess validity statistically, the Content Validity Index (CVI) was calculated for each section of the questionnaire based on expert ratings. The CVI was determined using the formula:

$$\text{CVI} = \frac{\text{Total number of items}}{\text{Number of items confirmed relevant}}$$

Table 3. 1: Measurement of Validity

	Number of questions	Valid questions	Content Validity Index (CVI)
Wetland change Drivers	05	04	0.800
Soil organic carbon	06	05	0.833
Average (CVI)			0.817

Source: Primary data (2024)

The items were evaluated on a scale where 1 indicates "relevant" and 2 indicates "not relevant." Experts deemed relevant items as capable of measuring the variables being studied. To assess the validity of the instruments, a Content Validity Index (CVI) was employed. The instruments were pre-tested with six environmental officers from the Masese wetland catchment area (Mason, et al., 2021). According to Amin, et al., (2024), a CVI of 0.7 is considered acceptable. From Table 3.1, it can be seen that all CVIs were above 0.7, indicating that the items were relevant to the study variables. On average, the Content Validity Index was 0.817, which aligns with Amin's recommendation that any tool must achieve a CVI of 0.7 or above to be considered valid.

3.5.4 Socio-economic Data Analysis

Data on drivers of wetland change were measured on a continuous scale thus descriptive and inferential statistical analysis techniques were applied. From the ranked drivers, means, standard deviation, minimum, maximum, range, and mode were generated summaries. At the inferential level, the results were compared for differences and similarities in relation to wetland use type's locations using multivariant analysis of variance. A binary logistic regression analysis was carried out in SPSS version 23 to identify the key factors influencing wetland alteration in the research area. The binary logistic regression was used to test the relationship between predictors (independent variables) decoded on a continuous or ordinal scale and a binary outcome (dependent variable) (Mukherjee et al., 2018). In the study, the probability of wetland change based on predictor variables (drivers) was analyzed. This statistical analysis outputs statistics in terms of coefficients of each predictor variable, odds ratios, Wald Chi-Square, significance levels, and confidence intervals among others (Mukherjee et al., 2018). The dependent variable (wetland change) was decoded and independent variables (wetland change drivers) were measured on a scale of 1 to 10 where 10 indicated the most significant level and 1 being the least significant thus satisfying the conditions for a binary logistic regression analysis (Mukherjee et al., 2018). The formula for Binary logistic regression is given below.

$$P(Y = 1 \mid X) = \frac{1}{1+e^{-(\beta_Q+\beta_{Q1}X_1+\beta_2X_2+..........+\beta_nX_n}} \qquad \text{Equation (5)}$$

Where:

$P(Y$=1$|X)$ is the probability of the binary outcome being 1 given the values of the independent variables $X1$, $X2$,...,$XnX1$,$X2$,...,Xn.

e is the base of the natural logarithm.

βQ, $\beta 1$, $\beta 2$,...,βn are the coefficients (parameters) estimated by the logistic regression model.

$X1$, $X2$,..., Xn are the values of the independent variables (predictors).

n is the number of independent variables.

The logistic regression model estimates the coefficients $\beta 0$, $\beta 1$, $\beta 2$,...,βn based on the training data, and these coefficients are used to predict the probability of the binary outcome for new observations based on their predictor values (Nussbaum, 2024).

In the study, the probability of wetland change based on predictor variables (drivers) was analyzed. This statistical analysis outputs statistics in terms of coefficients of each predictor variable, odds ratios, Wald Chi-Square, significance levels, and confidence intervals among others (Mukherjee et al., 2018). The dependent variable (wetland change) was decoded and independent variables (wetland change drivers) were measured on a scale of 1 to 10 where 10 indicated the most significant level and 1 being the least significant thus satisfying the conditions for a binary logistic regression analysis (Mukherjee et al., 2018).

3.6 Assessing the Soil organic carbon under different wetland use/cover changes in Masese wetland in Jinja City

3.6.1 Soil organic carbon

Soil sampling design involves strategically selecting sampling locations, determining appropriate depths, and employing systematic methodologies to ensure representative soil analysis (Wang, Li, et al., 2019). The researcher used a systematic sampling design following 100m apart along the length and 50m apart along the width in three wetland sites representing wetland use types that are intact wetlands, farmed / agriculture wetland sections, and built-up infrastructural sections like industries and settlements (Gearey et al., 2020) since they were the main wetland use types identified. Taking into account variables including wetland vegetation types, soil profiles, and land-use history, a systematic sampling technique was created to gather representative soil samples from these sites (De Mandal et al., 2020). 15 pits were dug out. Soil samples at different depth intervals of 0-15cm and 15–30 cm were collected in the three wetland use/cover types using a soil auger as the method. The 0–30 cm were the focus because they are tillage zones that are greatly impacted by management methods, particularly tillage systems that change the soil environment (Olson & Al-Kaisi, 2015). Two soil samples from each pit making a total of 30 soil samples. Multiple samples from each site were collected to account for depth-wise and spatial variability. Sampling was done at different depths thus 0-15 cm and 15-30 cm to assess SOC distribution in the soil profile (Dhaliwal et al., 2023). The samples were kept in black polythene bags and small plastic containers and then transported to the laboratory for analysis. The sampling locations were geocoded using a handheld GPS for spatial visualization of the results.

3.6.2 Analysis of Soils in a Laboratory

Soil samples were air-dried at room temperature to remove excess moisture, crushed and pounded to break the big soil clods using a mortar and pestle, and sieved through a 2mm sieve to remove non-soil materials and then analyzed for SOC using Walkley and Black's rapid titration method. This method is relatively quick and simple for large samples (Ramamoorthi & Meena, 2018). Weigh 0.5 grams of the soil sample into a boiling tube. 5 ml of potassium dichromate and 2.5 ml of concentrated sulphuric acid were added to the soil sample while in the fume board. The boiling tube is then put in the digestion block set at 148^0C for 30 minutes for complete oxidation. To the resultant solution, three drops of a mixed indicator are added and titrated against ferrous ammonium sulphate with a titer of T_t. A blank is prepared following the same steps to obtain a titer of T_b (Okalebo et al., 2002; Segnini et al., 2019)

Organic carbon (%) = $\frac{T \times 0.3 \times 0.2}{Sample\ weight}$ where T (titration volume) = ($T_t - T_b$)

3.6.3 Data analysis

The carbon contents of various wetland uses were compared using statistical analysis. To ascertain whether the carbon contents under the various wetland cover and usage types change significantly, Analysis of Variance (ANOVA) was used.

3.7 Data collection procedure

Upon approval of the research proposal, the researcher obtained a letter of introduction from Kyambogo University which helped him to seek permission to carry out research in cells bordering the Masese wetland system. The researcher used research assistants to administer the questionnaires to the target group of households bordering the Masese wetland. After the data collection, it was processed, analyzed and then the researcher came up with a written report

3.8 Ethical consideration

An introductory letter from the Directorate of Research and Graduate Training, Kyambogo University was secured and presented as proof of the study purpose to the authorities in Jinja city. Interviews were done after getting the consent of the interviewees and before each interview, the study's objectives were clearly explained to the respondents. Also, the respondents were further assured of the confidentiality of the information provided and that the study findings were used for research purposes only out of fear of the implications arising from the research findings. Plagiarism was avoided by recognizing authors and acknowledging them in the work. This means that findings were presented in their original form the way they were adopted in the field.

CHAPTER FOUR: PRESENTATION OF RESULTS

4.1 Introduction

The chapter includes comprehensive study findings on spatial-temporal changes in wetland use and cover for the years 2014, 2017, 2019, and 2023 (Section 4.1.1), the drivers of wetland change (Section 4.1.2), and Soil organic carbon (Section 4.1.3).

4.1.1 The spatial-temporal changes in wetland cover/use between 2014 and 2023 in the Masese wetland system in Jinja City

The analysis of remotely sensed data is summarized in Table 4.1 and Figure 4.1. The results revealed that the percentage of open water in the study area fluctuated between 9.5% and 7% from 2014 to 2017. It then decreased to 6.3% between 2017 and 2020, before rising again to 9% from 2020 to 2023. These findings suggest that the reduction in open water was temporary. Once the factors causing the decrease were removed, open water returned to its original extent. Overall, the net change in open water during the study period was zero, likely due to the area's coastal location, which is influenced by water level fluctuations in Lake Victoria and the Nile. Notably, the period around 2020 saw a significant rise in water levels, leading to the submergence of previously dry land areas.

Built-up areas accounted for 16.5% of the land in 2014 and have steadily increased to 17% in 2017, 20% in 2020, and 21% by 2023. The most significant change in built-up areas occurred between 2017 and 2020, with an increase of 3%. Smaller changes of 1% were observed between 2014 and 2017 and again between 2020 and 2023. Overall, built-up areas increased by 5% from 2014 to 2023. In 2023, wetlands experienced a reduction in built-up areas due to stricter environmental policies, heightened community awareness, and ongoing restoration efforts that promote sustainable land use practices aimed at protecting wetlands for flood mitigation and habitat preservation (Baskent, 2021).

Between 2014 and 2023, cropland represented the largest area within the Masese wetland system. Its coverage steadily increased from 26% in 2014 to 30% in 2017, and then to 35% by 2020. However, by 2023, this coverage decreased to 31%. Local government initiatives aimed at reclaiming wetland areas from agricultural encroachment likely contributed to this observed reduction in cropland. Specifically, cropland increased by 5% from 2014 to 2017 and by an additional 4% from 2017 to 2020, before decreasing by 4% between 2020 and 2023. Overall, cropland experienced the largest increase in area between 2014 and 2017, resulting in a net increase of 5% during the entire study period.

Grassland coverage maintained a spatial extent of 19% from 2014 to 2017. However, it decreased to 13% between 2017 and 2020. Between 2020 and 2023, grassland coverage increased to 16%, marking a 4% rise. Overall, this resulted in a net reduction of 7% in grassland coverage from 2014 to 2023.

The papyrus wetlands, which represent the permanent wetland areas within the Masese wetland system, accounted for 20% of the study area in both 2014 and 2017. This coverage decreased slightly to 18% between 2017 and 2020 and further to 17% by 2023. Overall, the papyrus wetland coverage has reduced by 3%, indicating that the encroachment of other land uses has gradually replaced parts of these permanent wetlands, resulting in significant socio-ecological impacts.

Tree plantations experienced changes in their spatial extent over the years. Between 2014 and 2017, the area decreased from 9% to 7%, marking a reduction of 2%. However, there was a temporary increase of 2% from 2017 to 2020, after which the area declined again from 9% to 6% between 2020 and 2023, resulting in a 3% reduction. Overall, the total decrease in tree plantation area was 3%, indicating that periodic clearing and replanting cycles have impacted the original tree plantation areas..

The results indicate that the area of open water remained relatively stable, with no significant net change during the study period. In contrast, both cropland and built-up areas saw substantial increases, each expanding by 5%. However, papyrus wetlands and grasslands experienced declines of 3% and 7%, respectively, likely due to the encroachment of cropland and built-up areas. This transformation in land cover and use underscores the replacement of permanent wetland areas with other types of land use, leading to socio-ecological implications for the Masese wetland system.

Table 4. 1: Spatial-temporal changes in wetland use/cover between 2014 and 2023 in Masese system in Jinja City

	Wetland use/ cover Type	**2014**		**2017**		**2020**		**2023**		**Change 2014 - 2023**	
		Area (sq. km.)	**%**	**Area (sq. km.)**	**%**	**Area (sq. km.)**	**%**	**Area (sq. km.)**	**%**	**Area (sq. km.)**	**%**
1	Open water	1.5	9.5	1.1	7.0	1	6.3	1.4	9	-0.1	0
2	Built up	2.6	16.5	2.7	17.1	3.1	19.6	3.4	21	0.8	5
3	Cropland	4.1	25.9	4.8	30.4	5.5	34.8	4.9	31	0.8	5
4	Grassland	3	19.0	3	19.0	2	12.7	2.5	16	-0.5	-3
5	Papyrus wetland	3.2	20.3	3.1	19.6	2.8	17.7	2.7	17	-0.5	-3
6	Tree plantation	1.4	8.9	1.1	7.0	1.4	8.9	0.9	6	-0.5	-3
	Total	15.8	100	15.8	100	15.8	100	15.8	100		
A_1	Accuracy (Overall)	0.8		0.83		0.82		0.78			

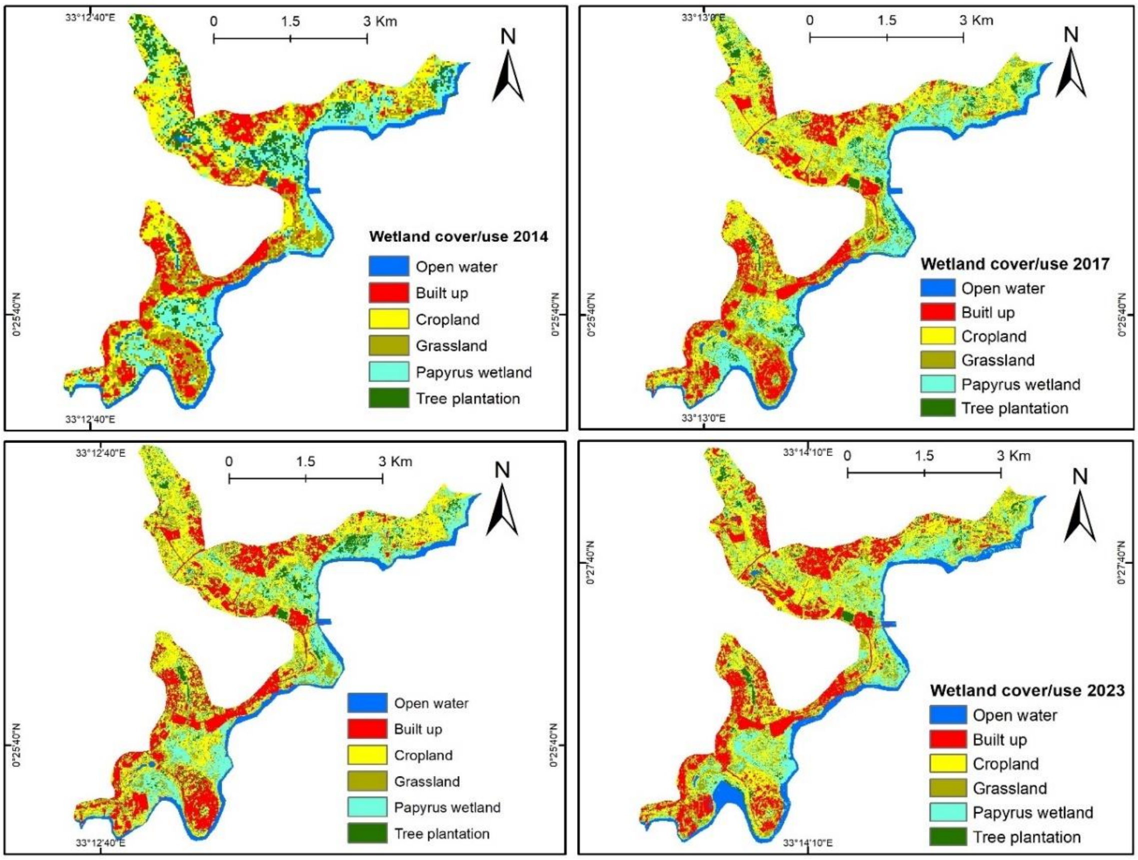

Figure 4. 1: Spatial-temporal changes in wetland cover/use between 2014 and 2023 in Masese wetland system in Jinja City

The classification accuracy results (Table 4.2) reveal that both overall accuracy and Kappa coefficient of above 70% for 2014 -2023 implying that the results from the wetland use /cover classification can be trusted and reveal the true image of the changes that have taken place in the study area.

Table 4.2: Confusion Matrix and Accuracy Assessment 2014 - 2023

2014	**1**	**2**	**3**	**4**	**5**	**6**	**2017**	**1**	**2**	**3**	**4**	**5**	**6**
1	41	0	0	1	0	2	1	50	0	0	0	1	0
2	0	41	1	3	0	0	2	0	31	2	0	0	0
3	1	2	21	4	3	1	3	0	0	17	5	21	1
4	0	1	4	13	21	2	4	0	0	8	14	1	1
5	1	0	3	1	21	2	5	0	0	1	0	22	2
6	6	2	4	0	2	11	6	0	0	2	0	3	16
Accuracy (Overall)			**0.7577**				**0.8379**						
Accuracy (Kappa)			**0.7037**				**0.8012**						
2020	**1**	**2**	**3**	**4**	**5**	**6**	**2023**	**1**	**2**	**3**	**4**	**5**	**6**
1	42	0	1	0	0	0	1	42	0	0	0	0	0
2	0	39	0	0	0	0	2	0	41	0	1	0	0
3	0	0	15	6	5	2	3	0	1	23	8	6	1
4	0	1	4	12	0	0	4	0	0	0	17	5	0
5	1	0	7	2	13	0	5	1	0	5	3	17	2
6	0	0	0	0	0	16	6	0	0	1	0	1	14
Accuracy (Overall)			0.825				0.7817						
Accuracy (Kappa)			07845				0.7339						

The results from key informant interviews revealed that the Masese wetland in Jinja City has undergone significant changes due to human activities. Industrial expansion, urban settlement, and agricultural encroachment have all contributed to a reduction in the wetland's area and a degradation of its ecological health. Increasingly, wetlands have been converted for industrial use, leading to habitat loss, reduced vegetation cover, and heightened pollution from untreated effluents.

One key informant emphasized:

"Wetlands have been converted into industrial establishments, and there is ongoing settlement in these areas, resulting in a reduction of their size."

Another respondent elaborated on the actors responsible for wetland degradation:

"Yes, continued encroachment by farmers and investors, such as Sun Belt, Bidco, Buwenge Distillers, Nile Agro, individual settlers, and subsistence agriculture for rice and vegetable cultivation, has completely altered the wetland areas."

In another interview, an informant quantified the change:

"Wetland coverage in the Masese wetland has reduced by almost 10% due to industrialization."

Lastly, a participant highlighted additional ecological impacts:

"There has been a reduction in wetland vegetation and an increase in pollution from the release of effluents."

4.1.2 Drivers of wetland use/cover change in Masese wetland in Jinja city between 2014 and 2023

The study assessed selected households' and key informants' perceptions of the drivers of wetland change in the Masese wetland system. The descriptive statistics for the most significant drivers of wetland change in Jinja City (ranked on a scale of 1 to 10) and the regression results are presented in Table 4.5. The descriptive statistics indicated that industrialization was rated as the most significant driver of wetland change (9.6±1), followed by urbanization (8.2±1.2), weak government policies and regulations (7.8±1.5), agricultural land expansion (6.1±2), political influence (5.7±1.8), and pollution from runoff (5.4±1.3). The least rated drivers were cultural practices (1.3±0.6), economic development (3.4±1.6), land tenure (3.6±1.4), and climate change (3.8±2.2). The highest-rated drivers received scores of five and above, suggesting that respondents perceived these as the most significant contributors to wetland change, while the lowest-rated drivers had scores below four, indicating a perceived lesser impact.

The binary regression modelling of wetland change (dependent variable), measured on a binary scale (Not changed & changed), against ten (10) drivers of wetland change (independent variables) provided further insights. The results (Table 4.3) showed that Wald chi-square statistics were greater than zero for all drivers, with coefficients above zero, indicating a contribution from each variable to wetland change, albeit at varying degrees. The standard error results demonstrated high precision in coefficient estimates. The logistic regression model identified industrialization, weak policies and regulations, and economic development as the most significant drivers of wetland change in the study area, with p-values less than 0.05, indicating statistical significance.

For industrialization, the odds of wetland change increased by a factor of approximately 1.493 for each one-unit increase in industrialization. However, the p-value for industrialization (0.054) was slightly above the typical significance threshold of 0.05, suggesting marginal significance. The remaining variables, including agricultural land expansion, urbanization, climate change, pollution from runoff, political influence, land tenure, and cultural practices, were not statistically significant predictors of wetland change as their p-values exceeded 0.05. These findings suggest that, while there are multiple drivers of wetland change in the Masese wetland system, not all contribute significantly.

Table 4. 3: Descriptive statistics and binary regression model results for perceived significant drivers of wetland change in Jinja City

	Model predictors	**Mean rating (1-10)**	**Standard deviation**	**B**	**S.E.**	**Wald**	**Df**	**Sig.**
	(Constant)			-11.859	8.81	1.812	1	0.178
1	Agricultural expansion	6.1	2.1	0.19	0.174	1.183	1	0.277
2	Urbanization	8.2	1.2	0.09	0.229	0.153	1	0.696
3	Climate change	3.8	2.2	0.042	0.172	0.059	1	0.807
4	Industrial activities	9.6	1.0	0.4	0.208	3.718	1	0.054
5	Pollution from runoff	5.4	1.3	0.185	0.205	0.812	1	0.368
6	Political influence	5.7	1.8	-0.052	0.188	0.078	1	0.780
7	Weak government policies and regulations	7.8	1.5	0.494	0.204	5.889	1	0.015
8	Land tenure	3.6	1.4	-0.005	0.191	0.001	1	0.979
9	Economic development	3.4	1.6	0.46	0.218	4.475	1	0.034
10	Cultural practices	1.3	.6	0.57	0.342	2.778	1	0.096

An interview session with a local council chairperson and other informants revealed the following insights:

One informant emphasized that industrial activities have the most significant impact on wetlands due to the use of permanent materials, such as sand, which alters the wetland structure. “Industrial activities use permanent materials like sand for surfacing, leading to lasting changes in the wetland.”

Agricultural expansion and urban settlements were highlighted as secondary drivers of wetland degradation. The informant explained that both agricultural expansion and urban settlements require extensive land use, which contributes to the loss of wetland areas. “Agriculture and settlements require a lot of land, resulting in significant utilization of wetland space.”

Concerns were raised about the negative impact of agrochemicals used in wetlands converted for agriculture. “The use of agrochemicals is harming the wetlands.” Additionally, the informant mentioned the extinction of aquatic species and the introduction of non-native tree species, specifically Eucalyptus, which further degraded the ecosystem. “Eucalyptus trees are being planted in the wetlands, contributing to their degradation and threatening native aquatic species.”

In another interview session, a key informant explained, “The Masese wetland extent in Jinja City has changed due to conversion into industrial establishments and urban settlements, particularly around Wanyama and Masese wetlands, compounded by untreated effluent release and agricultural activities.”

These interviews reveal that the informants are well aware of the significant threats facing the Masese wetland system. Industrial development, urban settlements, and agricultural activities are repeatedly emphasized as key drivers of wetland degradation in the area. This aligns with findings from household survey data, which also identified industrial expansion and urbanization as major contributors. However, the survey results differ slightly from the key informant interviews by placing less emphasis on agricultural expansion as a driver.

4.1.3 Quantification of Soil organic carbon under different wetland use/cover types in the Masese wetland system in Jinja City

Soil Organic Carbon was quantified for the Masese wetland system and the results were presented according to the major wetland use/cover types thus in farmed, built-up, and intact wetland sections were analyzed alongside other soil properties which also affect or get affected by soil organic carbon. The results are shown in Table 4.4. The results reveal a mean soil Ca of 6.4±2.4 in built-up wetland areas. The Ca under farmed wetland sections was 8.8 with a standard deviation of ±5.2 and that under intact wetland sections was 9.3±3.3. These show that intact wetland sections had higher soil Ca followed by farmed wetland areas and the lowest is under built-up areas. These imply that wetland disturbances like building and farming reduce soil Ca. In terms of soil OC, the results revealed a mean of 1.5% ±0.49 under built-up wetland locations, 3.1% ±4.2 for soils farmed wetland sections, and 2.3% ±1.4 for intact wetland sections. Here, the results show that farmed wetland areas had higher OC followed by intact wetland sections and the lowest OC was recorded under built-up wetland sections which means that such wetland disturbance acted against soil OC in Masese wetland in Jinja City. In terms of soil OM, farmed wetland sections had the highest mean OM (5.3±7.) followed by intact wetland areas (3.9±2.4) and the least was for built-up wetland areas (2.7±0.8). The higher OC levels in agricultural land compared to intact wetlands are likely due to a combination of intensive agricultural practices, such as residue incorporation and manure application

Table 4.4 presents detailed data on soil organic carbon (SOC) and related soil properties for various land use types within the Masese wetland. Notably, SOC levels were highest in the farmed sections of the wetland at 3.1% ±4.2. Intact wetland areas exhibited moderate SOC levels at 2.3% ±1.4, while the lowest levels were recorded in built-up areas at 1.5% ±0.49. Similarly, soil organic matter (OM) followed the same trend, with farmed areas showing the highest OM levels. This suggests that intensive agricultural practices enhance carbon retention, although they may also deplete carbon stocks due to land use pressures.

Overall, the results implied that land use significantly influences soil quality within the Masese wetland system. Built-up areas, where the wetland environment is most disturbed, show the lowest values for both SOC and soil organic matter, while farmed areas, despite being disturbed, maintain some of the highest values likely due to organic inputs from farming practices. This data illustrates the dual role of agricultural use in both enhancing SOC through residue inputs and degrading it over time through soil exposure and nutrient extraction.

Farmed areas support higher organic carbon but may risk long-term degradation, while built-up sections show reduced soil quality indicators, likely linked to construction and soil compaction. The preservation of intact wetland sections, showing moderate SOC levels, is vital for maintaining soil health and overall ecological function in the Masese wetland system.

Table 4. 4: Descriptive and exploratory statistics for soil properties under different wetland use and cover sections in Masese wetland

Soil properties in built up area	pH	N%	P(mg/kg)	K(cmol/kg)	Ca(cmol/kg)	OC%	OM%	%SAND	%CLAY	%SILT
No. of observations	10	10	10	10	10	10	10	10	10	10
Minimum	5.3	0.0	16.0	0.3	2.8	0.8	1.4	20.0	34.0	20.0
Maximum	8.2	0.2	110.4	2.5	9.5	2.5	4.2	40.0	60.0	32.0
1st Quartile	5.9	0.1	19.4	0.6	4.3	1.2	2.0	23.0	39.0	21.5
Median	6.7	0.1	34.2	1.6	6.0	1.5	2.5	27.0	44.0	27.0
3rd Quartile	7.6	0.2	70.7	2.0	8.9	1.9	3.2	36.0	49.5	30.0
Mean	6.8	0.1	46.4	1.4	6.4	1.5	2.7	28.6	45.0	26.4
Variance	0.9	0.0	1047.1	0.6	5.8	0.2	0.7	47.2	76.7	19.4
Standard deviation (n-1)	1.0	0.1	32.4	0.8	2.4	0.5	0.9	6.9	8.8	4.4

Soil properties in farmland	pH	N%	P(mg/kg)	K(cmol/kg)	Ca(cmol/kg)	OC%	OM%	%SAND	%CLAY	%SILT
No. of observations	10	10	10	10	10	10	10	8	8	8
Minimum	6.4	0.0	1.6	0.3	4.0	0.6	1.0	10.0	26.0	16.0
Maximum	10.0	0.7	140.7	3.7	18.0	11.6	20.0	58.0	66.0	30.0
1st Quartile	6.7	0.1	15.4	0.8	5.4	0.8	1.3	14.5	35.0	16.5
Median	7.1	0.1	42.2	1.6	6.0	1.4	2.4	21.0	57.0	20.0
3rd Quartile	8.3	0.3	101.5	2.7	13.3	3.9	6.7	47.0	63.5	24.0
Mean	7.6	0.2	58.9	1.8	8.8	3.1	5.3	27.5	51.5	21.0
Variance	1.4	0.1	2356.5	1.3	26.6	17.8	53.0	334.6	238.6	24.0

Standard deviation (n-1)	1.2	0.3	48.5	1.1	5.2	4.2	7.3	18.3	15.4	4.9

Soil properties in intact wetland (3)	**pH**	**N%**	**P(mg/kg)**	**K(cmol/kg)**	**Ca(cmol/kg)**	**OC%**	**OM%**	**%SAND**	**%CLAY**	**%SILT**
No. of observations	10.0	10.0	10.0	10.0	10.0	10.0	10.0	7.0	7.0	7.0
Minimum	6.8	0.0	2.2	0.3	4.0	0.4	0.7	30.0	24.0	22.0
Maximum	9.7	0.5	56.6	3.4	14.5	4.1	7.0	54.0	42.0	28.0
1st Quartile	6.9	0.1	5.3	0.6	7.1	0.8	1.3	36.0	28.0	24.0
Median	7.4	0.2	12.7	1.3	8.9	2.4	4.1	44.0	28.0	26.0
3rd Quartile	9.4	0.3	43.8	2.1	11.9	3.7	6.4	48.0	36.0	28.0
Mean	8.0	0.2	22.9	1.4	9.3	2.3	3.9	42.9	31.1	26.0
Variance	1.6	0.0	407.0	1.0	11.0	1.9	5.8	62.5	37.1	5.3
Standard deviation (n-1)	1.3	0.2	20.2	1.0	3.3	1.4	2.4	7.9	6.1	2.3

4.1.4 ANOVA Results

Soil properties data were analyzed using Analysis of Variance (ANOVA) to investigate the variations in soil properties related to different wetland uses. The results presented in Table 4.5 reveal significant differences in soil properties across three levels of wetland use: intact wetland, farmed wetland, and built-up wetland sections. Statistically significant differences were noted for soil pH ($p = 0.019$), potassium ($p=0.024$), percent sand ($p = 0.002$) among the various wetland uses, indicating that these properties are sensitive to changes in land use within the wetland environment.

Conversely, no statistically significant differences were found in nitrogen (N), calcium (Ca), organic carbon (OC), organic matter (OM), and silt content across the different wetland uses ($p > 0.002$) These findings suggest that while certain soil properties exhibit variability with changes in wetland use, others remain relatively stable. Soil properties are affected by wetland use changes, others, particularly those related to organic carbon, remain relatively stable. This stability in OC and OM levels implies that the current land uses have not significantly impacted the soil organic carbon content in the wetland soil.

Table 4. 5: Analysis of Variance for SOC and other soil properties in disturbed and undisturbed wetland section

Wetland use	**pH**	**N%**	**P (mg/kg)**	**K (cmol/kg)**	**Ca (cmol/kg)**	**OC %**	**OM %**	**% SAND**	**% CLAY**	**% SILT**
Sum of Squares (between groups)	11.1	0.1	9894.6	2.0	46.7	15.6	46.4	1795.2	2128.3	90.8
Sum of Squares (within groups)	32.4	0.8	31066.8	24.1	390.6	176.4	524.3	2247.3	2055.7	433.3
Df. (between groups)	2	2	2	2	2	2	2	2	2	2
Df. (within groups)	27	27	27	27	27	27	27	22	22	22
Mean Squares (between groups)	5.53	0.03	4947.32	0.98	23.35	7.80	23.19	897.62	1064.14	45.42
Mean Squares (between groups)	1.20	0.03	4.30	0.89	14.47	6.53	19.42	111.24	93.44	19.70
F-Ratio	4.62	0.94	0.02	1.09	1.61	1.19	1.19	8.07	11.39	2.31
Sig.	0.019	0.403	0.024	0.35	0.22	0.32	0.318	0.002	0.000	0.123

CHAPTER FIVE: DISCUSSION

5.0 Introduction

This section provides a detailed discussion of the key study findings by way of interpretation of their implications as well as cross-referencing with previous related study findings. This is done according to the study objectives.

5.1 The spatial-temporal changes in wetland cover/use change in the Masese wetland system in Masese wetland.

The findings from the study on the Masese wetland in Jinja City reveal a concerning trend of declining wetland areas, which decreased by approximately 3% between 2014 and 2023. Notably, this decrease was most noticeable from 2017 to 2020, which also happened to be the time when farmland and built-up areas significantly increased, each growing by roughly 5% during that time. This dynamic underscores the detrimental impact of urbanization on wetland ecosystems, as growth in built-up areas directly correlates with the loss of these critical environments.

Comparatively, insights from Bunyangha et al (2021) elucidate a consistent pattern of wetland decline in the Mpologoma catchment, which experienced an annual reduction rate of 0.63%. compared to farmland and built-up areas that appreciated in spatial extent at a rate of 9.32% and 6.22 respectively. The study predicted a continued decrease in land cover including wetlands in the future. Although the river Mpologama catchment is more of a rural setting compared to Jinja, Similar and related wetland pressures from human activities are experienced. Therefore, the observed wetland changes in the Masese wetland system are not a new phenomenon.

The broader regional context provided by Ondiek et al. (2020) further contextualizes the Masese wetland changes within East Africa, where wetland extent has declined by approximately 55% over the last five decades, largely driven by agricultural development. The confluence of these studies suggests that the alterations observed in the Masese wetland system are not isolated incidents but rather part of a pervasive trend of wetland degradation influenced by human activity.

Furthermore, the biodiversity-rich Kilombero Valley wetlands, which have seen a startling loss of at least 90% of their original area due to intensified human activities like cultivation and grazing, serve as an example of the profound effects of land use changes on wetland ecosystems, as highlighted by Munishi & Jewitt's (2019) work. In addition to upsetting ecological balance, this loss presents serious obstacles to the preservation of ecosystem services and biodiversity. In the context of Nigeria, Agbaogun & Akintunde-Alo (2020) provided critical insights into the repercussions of urban expansion on land cover dynamics, noting a notable decrease in vegetation cover alongside an increase in built-up areas from 1989 to 2019. Their findings further illustrated the resultant rise in average temperature, attributed to the loss of vegetation, highlighting the intricate relationship between land cover and climate moderation. While their study did not isolate temperature changes caused by various other factors, it effectively emphasizes the essential role vegetation plays in regulating local climates.

The alarming situation in the Masese wetland system underscores the urgent need for proactive measures, such as city greening initiatives, to mitigate the adverse impacts of urbanization on wetland ecosystems. As city expansion continues to encroach upon these vital ecological zones, the role of wetlands in climate regulation and environmental sustainability is increasingly jeopardized. Therefore, it is imperative to advocate for sustainable urban planning practices that prioritize the preservation of wetland areas to promote biodiversity and mitigate the effects of climate change in urban settings like Jinja City.

5.2 Significant drivers of wetland use/cover change in Masese wetland in Jinja City

The findings of the current study reveal critical insights into the factors influencing changes in wetland spatial extent in the Masese catchment. The significant influence of industrialization activities, economic development, and weak governmental policies and regulations on wetland changes aligns with prior research that underscores the impact of human activities on these vital ecosystems (Huang et al., 2022; Namaalwa et al., 2020; Omagor and Barasa, 2018). These studies collectively indicate a transformative effect of urbanization on wetland structures, suggesting that as areas become increasingly developed, the resultant pressures compromise wetland integrity.

Building on the comparative assessment by Businge. (2017), it becomes evident that while similar pressures exist in other regions, the dynamics at play in the Masese wetland reveal a nuanced landscape of environmental change. Businge et al. identified agricultural activities, over-harvesting, and infrastructure development as primary drivers of wetland degradation. In contrast, the current study highlights infrastructure development specifically related to urban expansion as a principal factor in wetland loss. The ongoing urbanization in Jinja City, particularly in the Masese Wetland, underscores a pattern where wetlands are increasingly viewed as viable alternatives for infrastructure needs, further exacerbating their decline.

Moreover, the findings reveal a concerning dimension regarding the enforcement of wetland and environmental management regulations. The weak enforcement mechanisms appear to be a substantial driver of wetland changes within the Masese system. This supports Businge's 2017) assertion regarding the pressing need for greater public awareness and community engagement in environmental governance. The limited understanding of existing policies among both regulatory bodies and community members may hinder effective implementation, suggesting a critical area for intervention in wetland management strategies.

On a broader scale, the study reaffirms previous assertions regarding the overarching drivers of wetland change in Uganda, namely increasing population, socio-economic pressures, and industrial development (GOU, 2016b). Such demographic shifts present a parallel challenge across both urban and rural settings, where burgeoning populations exceed the available habitable land. In this context, wetlands serve as essential buffers, absorbing the pressures resulting from the inadequacy of existing infrastructure and housing.

Interestingly, the current study diverges from earlier findings regarding agricultural expansion's impact on wetland degradation, particularly when compared to the work of Ondiek et al. (2020b), which documented a 55% reduction in wetland extent over a five-decade span primarily due to agricultural conversion. This discrepancy can be attributed to the urban character of the study area, where land use pressures manifest predominantly as urban infrastructure development rather than agricultural encroachment. The urban setting complicates traditional narratives surrounding agricultural expansion, suggesting that future research should consider the varying impacts of urban versus rural settings on wetland dynamics.

5.3 Soil organic carbon under different wetland use/cover types in Masese wetland in Jinja City

The current study's findings showed that different wetland use and cover types did not significantly differ in terms of soil organic carbon (SOC). This result is in contrast to other studies, including the one carried out by (Were et al. (2016), which indicated that different land use and cover types, specifically forests, croplands, and grasslands, are associated with varying SOC levels in the Eastern Mau Forest Reserve. Were et al.'s findings suggest a strong correlation between land use and SOC storage, raising questions about the discrepancies observed in the current investigation.

The lack of significant variation in SOC in the present study may suggest that the wetland areas examined have undergone relatively recent land use changes that have not yet had a profound impact on SOC. It is plausible that the study area has maintained similar conditions conducive to SOC accumulation over an extended period, resulting in a stable existing SOC stock that is resistant to minor fluctuations associated with recent land use modifications. This interpretation aligns with the findings of Dayathilake et al. (2021), who observed unexpectedly high SOC in urban freshwater wetlands, which also challenges conventional notions regarding SOC levels in different ecosystems.

In contrast, Abebe et al. (2020) reported significant variations in SOC across various land uses, attributing these differences to practices such as biomass removal and unsustainable agricultural methods, which resulted in elevated SOC and total nitrogen stocks in bushland and grazing areas. This contradiction prompts further investigation into the specific factors influencing SOC dynamics in different environmental contexts, particularly in urban wetlands, where human activity may yield complex interactions between land use and soil properties.

Moreover, Nabiollahi et al.(2019) highlighted that SOC under farmland tend to be lower than those under wetland and forest lands, although the differences were not statistically significant. This finding resonates with the current study's outcomes, indicating that while SOC levels may fluctuate due to land use changes, these variations may occur within narrow ranges, reflecting similar trends in the Masese wetland.

Additionally, the current study demonstrated significant variations in specific soil properties, including pH, potassium, sand, and silt percentages, across different wetland use types. This observation corroborates the findings of Lei et al. (2022), who identified substantial correlations between soil physicochemical properties and SOC, except for certain heavy metals and total phosphorus. Similarly, Satdichanh et al. (2023) suggested that the interplay between soil properties and topography contributes to a diverse range of SOC levels, emphasizing that land use practices can significantly impact soil attributes and, by extension, SOC.

While existing literature supports the notion that land use modifications can affect SOC levels (Addise et al., 2022; Funes et al., 2019; Nabiollahi et al., 2019), this study contributes to the discussion by advocating for land use practices that enhance SOC stability and improve overall soil quality (Nwaogu et al., 2018).

Furthermore, Addise et al. (2022) highlighted the spatial variability of SOC in southern Ethiopia, noting that SOC levels varied significantly with soil depth, with higher levels recorded in specific regions. This observation suggests that natural soil variations can also influence SOC distribution across landscapes. In light of these findings, it is conceivable that intrinsic factors affecting SOC variability may counteract significant spatial differences, even in landscapes subjected to human activity, as evidenced in the Masese wetland.

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CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

In this chapter, the conclusion and suggestions are presented. Future research needs and policy-related topics are covered in the recommendations.

6.2 Conclusions

The conclusions are derived based on the study findings and emerging discussion under each objective as follows

The Masese wetland system is undergoing significant changes in its use and cover. The findings of this study indicated that both cropland and built-up areas have expanded by 5% during the study period from 2014 to 2023. This suggests that urban infrastructure and farmland are increasing, potentially encroaching on other wetland types and uses. Additionally, the original wetland areas have decreased by 3% over the same period.

The study concluded that industrial developments and weak government policies and regulations in Jinja City have led to negative changes in the cover of wetlands within the Masese wetland system. This trend is likely to persist in the future, which poses significant risks to the sustainability and livability of the city.

The current uses of the Masese wetland system in Jinja City have not significantly affected the soil organic carbon (SOC) stocks. However, over time, these uses may change the status quo and impact the supply of ecosystem services derived from the wetland.

6.3 Recommendations

To address the issues of wetland loss, urban expansion, and the conservation of soil and wetland ecosystems, the following recommendations are proposed based on the study's findings:

Jinja City authorities and the City Planning Department should take the lead in reinforcing urban development guidelines. Developers should prioritize vertical development instead of horizontal expansion to avoid encroaching on fragile ecosystems, particularly wetlands.

The Ministry of Water and Environment should create and implement national policies focused on sustainable wetland management. The Jinja City Council should adapt these national policies into local regulations and ensure compliance. Furthermore, industrial developers should work alongside city authorities to identify sustainable locations for new industrial facilities to minimize their impact on wetlands.

Although the study found that current land uses have not significantly impacted wetland soil organic carbon (SOC) there is a risk of irreversible changes over time, as soil properties may take longer to manifest. Therefore, the National Environment Management Authority (NEMA) and city environmental officers should restore sections of wetlands that have previously been converted for agriculture. This will help promote the reintroduction of native vegetation and the recovery of SOC. The Ministry of Water and Environment should provide technical support and funding for these wetland restoration initiatives.

Establish Community-Based Organizations (CBOs) to raise awareness about the ecological value of wetlands and promote conservation practices. Implement restoration projects in disturbed wetlands to recover SOC and develop policies that encourage sustainable wetland management while preventing further degradation.

6.4 Suggestions for future research

Understanding how temporal variations in wetland usage and cover affect soil organic carbon (SOC) levels is made possible by long-term monitoring of changes in SOC stores in wetlands. The current study primarily focused on comparing SOC under different land uses. Additionally, investigating the impacts of climate change on SOC and ecosystem functioning in wetlands would significantly enhance current wetland management practices.

Further research is needed to explore the long-term effects of various restoration practices on SOC dynamics. It is also important to develop more precise models for predicting SOC changes in response to alterations in land use.

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APPENDICES

Appendix I: Household Questionnaire

Dear Respondent,

I am Peter Bamege, a student at Kyambogo University pursuing a Master of Arts in geography Degree. I am undertaking a research study titled, The Effects of Wetland Use/Cover Change on Soil Organic Carbon in Masese Wetland Catchment Area in Jinja City as part of the requirements for the successful compilation of my studies. You have been randomly selected to provide information for this study. Please, it is prudent that you answer all the questions as honestly as possible to enable the findings of the study to be valid and reliable thereby enabling their use by the wider society.

Informed consent

The information you provide will be treated with utmost confidentiality. Your identity shall remain concealed throughout all stages of the study as pseudonyms shall be used to refer to all respondents. Note that your participation is voluntary but if you choose to participate indicate consent to participate. I will be glad if you accept to participate.

SECTION A: Respondents' Bio-data

A1. What is your household Position?

1. Father
2. Mother
3. Son
4. Daughter
5. Grandchild
6. Grandfather
7. Grandmother
8. Others

A2. What is the composition of the family? (Members who have lived here in the past 3 months).

Category	**Males**	**Females**
Children (Below 18 years)		
Youth (18-35 years)		
Adult (Above 35 years)		

A3. Sex of the respondent

1. Female	2. Male

A4. Age of respondent (Age in complete years) ……………………….

A5. Marital status of household representative

1. Married	2. Single	3. Separated/divorced	4. Widowed

A6. What is your level of education?

1. No formal education
2. Primary/elementary
3. Ordinary (O) level
4. Advanced (A) level
5. Specialized/Vocational training
6. Graduate (Diploma/Degree)
7. Post-graduate (Masters/PhD)
8. Others (Specify)…………

A7. How many years have you lived in this ward/cell?

………………………………………………..

SECTION B: Location

B1. Administrative unit

City	City Division	Ward	Cell

B2. Coordinates: Latitude……………………Longitude……………Elevation…………

SECTION 1: WETLANDS STATUS AND BENEFITS

1a. What are the wetland types in your area? (multiple response)

1. Marshes
2. Swamps
3. Bogs
4. Fens
5. Mangrove
6. Others

1b. Which of the following benefit(s) does your household or community get from the nearby wetlands? (Multiple responses).

1. Clay mining
2. Collection of craft materials like papyrus
3. Collection of firewood
4. Collection of herbal medicine
5. Crop cultivation
6. Fish farming (ponds)
7. Fish harvesting (fishing)
8. Fruit harvesting
9. Gold mining
10. Grasses for mulching
11. Grasses for thatching houses
12. Grazing

13. Hydro supply
14. Hunting
15. Tourism
16. Sand mining
17. Transport
18. Water for domestic use
19. Water for irrigation
20. Water for livestock
21. Water for industries
22. Others (Specify)………………

1c. In the past 5 years, have the benefits obtained from the nearby wetland changed?

a. Yes
b. No

If yes, rate the changes in the benefits provided by the nearby wetland?

Benefit/Activity	**Reduced**	**Remained the same**	**Increased**
Clay mined			
Craft materials like papyrus			
Firewood			
Herbal medicine			
Crops cultivated			
Fish farming (ponds)			
Fish harvesting (fishing)			
Fruits harvested			
Gold mined			
Grasses for mulching			
Grasses for thatching houses			
Pastures			
Hydro supply			
Wild animals hunted			
Tourism			
Sand mined			
Transport services			
Water for domestic use			
Water for irrigation			
Water for livestock			
Water for industries			
Others (Specify)………………			

1d. What is the state of wetlands in your area?

1. Intact
2. Improved
3. Deteriorated/negatively changed

1e. What was/is the coverage of wetland? (in hectares)

1. 5 years ago, _______________
2. Currently _________________

1f. How would you describe the overall change in wetland cover in your area over the past decade?

1. Significant decreased
2. Slightly decreased
3. Remained the same
4. Slightly increased
5. Significantly increased

SECTION 2: DRIVERS OF WETLAND CHANGE

2a. To what extent are you concerned about the following threats to wetlands, not concerned at all and 5 being extremely concerned?

Concern	Not concerned	Slightly concerned	Moderately Concerned	Very concerned
Wetland pollution				
Habitat destruction				
Flooding in wetlands				
Invasive species				
Overfishing				
Climate change impact on wetlands				

2b. Rank the significance of the following factors in driving wetland change in your area on the scale of 1 to 10, where 1 represents the least effect and 10 represents the most significant effect.

Wetland change driver/factor	**Rank 1 - 10**	**Reason for the rank**
Agricultural expansion		
Urbanization		
Climate change		
Industrial activities		
Pollution from runoff		
Political influence		
Weak government policies and regulations		
Land tenure		
Economic development		
Cultural practices		

2c. Which of the following have been the impact(s) of wetland change? (***Multiple responses***)

1. Decline/loss of wetland biodiversity
2. Drought
3. Flooding
4. Human-wildlife conflicts
5. Increased pests and diseases
6. Invasion of alien species
7. Loss of habitat for some animals
8. Reduced amount of rainfall
9. Reduced firewood and herbal medicine
10. Reduction of wetland size
11. Soil erosion
12. Others (specify)

2d. Of the following, what has been done to conserve and restore wetlands? (***Multiple responses***)

1. Cancellation of land titles in wetlands

2. Demarcation of the wetland boundaries
3. Development and implementation of wetland management plans
4. Enforcement of the wetland policy and environmental bye-laws
5. Eviction of people farming and settling in wetlands
6. Establishing a good relationship between local communities and the local government
7. Provision of alternative livelihoods to people farming in wetlands
8. Regulation of human activities such as infilling of wetlands
9. Sensitization of people about the benefits of wetlands
10. Others (specify)

2e. Rate the effectiveness of the wetland conservation and restoration measures implemented.

Measure	**Not effective**	**Effective**	**Very effective**
Cancellation of land titles in wetlands			
Demarcation of the wetland boundaries			
Development and implementation of wetland management plans			
Enforcement of the wetland policy and environmental bye-laws			
Eviction of people farming and settling in wetlands			
Establishing a good relationship between local communities and the local government			
Provision of alternative livelihoods to people farming in wetlands			

Regulation of human activities such as infilling of wetlands			
Sensitization of people about the benefits of wetlands			
Others (specify)			

Any comments????

Thank You!

Appendix II: Key Informant Interview Guide for City/Division Environmental Officers, Natural Resource Officer, Wetlands management committee chairperson and members.

Introduction & Consent

I am Peter Bamege, a student at Kyambogo University pursuing a Master of Arts in geography Degree. I am undertaking a research study titled, Assessing the Effects of Wetland Use/Cover Change on Soil Organic Carbon Stock in Masese Wetland in Jinja City as part of the requirements for the successful compilation of my studies. You have been purposely selected to participate, and your participation is voluntary but very important to achieving the objectives of the study. Please note that the information you provide will be solely used for academic purposes and treated with utmost confidentiality.

Section 1: Identification

1. Enumerator name?
2. Date?
3. Start time?
4. How long have you been involved in wetland management in this city/ division/ ward/ cell?
5. Can you provide a brief overview of your experience and expertise in wetland management?

Section 2: Wetland status

1. What are the wetland types in your area?
2. What are the benefits of these wetlands?
3. In your observation, have you noticed any changes in the wetlands over the past 5 years? If yes, could you describe the changes you have observed?
4. What indicators do you use to assess the wetlands degradation in this area region?
5. How do you think changes in wetlands have affected former benefits?

Section 3: Drivers/factors of wetland change and degradation

1. To what extent are you concerned about wetland pollution, habitat destruction, flooding in wetlands, invasive species, overfishing, climate change impact on wetlands, agricultural land and settlements expansion into wetlands?

2. What are the most significant drivers of wetland degradation/change in Jinja city?

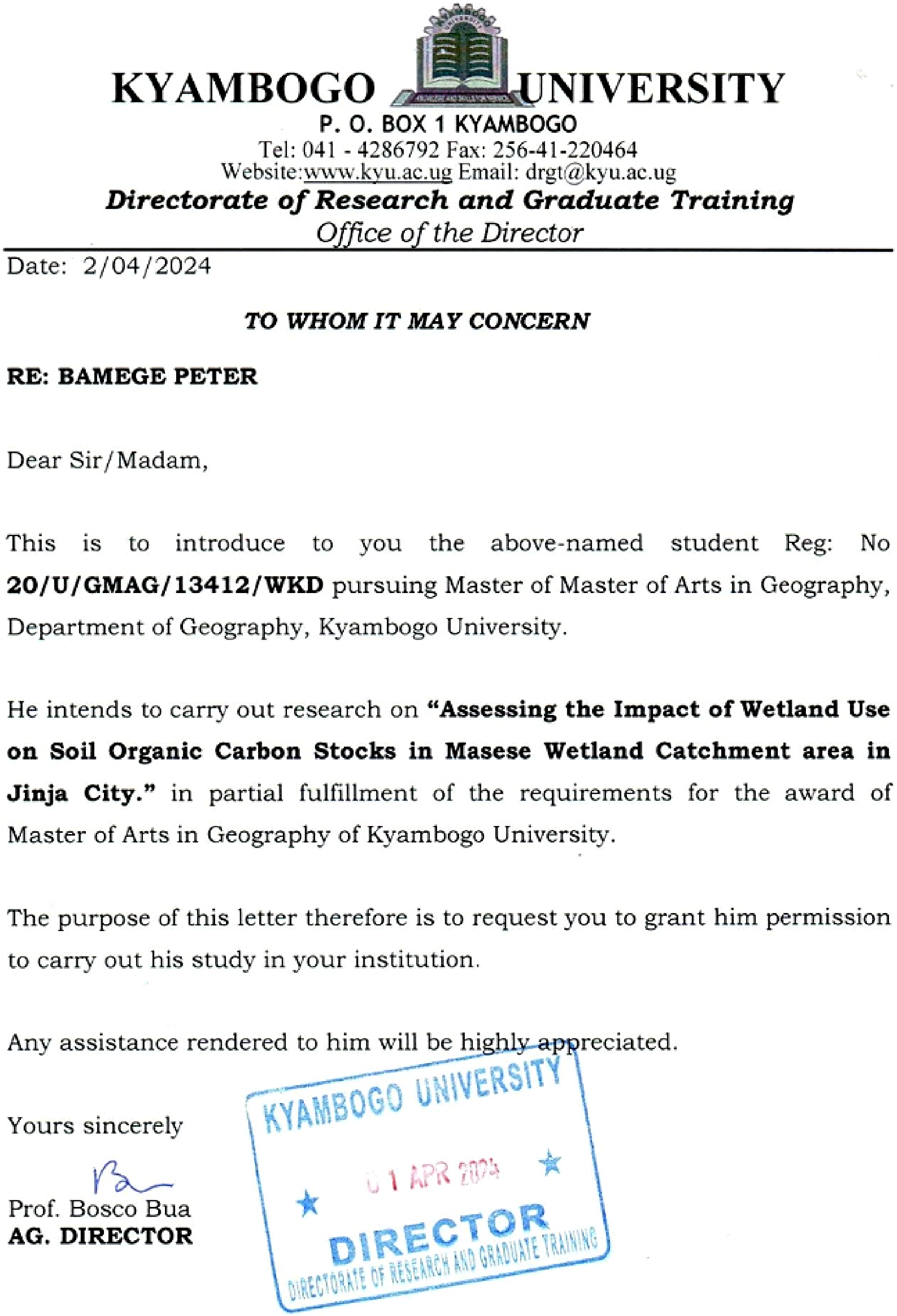
Section 4: Impact of wetland change/degradation and conservation measures

1. What have been the socio-economic and environmental impact(s) of wetland change/degradation?
2. What has been done to conserve and restore wetlands in Jinja city?
3. How effective have been the measures?

Any other comments????

Thank You!

Appendix III: Key Introductory letter



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TO WHOM IT MAY CONCERN

RE: BAMEGE PETER

Dear Sir/Madam,

This is to introduce to you the above-named student Reg: No **20/U/GMAG/13412/WKD** pursuing Master of Master of Arts in Geography, Department of Geography, Kyambogo University.

He intends to carry out research on **"Assessing the Impact of Wetland Use on Soil Organic Carbon Stocks in Masese Wetland Catchment area in Jinja City."** in partial fulfillment of the requirements for the award of Master of Arts in Geography of Kyambogo University.

The purpose of this letter therefore is to request you to grant him permission to carry out his study in your institution.

Any assistance rendered to him will be highly appreciated.

KYAMBOGO UNIVERSITY
01 APR 2024
DIRECTOR
DIRECTORATE OF RESEARCH AND GRADUATE TRAINING

Yours sincerely

Prof. Bosco Bua
AG. DIRECTOR