WETLAND DEGRADATION AND CARBON SEQUESTRATION POTENTIAL – A CASE OF LUBIGI WETLAND, UGANDA

BY

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16/U/13579/GMSM/PE

A DISSERTATION SUBMITTED TO KYAMBOGO UNIVERSITY GRADUATE SCHOOL IN PARTIAL FULFILLMENT FOR THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTERS OF SCIENCE IN CONSERVATION AND NATURAL RESOURCES MANAGEMENT OF KYAMBOGO UNIVERSITY

NOVEMBER, 2019

DECLARATION

This dissertation is my original work and has never been presented for a degree in any other University.

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SUPERVISORS' APPROVAL:

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DEDICATION

Honour and Glory to my creator - the Almighty God for making me start and finish this study successfully.

ACKNOWLEDGEMENT

First and foremost I would like to thank my supervisors' Dr. Norah Mbeiza Mutekanga and Dr Rosemary Nalwanga for their dedication, guidance, and support throughout the course of doing this study. Without you, it would have been a night mare to realize this success.

Special thanks goes to my family members, my wife Hellen Odeke Amiko and children; Olele Isaac, Odeke Emmanual, Asingo Rebecca and Queen Esther Anyimo. For you people were very encouraging and patient with me especially when we had to commit some resources into my studies during period of need.

In addition, I would like to thank my course mates for their encouragement, interactions and discussions during the course. It was nice being with you people; Abaho, Chebrot, Peter, and Hellen.

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ABSTRACT

Wetlands are known for their high carbon sequestration potential owing to their high biomass content per unit area. This is however changing due to human needs to convert them to various land use types. The aim of this study was to determine the impact of wetland degradation on carbon sequestration potentials of selected wetland degradation sites at lubigi wetland. One of the study objectives examined the use of GIS and Remote Sensing in mapping land use land cover change in Lubigi wetland between 1988 and 2018. The land cover maps were obtained from the classification of the 1988, 1995, 2001, 2010 and 2018 Landsat imagery. For the remaining three objectives; (relating carbon stocks below ground and above ground vegetation biomass across different degradation levels of wetland, establishing the relationship between selected soil physico-chemical parameters and soil carbon stocks and determining carbon sequestration potentials across different degradation levels of wetland), four sites were selected purposefully and triplicate vegetation and soil core samples were collected from each site and analyzed for above ground biomass, above ground plant carbon, and soil organic carbon contents.

The results indicated that the thick vegetation wetland had significantly higher ($p<0.05$) plant and soil organic carbon content than the other land use categories. The above ground plant carbon ranged between 281 g/m^2 in the thick vegetation wetland to 191.8 g/m^2 in the cultivated wetland. Soil organic carbon content ranged between 84.2 g/kg in the thick vegetation wetland to 27.2 g/kg in the bare land site. Soil organic carbon content was positively correlated ($p<0.05$) with above ground biomass and soil moisture whereas soil temperature showed significant negative correlation ($p<0.05$). The results showed a high reduction of organic carbon storage (sequestration) of both the soil and above ground in the disturbed areas. The mapping result indicated a progressive loss in area of Lubigi wetland to thin vegetation and build up areas. The view of the respondents from the survey also indicated the high conversion and loss of wetlands over time in the area due to population growth and urbanisation.

From the study it is concluded that carbon sequestration potential in Lubigi wetland has been progressively declining due to loss in area and degradation of wetland. It is recommended that Special attention should be given to protect all wetlands in the country so as to enhance their capacity to sequester carbon and thus mitigate climate change.

Keywords: Lubigi wetland, Degradation, Carbon sequestration, Organic carbon

ACRONYMS

AGB	Above Ground Biomass
BD	Bulk Density
C	Carbon
CCS	Carbondioxide Capture and Storage
CH4	Methane
EC	Electrical Conductivity
Eq/Yr	Equivalent per Year
Gt	Giga ton
GHGs	Green House Gases
IPCC	Intergovernmental Panel on Climate Change
LULCC	Land Use Land Cover Change
m.a.s.l	meters above sea level
PPM	Parts Per Million
OC	Organic Carbon
OM	Organic matter
POC	Plant Organic Carbon
POM	Plant Organic Matter
SOC	Soil Organic Carbon
SOM	Soil Organic Matter

CHAPTER ONE: INTRODUCTION AND BACKGROUND

1.1 Introduction

The Earth's climate is changing, as witnessed by higher atmospheric temperatures, decreased snow and ice cover, and increasing sea level in the 20^{th} century (Mitsch and Gosselink, 2015). The cause of this climate change is the increased concentration of greenhouse gases (GHGs), primarily carbon dioxide in the atmosphere, mostly caused by anthropogenic emission (Evans *et al*., 2014). The growth of human population together with industrialization has led to rapid increases in biomass burning, agricultural activities, and land use changes in tropical regions resulting in enhanced emissions of aerosols and GHGs into the atmosphere (Mistch and Gosselink, 2000; Arina *et al*., 2013). Cumulative CO_2 emissions associated with agriculture, deforestation and other land use changes have increased from about 490 Gt CO_2 to approximately 680 Gt CO_2 in 2010 (IPCC, 2014). To reduce this emission, mitigation measures not only include the reduction and efficient use of fossil fuels, but also reducing the land-based emissions through conservation of many existing reservoirs such as wetlands (Jones and Mathuri, 2007; IPCC, 2010; Saunders *et al*., 2014). If they are managed well, wetland ecosystems and their biodiversity play an important role in the mitigation of climate change and are important in helping humans to adapt to climate change by ensuring water and food security (Ramsar Convention Secretariat, 2011).

1.2 Background to the study

Tropical wetlands have been shown to exhibit high rates of net primary productivity and may therefore, play an important role in global climate change mitigation through carbon assimilation and sequestration (Saunders *et al*., 2012). Wetland ecosystems are transitional regions between terrestrial and aquatic ecosystems with unique soil conditions, plants, and animals, and are essential components of terrestrial carbon and nutrient cycles (Mitsch and Gosselink, 2007; Cui *et al*., 2009; Lathrop, 2011; Li *et al*., 2012). Further, wetlands are defined as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, or salt, including areas of marine water the depth of which at low tide does not exceed six metres" (Ramsar Convention Secretariat, 2011; Russi, 2013;).

Land Use and Land Cover Change (LULCC) substantially alters the structure and functioning of wetland ecosystems which affects plant communities and microclimate thereby changing fluxes in water, nutrients, and energy across the land-atmosphere interface (Qichun, *et al.* 2016). Specifically, wetlands are rich in carbon (C), so deforestation or disturbance of these ecosystems results in large emissions of CO_2 to the atmosphere (Lovelock *et al*., 2011). Wetland vegetation is an internationally important biodiversity resource because it provides important ecosystem services (Zhiqiang and Jiahu, 2016) such as erosion control, water quality improvement, carbon sequestration and fisheries and wildlife habitat protection, while supporting economic activities such as livestock grazing and medicinal plants collection (Margono and Bwangoy, 2014). The exceptional carbon storage and potential emissions from land use change within wetlands have implications for global climate change (CIFOR, 2009).

Wetlands occupy approximately six percent (6%) of the earth's surface area (Ramsar Convention Secretariat, 2006). Wetlands have one of the highest deforestation rates; one-third of the world's mangrove forests have been lost in the past 50 years, while one-third of salt marshes has disappeared since the 1800s (Alongi, 2002; McLeod *et al*., 2011). Globally about 64% of wetlands have been lost since 1900 because of human activities, (Davidson, 2014) and their destruction will likely continue (Fraser and Keddy, 2005; Mitsch, 2005; Mitsch and Day, 2006). Natural wetlands occur on 3.8% of the Chinese landscape (660,000 km^2), accounting for approximately 10% of the global area of wetlands (Marti, 2011). However between 1990 and 2000, 30% of China's natural wetlands were lost (Cyranoski 2009). So, wetland degradation and loss is a global trend.

Uganda's wetlands originally covered about, 29,000 sq. km, about 13% of the total area of the country (NEMA, 2016; Pomeroy, 2017). They comprise swamps (8,832 sq. km), swamp forest (365 sq. km) and sites with impeded drainage 20,392 sq. km and include areas of seasonally flooded grassland, swamp forest, permanently flooded papyrus such as Lubigi wetland, grass swamp and upland bog (NEMA, 2016). Most wetlands in Uganda occur outside of protected areas, and their range and quality is rapidly being eroded for agricultural land. By end of June, 2016 Uganda's land area covered by wetlands had reduced to about 10.9% (MWE, 2017). In Eastern Uganda alone 20%, Central region 2.8%, Northern 2.4% and Western 3.6% of wetlands have been destroyed (NEMA 2008), warning that this has implications on wetlands biodiversity and functionality (NEMA, 2016).

Whereas wetland degradation is defined as "the likelihood that a wetland site, or portion thereof, will be destroyed directly or indirectly, through human actions" (NRSP, 2001 in Eilu and Winterbottom (2006). Wetland loss is defined as "the disappearance of wetland areas due to its conversion to a non-wetland area" (Ramsar convention, 2006). Although Uganda's wetlands contain significant habitats, flora and fauna, many are under threat of degradation and loss which impairs wetland functions (USAID, 2006). Whilst the national policy is for wetlands to be conserved, implementation is weak and there is very little chance of the various National Targets being approached, let alone met (Pomeroy., 2017), adding that wetlands, particularly seasonal wetlands, are rapidly being converted into rice fields, other forms of agriculture, or for seasonal grazing by livestock. Near urban areas, they are considered prime sites for factories (NEMA, 2016).

Lubigi wetland is among the 8 major drainage and Wetland Systems of Kampala consisting of Mayanja/Kaliddubi wetlands, the Nalukolongo wetland, and the Nakivubo wetland among others (KCCA, 2014). The city of Kampala has undergone a period of rapid urbanization that has contributed to the degradation of the city's natural environment (World Bank, 2015). By 1993, 25% of the original wetland area of Kampala wetland systems was converted for development, and by 1999, 46 % of the original wetland areas of Kampala had been converted for urban development (KCCA, 2014, World Bank, 2015). The portion of the wetland along the Western most section of the bypass has a high level of species richness and overall function, while areas of the wetland toward the North East sections of the bypass are increasingly degraded (UNRA, 2011). The Western most sections have been modified significantly for a flood control project that has been constructed within the wetland, altering vegetation, soil quality, and hydrological function (UNRA, 2011). The wetland is also being used by the residents for informal settlements and slums for domestic and small-scale income-generation uses such as growing yams, sugarcane, cassava, sweet potatoes, mixed vegetables and banana in addition to harvesting of papyrus, brick-making, fish farming and harvesting of grass for livestock among others (Emerton *et al*., 1998; World Bank, 2015).

Recent developments at Lubigi Wetland especially development projects initiated by government and invasions by public have raised concerns about the future conservation status of the wetland (HRNJ - UGANDA, 2010, AROCHA, 2012, World Bank, 2015). These among others include the building of a power transmission line for the new Bujagali power station from Kawanda to Mutungo through Lubigi wetland (Kityo and Pomeroy, 2006), the construction of the Northern

Bypass high way on the section from Busega to Bwaise which passed on Lubigi wetland (UNRA, 2011), and the building of a sewage treatment plant by National Water and Sewerage Corporation inside the Lubigi wetland (NWSC, 2013). In addition, there have also been numerous actions by members of the public including war veterans to reclaim parts of Lubigi wetlands for various activities including farming, construction of houses, kiosks, brick making, and car parks (AROCHA, 2015).

The long term consequences of the above activities have led to accelerated reduction in area of Lubigi wetland from 489ha in 1995 to 85ha in 2009 (AROCHA, 2015; Watebawa, 2010). Despite the above, Uganda’s Intended Nationally Determined Contributions to United Nations Framework Convention on Climate Change (UNFCCC), indicate policies and measures of Uganda's mitigation contribution which include increasing wetland coverage to 12% by 2030, from 10.9% in 2014 through restoration of degraded wetlands (MWE 2015). However, to target wetlands conservation and management within REDD+ and other financing programmes, accurate estimates of carbon stocks, sequestration rates and emissions baselines are needed (IPCC, 2007; Alongi, 2011).

So, the rate of degradation at Lubigi wetland has alarmed both the environmental conservationists and the public, with the degradation standing at 42% compared to the national average of 30% (HRNJ-UGANDA, 2010).

While urbanization and local use of wetland goods and services is important for development and livelihoods, these activities also directly contribute to degradation of the wetland and its functions (Emerton *et al*., 1998; Abebe, 2013; KCCA, 2014). There is limited enforcement and monitoring of activities in the wetlands despite the development of environmental regulations protecting wetlands from encroachment (World Bank, 2015). This contrasts the policy to reduce greenhouse gas emissions through reforestation and conservation of tropical wetlands in developing countries through carbon offset and trading agreements (Murdiyarso *et al*., 2010). Likewise, for many policy initiatives, such as the United Nations Framework Convention on Climate Change (UNFCCC) and Reducing Emissions from Deforestation and forest Degradation (REDD+) program, the monitoring of wetland use change is of critical importance (Margono and Bwangoy, 2014).

A number of studies have been done in Lubigi wetland such as baseline study by AROCHA, 1999), GIS mapping of LULC in Lubigi wetland (AROCHA, 2015); flood risk assessment (MSC. ITC Mhonda A., 2013), and effect of seasonal changes in climate factors on papyrus ecosystem development, (Opio A. *et al*., 2016). Other studies compiled peer reviewed related literature on carbon cycle dynamics and carbon sequestration potential of *Cyperus papyrus L*. wetlands in tropical Africa (M. J. Saunders, Frank Kansiime, Michael B. Jones., 2013) and Abundance and Conservation of *Cyperus papyrus* in the Nakivubo wetland (Nerima and Orikiriza, 2013). These studies did not however, focus their investigations on the direct impact of various LULCC on wetland carbon stocks sequestration potentials. It is already urged that quantifying ecosystem carbon stocks is vital for understanding the relationship between changes in Land Use and Land Cover (LULC) and carbon emissions, Soka and Nzunda, (2014); however, little is known about how the various degradation levels of wetlands in Uganda are impacting on carbon sequestration potential and this formed the rational for this study.

1.3 Statement of the problem

Lubigi wetland is currently undergoing rapid degradation and the impact this might cause to its carbon sequestration potential is of high concern. Lubigi wetland area has reduced from 489 ha in 1995 to 85ha in 2009 and it is at 42% higher degradation rate than the national average of

30%. Recent developments also have raised concern on its biodiversity and its contribution to proper functioning of the wetland. In addition, Uganda is working with UNFCCC to mitigate loss of wetlands to 12% by 2030 from 10.9% in 2014 through restoration of degraded wetlands. A number of studies have been carried out on this wetland, but there is limited information about the impact of wetland degradation on carbon sequestration potential in Lubigi wetland.

Therefore, this study was intended to contribute to the common cause by availing updated information on the impact of the ongoing wetland degradation activities on sequestration potential of Lubigi wetland.

1.4 Main objective of the study

The main objective of this study was to establish the impacts of Lubigi wetland degradation on its carbon sequestration potential.

1.4.1 Specific objectives

1. To determine spatial and temporal trends in land use and land cover changes (LULCC) in Lubigi wetland from 1988 to 2018.
2. To relate carbon stocks below ground and above ground vegetation biomass across different degradation levels of wetland.
3. To establish the relationship between selected soil physico-chemical parameters and soil carbon stocks.
4. To determine carbon sequestration potentials across different degradation levels of wetland.

1.5 Research Questions

1. What are the spatial and temporal trends in land use and land cover changes in Lubigi wetland from 1988 to 2018?
2. How do carbon stocks below and above ground vegetation biomass relate across different degradation levels of wetland?
3. What is the relationship between selected soil physico-chemical parameters and soil carbon stocks?
4. What are the carbon sequestration potentials across different degradation levels of wetland?

1.6 Scope of the Study

1.6.1Subject scope

The study focused on spatial and temporal trends in degradation of wetlands and how degradation levels impact on carbon sequestration potential of Lubigi wetland.

1.6.2 Geographical scope

The study was carried out in Lubigi wetland.

1.6.3Time scope

The research was conducted in the month of February 2019. This period coincides with a mixture of activities involving harvesting of food crops and preparations of gardens for next rainy season. This enabled researcher to interact with adequate number of respondents in situ.

1.7 Significance of the Study

i. In policy making, this research will help the wetland based organisations, institutions and policy makers in the Water and Environment sector not only to gain more awareness on how wetland cover changes (LULCCs) contribute to deterioration of wetland carbon sequestration function but also understand the magnitude contributed by each level of wetland degradation. This information will guide government officials in the sector while advocating for wise use and conservation of wetlands.

ii. To the community in and around Lubigi wetlands, the findings will raise awareness on the impact of each land use type on capacity of wetlands to sequester carbon, hence escalating negative impacts of climate change that they are currently experiencing.

iii. In the academia, the findings will add more knowledge to the already existing literature on management of wetlands especially for carbon sequestration.

CHAPTER TWO: LITERATURE REVIEW

2.1 Land use and land cover changes (LULCC)

Changes in land use to meet the demands of a growing global population are inducing a shift in the ecological functions of wetlands and other ecosystems (Villa, 2014). Carbon emissions from land use and land management have increased dramatically over the past two centuries because of the expansion of cropland and pasture, infrastructure extension, and other effects driven by market growth and demographic pressures (Geist and Lambin, 2001). Large mitigation potential lies in improved agricultural management such as improved grazing land management and the restoration of cultivated organic soils and degraded lands (EUCCP, 2010).

2.1.1 Land Cover/Land Use Change Mapping

Land cover is the observed (bio) physical cover on the earth's surface such as vegetation and built up areas whereas land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it such as farming (FAO, 2005). Land use affects land cover and changes in land cover affect land use (Ayele, 2017). Accurate, efficient, and repeatable mapping and assessment of changes in wetlands and riparian areas (referred to collectively as wetlands) is critical for monitoring human, climatic, and other effects on these important systems (Baker *et al*., 2007; FAO, 2005).

Remote sensing data have been applied widely to monitor land cover change, mostly in terms of deforestation and forest degradation (Margono and Turubanova *et. al.,* 2012). At the same time, remote sensing has also been used to map areas of likely past wetland extent that have been converted to other land uses (Melack and Hess, 2011). For many monitoring applications, the quantification of wetland extent is required. Specifically, Landsat imagery capture floristic differences that can be associated with wetland status, as well as water extent and leaf moisture content, both indicators of possible wetland status (Margono and Bwangoy, *et. al.*, 2014). These researchers mapped wetland extent in Indonesia, the Landsat data inputs included Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat Thematic Mapper (TM) imagery.

Wetlands play an important role in the provision of ecosystem services, ranging from the regulation of hydrological systems to carbon sequestration and biodiversity habitat (Russi *et. al.*, 2013). The loss or degradation of wetlands reduces the watersheds capacity to maintain biodiversity, water quality, flood deterrence, and carbon sequestration (Margono and Bwangoy, *et. al.*, 2014).

Therefore, determining spatial and temporal trends in degradation levels of Lubigi wetland could be one of the means of advocating for its urgent restoration and conservation by concerned authorities.

2.2 Wetlands, Greenhouse Gases (GHGs) influx, and Climate change

According to many reports, the Earth's climate is highly changing over time due to different reasons. The primary cause of climate change is the increasing concentration of GHGs in the atmosphere, mostly caused by anthropogenic emission (Mitsch and Gosselink, 2000; IPCC, 2007). The primary greenhouse gas is carbondioxide (CO_2) which is released through the burning of fossil fuels and also by cement production. Atmospheric CO_2 is said to have increased by over 30% since the mid-18th century, with a concentration of about 379 parts per million (ppm) by 2005 (IPCC, 2007). Human activities, especially the burning of fossil fuels such as coal, oil, and gas, have caused a substantial increase in the concentration of carbon dioxide (CO_2) in the atmosphere. This increase in atmospheric CO_2 from about 280 to more than 380 ppm over the last 250 years is causing measurable global warming (IPCC, 2007).

One of the natural carbon reservoirs which are being highly affected by human pressure are wetlands. Human influences have caused significant changes in the chemical cycling of many wetlands as a result of land clearing and subsequent erosion, hydrological modification, and pollution (Saunders *et al.*, 2014). Although wetlands cover 5-8% of the Earth's land area, they have a disproportionate influence on global cycles of such elements as carbon, nitrogen and sulfur. Modification of LULC such as Lubigi wetland, affects its ecosystem which has influence to indirectly reflect on weather parameters and eventually leads to local climate modification (Balogun *et al.*, 2009). Hence, there has been considerable interest in the role of wetlands in issues like global climate change.

2.2.1 Wetland soil

Wetlands are estimated to account for one-third of the world's organic soil carbon pool (Lal, 2008) and this organic carbon sequestration in soils is a potential tool for reducing greenhouse gas (GHG) emissions (Piccolo, 2012). Wetlands accumulate significant amounts of carbon in their soils compared to adjacent upland sites (Bernal, 2008). There are two major factors which are influencing soil carbon sequestration potential. These are: a) climatic conditions like climate, soil parent material, land use/cover change, vegetation, and topography. b) human induced factors such as land use, management, and degradation (Piccolo, 2012). Hence, protecting the wetland soil from such disturbing factors would play a big role in keeping the stored organic matter from being decomposed and then released to the atmosphere.

2.2.2 Wetland vegetation biomass

Plant communities play a key role in the emission and uptake of GHGs in wetland ecosystems (Villa, 2014). With the help of photosynthesis, wetland trees and other plants convert atmospheric carbon dioxide into their belowground as well as aboveground biomass. As a result, carbon may be temporarily stored in wetlands as trees and plants and the living material which feed upon them, and detritus including fallen plants and animals which feed upon them (Roshan, *et al*., 2009).

Sequestration of CO_2 by plants occurs both in terrestrial and inland aquatic ecosystems such as wetlands. CO_2 sequestration in terrestrial ecosystems is significant in protected areas and in extensively and intensively managed land-use systems, but to different degrees depending on vegetation, soil types and conditions. Similarly, the high rates of atmospheric CO_2 fixation and primary production of wetland vegetation result in large fluxes of CO_2 which can lead, under suitable hydrological conditions, to correspondingly high rates of carbon sequestration (Jones and Humphries, 2002). Restoration of degraded lands, and drastically disturbed ecosystems (i.e. mined lands) comprise an important sink for atmospheric CO_2 (Lal, 2008).

2.2.3 Factors affecting storage of carbon in wetlands

Soil organic carbon consists of decomposed organic matter in mineral and organic soil layers (Schoene *et al*. 2007). The studied factors by Bernal (2008); Mitsch *et al*., (2010) which are determining the soil carbon pool of wetlands are a) climate (higher temperatures enhance decomposition of organic matter and reduction of the carbon pool), b)wetland type, defined by the vegetation community (significant organic matter inputs from forest canopy enhances the carbon pool), c) the hydrogeomorphic settings (slowly flowing or stagnant wetlands store more carbon in the soil than do riverine wetlands) and d) Hydrology (if rainfall does not come on time and water table drops) wetlands will dry out and the stored carbon will release back to the atmosphere by oxidation and other processes.

The balance between carbon input (organic matter production) and output (decomposition, methanogenesis, etc.) and the resulting net storage of carbon in wetlands depends on several factors such as the topography and the geological position of wetland, the hydrological regime, the type of vegetation, the temperature and moisture of the soil, pH and the morphology (Mitra *et al.*, 2003; EUCCP, 2010). It is obvious that wetlands are highly affected by the changing climate and are the first group of ecosystems to experience the impacts (Mitsch *et al*., 2010).

2.2.4 Soil temperature

There is a strong relation between climate and soil carbon pools where organic carbon content decreases with increasing temperatures, because decomposition rates doubles with every $10^{o}{}_{c}$ increase in temperature (Shalu Adhikari *et al.*, 2009). The response of soil organic matter decomposition to increasing temperature is a critical aspect of ecosystem responses to global change (Conant *et al.,* 2011). Warmer climatic zones are being affected by the increasing temperature and would have the lowest levels of soil organic matter (Collins and Kuehl, 2001) even though, increasing rainfall and other factors in an area can have a tremendous effect on soil organic matter production. As a result, moisture promotes greater plant growth and the production of large quantities of plant materials for organic matter synthesis. The interactions between temperature and moisture should also be considered when estimating the effects of increasing temperatures, caused by climate change, on decomposition rates. An increase in temperature will have an unambiguously positive effect on decomposition only when the moisture conditions are favorable (Raija, 2006).

2.2.5 Vegetation cover

The world's biota stores 500 billion metric tons of carbon and that the soils of the world store an additional of 1380 billion metric tons (BMT) (Brown and Lugo, 1982). It is not only the carbon that can be fixed by the vegetation cover but also highly affects the underground store by different means (Jobbagy and Jackson, 2000). According to Bernal (2008) two of the key factors that enhance carbon accumulation in wetland soils are the anaerobic conditions produced by the presence of standing water and the high productivity of wetland ecosystems (due to the standing vegetation in and around the pool of water and the net accumulation of nutrients, sediments, and organic matter coming from the vegetation cover and/or the associated body of water). The type of vegetation cover is determined by the presence of water (time and duration of the flood) (Bernal and Mitsch, 2012). This means that better management of the vegetation cover of wetlands is needed so as to enhance the C storage capacity of the soil in addition to the capture of atmospheric carbon dioxide.

2.2.6 Hydrology

Carbon sequestration in wetlands highly relies on water table (Evans *et al*., 2014) as the saturation of surface soils limits the diffusion of oxygen into the peat, thereby limiting microbial activity and decomposition rates, and generally it is expected to decrease CO_2 emissions to the atmosphere (Chivers *et al.,* 2009). This was also supported by the study of Chimner and Cooper (2003) who stated that CO_2 emissions were higher when the water table was below the soil surface. CO_2 emissions nearly doubled from a mean of 231.3 mg CO_2^{-C} m^{-2} h^{-1} when the water table was +1 and +5 cm above the soil surface to a mean of 453.7 mg $CO2^{-C}$ m^{-2} h^{-1} when the water table was between 0 and 5cm below the soil surface. The influence of water level fluctuations on vegetation distribution is of growing interest as wetlands are increasingly disturbed by climate change and intensive human activity (Zhiqiang and Jiahu, 2016). So protecting the wetland’s hydrology from draining is needed so as not to release the long term stored C to the atmosphere (Chimner and Cooper (2003).

2.2.7 Soil pH

The soil organic carbon (SOC) pool is susceptible to the chemical conditions in the soil, and modification of soil chemistry can be used to influence the rate of accumulation of humic material, as well as the redistribution of organic carbon into deeper subsurface layers (Rackley, 2010). In addition, the soil pH also has influence on plant growth by its effect on the activity of beneficial microorganisms like bacteria that decompose soil organic matter. These organisms are hindered in strong acidic soils and this can prevent the soil organic matter from breaking down or mineralization, resulting in an accumulation of organic matter (McCauley *et al.,* 2009). This means, farming in wetlands where ammonium - based fertilizers such as urea and ammonium phosphates can lower soil pH and thus activate microbial decomposition of organic matter.

It is therefore important to keep wetland pH levels undisturbed, so that carbon can be stored for a long time.

2.3 Carbon Sequestration

The term "carbon sequestration" was defined in different ways by different bodies and organizations. Here are some of the definitions (short descriptions) of carbon sequestration which are taken from different sources. United States geological survey (USGS, 2008) defined the term as:

"Carbon sequestration is used to describe both natural and deliberate processes by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments (vegetation, soils, and sediments), and geologic formations. Before human-caused CO_2 emissions began, the natural processes that make up the global "carbon cycle" maintained a near balance between the uptake of CO_2 and its release back to the

atmosphere. However, existing CO_2 uptake mechanisms (sometimes called CO_2 or carbon "sinks") are insufficient to offset the accelerating pace of emissions related to human activities."

According to the United States Department of Energy (USDOE, 1999):

"Carbon sequestration is defined as the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere. The idea is to keep carbon emissions produced by human activities from reaching the atmosphere by capturing and diverting them to secure storage, or to remove carbon from the atmosphere by various means and store it."

The United States Environmental Protection Agency (EPA, 2001):

"Carbon sequestration as *"the uptake and storage of carbon. Trees and plants, for example, absorb carbon dioxide, and release oxygen and store carbon. Fossil fuels were at one time biomass and continue to store the carbon until burned."*

It is therefore inferred from the above definitions that authors agree CO_2 and other GHGs are accumulating in the atmosphere to undesirable levels threatening the wellbeing of the environment and continuity of life forms, including humans, hence they should be captured in the form of organic matter and sustained so be it in soil, water or plant tissues.

2.3.1 Carbon sequestration in wetlands

Wetlands offer many ecosystem services to humankind including the long term storage or "sequestering" of carbon (C) in their soils and vegetation (Villa, 2014). Although these ecosystems cover only about 5-8 % of the earth's surface (Mitsch and Gosselik, 2015), they play a key role in biogeochemical cycles especially as sources or sinks for carbon (Junk *et al*., 2013). Wetlands are different from other biomes in their ability to sequester large amounts of carbon, not only in their macrophyte and phytoplankton communities but also as a consequence of high primary production and then deposition of decaying matter in the anaerobic areas of their waterlogged soil (Jones and Humphries, 2002). In general, the conditions in wetlands lead to the accumulation of organic matter in the soil and sediment, which makes wetlands one of the most effective ecosystems for storing soil carbon in addition to the atmospheric carbon fixation.

Carbon is sequestered in wetlands when carbon inputs (productivity and/ or sedimentation/formation of peat) surpasses carbon outputs (decomposition and C exports from wetlands into the atmosphere) and the remaining organic material, mostly decayed plant material, is accumulated in the wetland's anaerobic sediment layer as partially decayed organic material, or peat (Roshan, *et al*., 2009; Villa and Mitsch, 2015).

2.3.2 Carbon sequestration in tropical wetlands

The world's wetlands are generally thought to be 7-10 million Km^2 (Mitsch and Gosselink, 2015), by which 30% of these wetlands are found in the tropics (Mitsch *et al.,* 2010). Tropical wetlands are amongst the most productive ecosystems though high temperatures may hinder carbon accumulation in the soil (Bernal, 2008) or in the form of vegetation. These wetland ecosystems represent a significant carbon sink, especially tropical peat lands (Bernal and Mitsch, 2013), however it is inaccurate to report the role of tropical wetlands in global carbon budget as if they were only represented by river floodplains (low soil carbon sequestration and high CH_4 and CO_2 emissions) or only by tropical peat lands (high soil carbon sequestration and low CH_4 emissions). According to Mitsch *et al.* (2010) there is no clear understanding about the rate at which atmospheric carbon is sequestered in tropical wetlands compared to temperate and boreal wetlands. They put two arguments regarding to carbon storage potential of tropical wetlands. On one side, tropical wetlands are the most productive ecosystems so that these wetlands can sequester large amount of carbon in their biomass. Tropical wetlands store 80% more carbon than temperate wetlands according to findings based on the studies conducted to compare ecosystems in Costa Rica and Ohio (Bernal 2008). Tropical wetland in Costa Rica accumulated around 1 ton of carbon per acre (2.63t/ha) per year, while the temperate wetland in Ohio accumulated 0.6 tons of carbon per acre (1.4t/ha) per year (Bernal 2008). On the other side, higher temperatures in the tropics could lead to more rapid decomposition of the stored organic matter in the wetlands. Overall carbon sequestration rates estimated from boreal, temperate, and tropical wetlands range from 8-480 g C m^{-2} $year^{-1}$, but tropical wetlands are more vulnerable than temperate and boreal wetlands because of over-exploitation and lack of legal protection (Bernal, 2008). Papyrus wetlands have the potential to act as a sink for significant amounts of carbon, in the region of 10 t C/ha/yr however, carbon exports from crop biomass removal from cultivated wetlands also account for equivalent net loss (Saunders *et al*., 2012). Hence, development of any wetland conservation strategies should promote multiplicity of wetland functions such as the supply of potable water, biofuels, building materials, flood control and carbon sequestration.

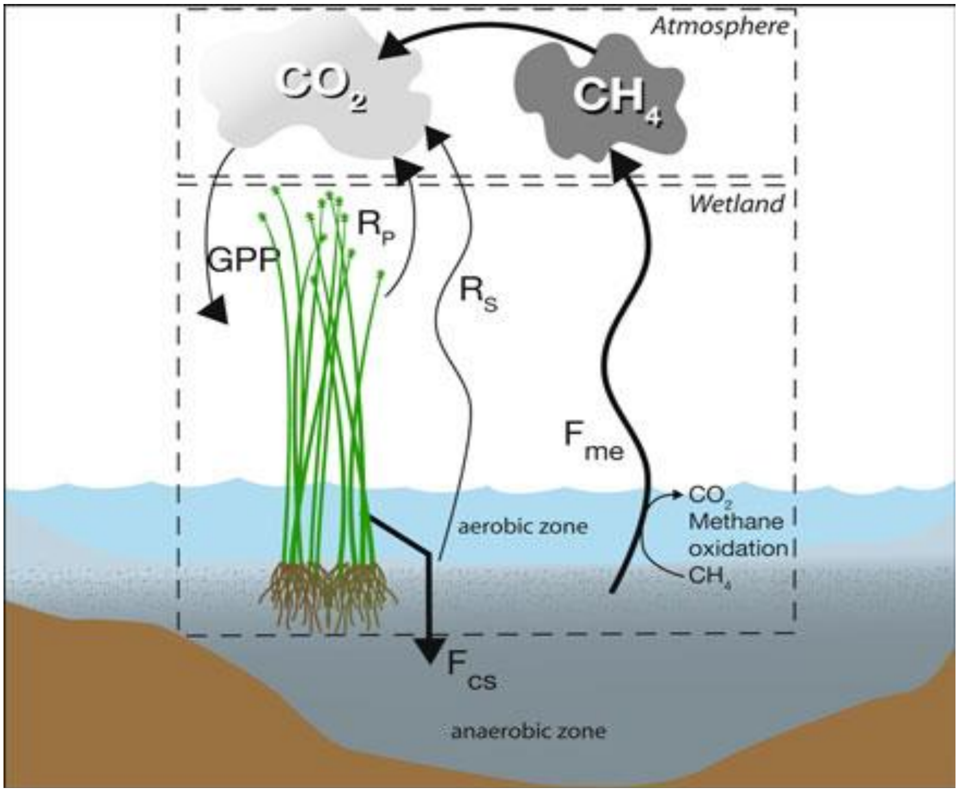

Figure 2.1: Carbon cycle. After William J. Mitsch, et. al., (2012)

2.3.3 Impact of wetland degradation on carbon sequestration

The major causes to climate changes are reportedly emission of greenhouse gases (GHGs) through anthropogenic activities including land-use changes, deforestation, biomass burning, draining of wetlands, soil cultivation and fossil fuel combustion (Lal, 2008). Wetland loss through degradation results in a loss of wildlife habitat and reduced productivity which can lead to the decrease of the ecosystem's capacity as carbon sequestrating reservoir (Wetland policy for Prince Edward Island (PEI), 2000) Anthropogenic activities have increased the atmospheric concentrations of greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapor. High concentrations of CO_2 have been recognized as the main cause of global warming, which is a worldwide environmental concern due to the threat to life on the planet (Muniz *et al*., 2014). African swamps could form a significant sink for carbon when continuously inundated and carbon gains in photosynthesis exceed carbon losses in respiration (Jones & Muthuri, 1997). Conversely, when the detritus is exposed to the atmosphere, and aerobic conditions prevail, these systems may become a net carbon source for the atmosphere as carbon losses exceed carbon gains (Jones and Humphries, 2002; Mitra, *et al.*, 2003). In this case, tropical wetlands can be more vulnerable due to over exploitation of the water and biomass for subsistent incomes (Chimner and Ewel, 2005). Keeping wetlands with their natural character of these ecosystems is probably the best choice of storing carbon.

2.4 Management of wetlands for carbon sequestration

2.4.1 Factors contributing to wetland loss

While wetlands are the most productive ecosystems on Earth; they are also the most threatened (Abebe Yilma and Kim, 2003). Wetland ecosystems in Uganda are equally under a big threat (World Bank, 2015). Wetland degradation has been and is still seen as an advanced mode of developmental activity, even at the government level (UNRA, 2011). Despite the huge benefits gained from wetlands, their destruction around the world has often been common and is mainly caused by land reclamation and drainage because of high human population density (Junk *et al.*, 2013). Population pressure and social economic changes have stimulated the need for more agriculturally productive land in quest to improve the food security (Dixon and Wood, 2003; Junk *et al.*, 2013; Mitchell, 2013).

The main driver of wetland degradation and loss is land use change including, conversion to agriculture and pasture, reservoir building, urbanization and infrastructure development (Zedler and Kercher, 2005). Drainage for agriculture has been a prime cause of wetland loss to date, with an estimation of 26% of the global land area having been drained for intensive agriculture (56%

to 65% in Europe and North America, 27% in Asia, 6% in South America and 2% in Africa) as of 1985 (Davidson, 2014). While rates of wetland loss are well documented for the developed world, the limited study of these ecosystems in developing countries leaves us with little to say (Abebe Yilma and Kim, 2003).

2.4.2 Wetland management and wise use for carbon sequestration and mitigating climate change

The wise use and restoration of wetlands is essential to protect stored carbon and reduce avoidable carbon emissions (Fennessy and Lei 2018) adding that wetlands are globally important carbon sinks, storing vast amounts of carbon and thereby helping to mitigate climate change. Degradation on a massive scale has already occurred in global wetlands ecosystems of immense importance (Mitra *et al*., 2003) and appropriate measures must be taken to stop or at least to reduce this progressive loss and degradation of wetlands. Conservation activities must be initiated in making the wise use of wetlands of the economic wealth they support and the various environmental values they provide including enhancing their ability to sequester global carbon (Fennessy and Lei 2018). Enhancing carbon reserves in wetlands in the context of climate change is consistent with reducing greenhouse gas emissions from the wetlands and restoring their carbon reserves (IPCC, 2007). However, degradation of wetlands and disturbance of the anaerobic environment of the soil and removal of its vegetation cover leads to a higher rate of decomposition and removal of the large amount of carbon stored in it and thus releases greenhouse gases in to the atmosphere (Liu *et al*., 2013). Therefore, protecting the existing wetlands and restoring the degraded ones is a practical way of retaining the existing carbon reserves and thus avoiding emission of CO2 and greenhouse gases to the atmosphere (Mitra *et al*., 2003; Bernal and Mitsch, 2012).

CHAPTER THREE: STUDY AREA, MATERIALS AND METHODS

3.1 Study area

Lubigi wetland is the largest remaining wetland in Kampala city which drains into River Mayanja in the Lake Kyoga basin. The main part of the wetland is located in Wakiso district. The wetland is located on the Northwest side of Kampala in Rubaga and Kawempe divisions about 7.02 km from the city center. It receives storm water and polluted water from Kampala city and discharges it into Mayanja River and finally Lake Kyoga. Lubigi is fed by River Nsooba in the North East, River Nakasero from the North West, River Nabisisasiro from the East, River Kigyankondo from the West, River Nalukolongo from the South East and it forms part of Mayanja-Kato system in the South-West. Lubigi wetland is a monotypic *C. papyrus* wetland. Lubigi wetland was one of the largest wetlands in Kampala district, which initially covered a total area of 2.96 km^2 (Namakambo, 2000), but is now substantially reduced in area to about 85ha (AROCHA, 2015).

The delineation of the study area boundary was based on an automatic procedure using DEM data in SWAT (Soil and Water Assessment Tool). This tool carries out advanced GIS functions to aid in segmenting the watershed into several hydrologically connected sub watersheds for use in modeling with SWAT. In this study, the modelled catchment boundary covers a section of Lubigi wetland in Kampala, Wakiso and Mpigi districts, **Figure 3.1**.

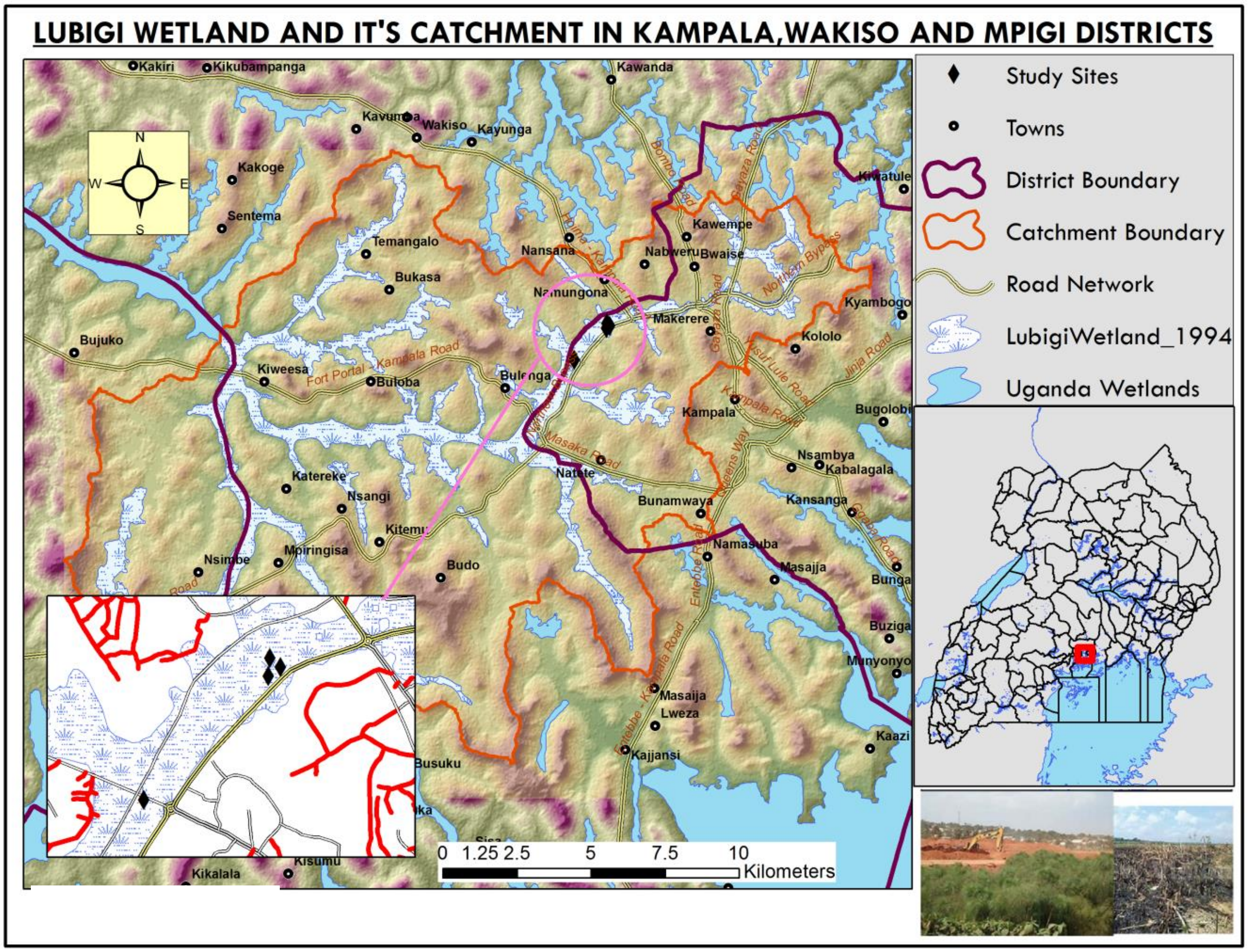

Figure 3.1: Map of Lubigi Wetland and its catchment showing study sites.

3.2 Climatic conditions

Daily average temperature of the area ranges between 17°C to 27°C during the year. This is a typical tropical wetland conditions, characterized with wet and dry climate. Rainy seasons are from September to December and March to May of each year. Erratic changes have been observed in the onset and end of the different seasons in the recent past (Opio *et. al*., 2016). The wetland and its catchment area receives about 1200 to 1700mm of rainfall annually (Kityo and Pomeroy, 2006).

3.3 Materials and Methods

To achieve the aim and objectives of this research, a precise methodology was developed to simplify the work flow. This helped to identify the required data sets and to define relevant methods to manipulate these data sets in order to achieve the ideal results. The methodology for this research is illustrated in the flow diagram as shown in **Figure 3.2 below**.

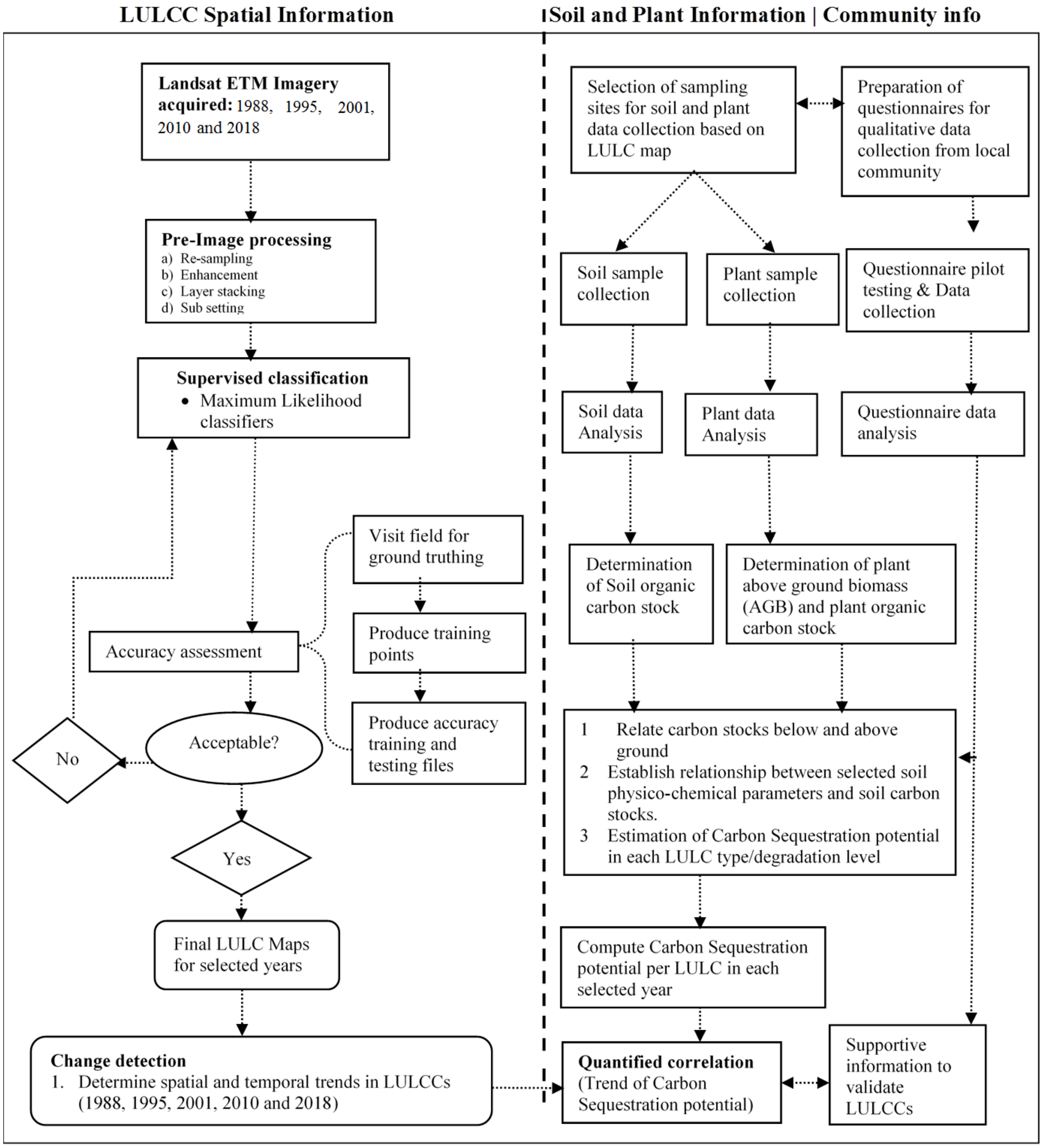

Figure 3.2 work flow summarizing methodology

3.4 Spatial data collection

To conduct this study, both quantitative data (for determination of spatial and temporal trends in wetland use/cover changes and carbon stocks in each wetland degradation level) and qualitative data (views of respondents/local people in study) were collected from primary and secondary sources in the study area. Primary data was collected through field sampling and questionnaires with selected respondents as well as direct field observations. Secondary data was collected from both published and unpublished documents and other related sources.

Based on the ascertained results of the research, a number of relevant data sets were obtained and used as input for execution of the project. **Table 3.1** includes all the collected spatial data sets, their description and source.

Table 3.1: Summary of spatial data sets

No	Data	Description
1	Landsat Imagery (Landsat 5 TM and Landsat 8 ETM imagery)	These were acquired from United States Geological Survey (USGS) for 5 different years: 1988, 1995, 2001, 2010 and 2018. Caution was taken to ensure that the images were cloud free and georeferenced using WGS84 datum and a projection of UTM zone 36N. The images were then imported into ArcMap 10.6 GIS software for extracting land use class maps through classification.
2	Topography	A 5m resolution Digital Elevation Model (DEM) was obtained from stereo imagery captured by Airbus Defense and Space’s Pleiades satellite.
3	Rivers	The rivers layer was obtained from Uganda National Bureau of Statistics (2008)
4	Roads	The roads layer was obtained from a roads map by Uganda National Bureau of Statistics (2012).
5	Districts	The districts layer was obtained from districts map by Uganda National Bureau of Statistics (2016).

3.5 Data collection from community regarding wetland degradation

Data was collected from community in the wetland regarding their perceptions on wetland conversion and degradation. This was important for qualifying some of the findings got from quantitative data. Data collection proceeded as described below.

3.5.1 Study Population

The study targeted a population of 35 people mostly those who live or stay immediate to area of study. These people were those who used the wetland in various ways. Other members of the public equally had a chance to participate in interviews.

3.5.2 Sample Size

The sample size was determined using Slovin's formula which is described below;

$n = N / (1 + N p^2)$ …………………………………………………………………..3.1

Where;

n = the required sample size

N = the targeted population size

p = critical value (that is the significant value) with a 95% confidence level; where p = 0.05

Hence the sample size is obtained as follows;

N = 35

$n=35/(1+50 (0.05)^2$

n=35/1+50 (0.0025)

n=35/ (1+0.125)

n= 35/1.125

n= 31.

3.5.3 Sampling Procedures

Purposive sampling was used to identify those individuals whose roles, responsibilities or livelihoods depended on Lubigi wetland in one way or the other. Other members of the public were interviewed to corroborate results of direct wetland users. Simple random sampling was used to select each individual from a sample until the total required sample size was obtained. This was done by writing names on chits of paper, then wrapping them in a container, mixed thoroughly well by shaking the container then picking one by one till sample size was reached. By doing this, each member of the population was given equal chance of being included in the sample, thus reducing bias when selecting respondents.

3.5.4 Administration of questionnaires

Questionnaires were distributed to the selected respondents to fill. Where the respondent did not know how to read and write, the researcher read questions as they appeared in the questionnaire and wrote down responses as provided by the respondent.

3.6 Land cover mapping and accuracy assessment

3.6.1 Land cover mapping

The Landsat images were visually interpreted, and five land cover classes were identified in the study area. These include water, thick vegetation, thin vegetation, bare land and built-up. To map the extents of these classes, supervised classification was used to define the information classes of interest (land cover types) called training sites. The spectral signature of each class was developed based on reflectance values of each image in the false colour composite. The training sites were digitized and each class was assigned to a different colour for easy differentiation. A statistical characterization of the reflectance of each information class was developed using the maximum likelihood classifier. The classified images were subjected to a majority filter to remove the noisy appearance.

3.6.2 Accuracy assessment

The user's accuracy or reliability is the probability that a pixel classified on the map actually represent that category on the ground (Jensen 2003). The ground truth data for the accuracy assessment was obtained by generating reference points that were randomly selected from reference images of the corresponding years. Accuracy assessment was done by generating confusion matrices based on test samples for each land cover map. The Kappa index of agreement was used as the evaluation criteria for the classification. Kappa analysis is a discrete multivariate technique used in accuracy assessment, Kappa value (Kap) is computed as:

$$K_{ap} = \frac{N\sum_{i=1}^{r} xii - \sum_{i=1}^{r}\left(x_i \times x_{+i}\right)}{N^2 - \sum_{i=1}^{r}\left(x_{i+} \times x_{+i}\right)} \qquad \textbf{3.2}$$

where r is the number of rows in the matrix, xii is the observation in row i and column i, xi+ and x+i are the marginal totals of row i and column i, respectively and N is the total number of observations. The Kappa value is between -1 and 1. If the test samples are in perfect agreement (all the same between classification results and ground truthing results), values for the Kappa index (Kap) equal to 1.

3.6.3 Change detection

Change detection is defined as the process of identifying differences in the state of an object or phenomenon by observing it at different times (Mausel P. et. al., 2003). This process is usually applied to Earth surface changes at two or more times. The temporal image differencing procedure was used to subtract the first date image from the second date image, pixel by pixel to produce a different map that indicates areas of change between the five years.

3.6.4 Selection of sampling sites for soil and plant data collection

The study site was stratified according to different degradation levels (sampling units) of wetland by preliminary field observation using criteria such as vegetation cover, water level, topography, human and livestock intervention among others (Harding, 2005; Afework *et al*., 2015; Mugagga *et al*., 2015). Four land use degradation levels were selected/delineated as per study area conditions as shown in **Table 3.2**below.

Table 3.2: Sampling units were stratified according to different degradation levels of wetland

No	Degradation level	Description of degradation levels of sampling units
1	Thick Vegetation (Undisturbed section)	This is a pristine or undisturbed section of wetland with thick or dominant papyrus vegetation. There is none or very minimal human disturbance especially through harvesting of papyrus for craft materials (e.g. mats). It has the normal specialized papyrus wetland vegetation type for effective functioning of wetland ecosystem. There is a 'good' volume of aboveground vegetation biomass and undisturbed soil.
2	Thin vegetation (Grass cut section)	This is a moderately disturbed section of wetland. Vegetation cover is low/thin compared to above. There is lush short grass which is frequently harvested at young age for feeding livestock. Much as the wetland surface is maintained leafy/green by the actively re-growing/coppicing elephant grass, there is low volume of aboveground vegetation biomass but the soil is undisturbed. This site has a very high potential of recovering into normal wetland ecosystem provided constant harvesting grass is stopped.

3	Cultivated wetland	This is a section of the wetland which was drained for periodic cultivation with crops such as sweet potatoes, cabbage, egg plants, and onions among others. There is low volume of aboveground natural vegetation biomass and the soil undergoes frequent disturbance. Though these areas have almost completely lost the characteristics of a normal wetland, they have a potential of recovering into normal wetland ecosystem if cultivation is stopped. The satellite images used could not clearly distinguish between cultivated land and thin vegetation areas. The researcher thought that there would be a difference in terms of carbon sequestration potential among the two.
4	Bare land	This is part of the wetland whose surface was drained and made permanently bare ground through dumping with stones, soil and marram to form an impervious, hard ground surface with little or no vegetation on it. Such areas include car parks, car washing bays .

3.6.5 Locating sampling points

Sampling points were systematically allocated on a 2 by 6 meter belt transects spanning along purposefully selected wetland degradation levels referred to in table 3.1 and according to Hairiah *et al*., (2001). One transect was laid per degradation level. A starting point of each transect was randomly located and thereafter fixed on East – West direction using a compass. Quadrats of 1m x 1m were placed along the 2 by 6 meter transect as indicated in **Figure 3-3**. A starting point for sampling was selected randomly by throwing the quadrat backwards. The rest of the quadrats were then spaced 2m apart giving a total of 3 quadrats per transect per degradation level, which totaled to 12 quadrats for the 4 degradation levels shown in **Table 3.2**.

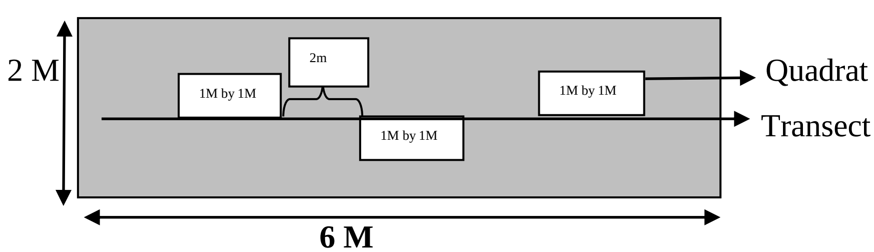

Figure 3.3 work flow summarizing methodology

3.6.6 Plant sample collection

Destructive method was followed which involves cutting, drying and weighing of all components of the above ground living biomass in each quadrat for estimating above ground biomass (AGB) and plant organic matter content (Hairiah et al., 2001; Arina et al., 2013) as shown below:

a) One sample was collected from each of the 3 quadrats per transect in each degradation level. Thus a total of <u>12 samples</u> were obtained from the 4 degradation levels.

b) All vegetation within the 1x1 M^2 quadrat was harvested using a sickle.

c) Total fresh sample (gm-^{2}) was weighed and mixed well onsite using digital weighing balance.

d) A composite fresh sample (~300 g) following to Hairiah *et al*., (2001)) was weighed, zipped in white plastic bag, labeled and immediately transported to the laboratory for estimating above ground biomass (AGB) and plant organic matter content.

e) Samples were then dried at 45$^o{}_C$ for 48 hours and ground.

Plants in the belt transect not known to researcher were collected, pressed, and zipped in plastic bag, carefully labeled and then transported to Makerere University National Herbarium for identification.

3.6.7 Soil sample collection

Soil samples were collected from the field for the determination of physico-chemical and soil carbon content analysis (Hairiah *et al*., 2001; Kuffman and Donato, 2012):

a) Soil samples were collected from each of the 3 quadrats per transect in each degradation level at three different levels giving 9 samples per transect. Therefore, a total of 36 samples were collected from the 4 degradation levels.

b) A thin top layer of about 5 cm of the surface soil layer was carefully removed from each sampling point to eliminate the litter.

c) For each selected sampling point, composite soil samples were collected at three soil depths, 0-15 cm 15-30, and 30-60 cm, using a post hole soil auger (Junbao *et al*., 2013; Mugagga *et al*., 2015) since carbon profiles rapidly decrease with soil depth in tropical wetlands (Bernal, 2008; Villa, 2014). It may not be possible to obtain soil samples beyond 60 cm due to the high ground water table in wetland soils.

d) Composite sample from three soil cores per sampling point was taken to include a variation in organic matter deposition in the area (Bernal, 2008) using auger (soil sampler) by carefully inserting the corer in to the soil up to 60cm depth (Hairiah *et al*., 2001). Soil samples were taken from the same sites where plant samples were previously collected for consistency. Each soil sample was placed in plastic zip-lock bags, carefully labeled and transported for laboratory analysis in ice boxes cooled at 4°C to suspend microbial activity and volatilization of labile carbon.

3.7 Laboratory analysis and procedures

3.7.1 Plant sample analysis

Plant samples collected from the field were analyzed for the estimation of the aboveground biomass (AGB) and aboveground plant organic carbon as shown in sections **3.6.1.1** and **3.6.1.2**.

3.7.1.1 Plant above ground biomass

a) Immediately after arrival from field, fresh subsamples were oven dried at 80^{o}c for 24 hours for conversion to dry weight biomass.

b) Above ground biomass (AGB) was obtained based on the following calculation.

c) AGB Total dry weight (kg m^{-2}) =

$$\frac{\text{Total fresh weight (kg) x Subsample dry weight (g)}}{\text{Sub sample fresh weight (g) x Sample area } (m^2)} \quad \ldots\ldots 3.3$$

(after Hairiah *et al*., 2001)

3.7.1.2 Plant organic carbon

a) Air-dried samples at room temperature were crushed to pass through a 2 mm sieve and sub-samples taken for carbon stock analysis.

b) Sub-samples were oven dried at 105^{o}c for 48 hours and weighed.

c) Organic matter was determined using ignition method by burning the oven dried samples at 550^{o}c for 4 hours (Kalra and Maynard, 1991; Yohannes Afework, 2013).

d) Once organic matter was determined, then organic carbon was obtained by converting the resulting organic matter using a conversion factor of 45%. On average 45% of the total organic matter (OM) for plant samples is carbon stock (USDA, 2007).

3.7.2 Soil sample preparation and analysis

The soil samples were transported to the Soil, Plant and Water Analytical Laboratory at the Department of Agricultural Production – College of Agricultural and Environmental Sciences – Makerere University. In the laboratory, the samples were dried at 25^{o}C for five days to eliminate moisture. Thereafter the samples were ground using porcelain pestle and mortar and sieved through a 2 millimetre sieve to remove debris and other non-soil materials including stones and roots. The sieved soil samples were repackaged, and clearly relabelled.

3.7.2.1 Physico-chemical parameters

Physical and chemical parameters including bulk density, soil pH, soil organic matter and carbon, electrical conductivity, soil texture and moisture content, total nitrogen, available phosphorus, Potassium, Calcium, Magnesium and sodium of the soil was determined following (Kalra and Maynard, 1991; Okalebo *et al.*, 2002). Soil temperature was recorded on site up to the depths of 60 cm (where the soil sample was taken) at sampling time using soil thermometer.

Each of the above soil properties was specifically analysed by particular analytical method and procedures as follows; Soil pH and electrical conductivity were measured in a soil-water solution at a ratio of 1:2.5 by the help of a pH and conductivity meters respectively (digital HACH multi parameter meter (HQ40d model); Total Nitrogen (N) determined calorimetrically following a digestion using concentrated sulphuric acid and Selenium powder plus Salicylic acid. Available phosphorus content was determined spectrophotometrically at 882 nm wavelength after its reaction with ammonium molybdate in the presence of ascorbic acid, (Murphy and Riley, 1962). Organic matter was analysed using the Walkley - Black method, exchangeable Potassium (K) sodium (Na) and Calcium (Ca) were read on Mehlich 1 extracts using a flame photometer. Exchangeable magnesium (mg) was determined on the mehlich 1 extract using an atomic absorption spectrophotometer. For each analysis, a reference sample and blanks were repeatedly included for quality control and assurance.

3.7.2.2 Soil bulk density estimation

Intact soil core samples were oven dried to constant weight at 105 ^{o}C for about 48 hours and cooled in a desiccator before their dry weights are taken. The dry weights obtained were divided by the calculated volume of the cylinders that contained the samples as illustrated by (Okalebo et al., 2002).

3.8 Estimation of total carbon sequestered in each land use type/degradation level

Total carbon sequestered in soil per hectare was determined by calculating the volume of soil using bulk density (Yu*et et al.,* 2012). To calculate the total carbon stock per unit area of sampling unit, the sum of carbon content found in plant and soil was taken. Finally, the total carbon sequestered in each land use type/degradation level was calculated in the form of CO_2 equivalent (i.e. ton CO_2 equivalent) following Zerihun *et al*., (2011): CO_2 equivalent = Carbon stock in ton/ha x 44/12. Positive values represent uptake, while negative values indicate carbon loss from the biome (Shuqing Zhao *et al.*, 2013).

The following formula according to Pearson *et al., (*2005) was used to calculate the amount of carbon sequestered in the soil from the different degradation levels.

$$C\ (t/ha) = \frac{(10000m^2 \times BD\ (kg/m^3) \times D\ (m) \times C(g/kg))}{1{,}000{,}000} \quad \text{……………………………..……3.4}$$

Where; C(t/ha) is carbon in tons per hectare

D is the depth of the soil

BD is the soil bulky density

C is the soil organic carbon

The following formula according to Pearson *et al., (*2005) was used to calculate the amount of carbon sequestered in the plants from the different degradation levels.

$$C\ (t/ha) = \frac{C(\frac{g}{m^2})}{100} \quad \text{……………………………………………………………………………3.5}$$

Where, C(t/ha) is carbon in tons per hectare

C (g/m2) is the plant organic carbon

3.9 Analysis of soil and plant data

To analyze the data descriptive statistics was used. One-way Analysis of variance (ANOVA) was performed to detect the significant differences in the organic carbon content of the different wetland degradation levels. Results of organic carbon content where then used to calculate carbon sequestration potential within the different degradation levels of wetland described. Genstat analysis was also performed to show significant differences in the physio-chemical parameters among the described wetland degradation levels.

3.10 Analysis of digital data (satellite images) to show degradation levels

Following the extraction of LULCC maps through satellite imagery classification for the years; 1988, 1995, 2001, 2010 and 2018 Landsat imagery, the boundary of Lubigi wetland was digitized including boundaries of areas occupied by each degrading activity such as farming, road networks, and housing in order to calculate areas (ha) they occupy using spatial analysis tools in GIS. The years were selected basing on the availability of data and 10 year intervals in between the selected years was key for generating sufficient information. Geographical coordinates were collected during the ground-thruthing exercise for image accuracy classification. The standard error matrix was used for accuracy assessment. The outputs of the analysis of trends in LULCC changes were various maps depicting LULCC changes over time which also informed on the drivers of changes in land use and land cover accordingly.

3.11 Accuracy Assessment of digital data

To use, GIS tools to estimate the lost areas covered by different activities, accuracy assessment was done using a point-based approach. This was aimed at assessing the accuracy of the map classes (bareland, cultivated land, thick vegetation, and thin vegetation), with one or more evaluation points representing each map class. The map represents vegetation types using one or more polygons per type. Points were selected from within those polygons using a stratified random sampling design, so that points were distributed across all map classes with a higher number of points placed within map classes with large areas.

Data analysis for the accuracy assessment consisted of creation of contingency tables which summarize misclassification rates for each land cover type, calculation of user's and producer's accuracy for each land cover type, and evaluation of the overall accuracy of the map using the kappa statistic (Cohen, 1960).

The overall accuracy was computed by dividing the total correctly classified pixels (the sum of the major diagonal elements) by the total number of pixels in the error matrix.

3.12 Analysis of data from respondents

Descriptive statistics were used to analyse relationships in the primary data obtained from respondents.

CHAPTER FOUR: PRESENTATION OF RESULTS

4.1 Spatial and temporal trends in land use and land cover changes (LULCC)

To determine spatial and temporal trends in land use and land cover changes in Lubigi wetland, the collected data sets were manipulated using GIS tools to obtain the required results. The results are represented in form of maps, graphs and tables.

4.1.1 Land cover maps

The land cover maps obtained from the classification of the 1988,1995,2001, 2010 and 2018 Landsat imagery have five classes which include: Open water, Thick vegetation, Thin vegetation, Bare land and Built up.

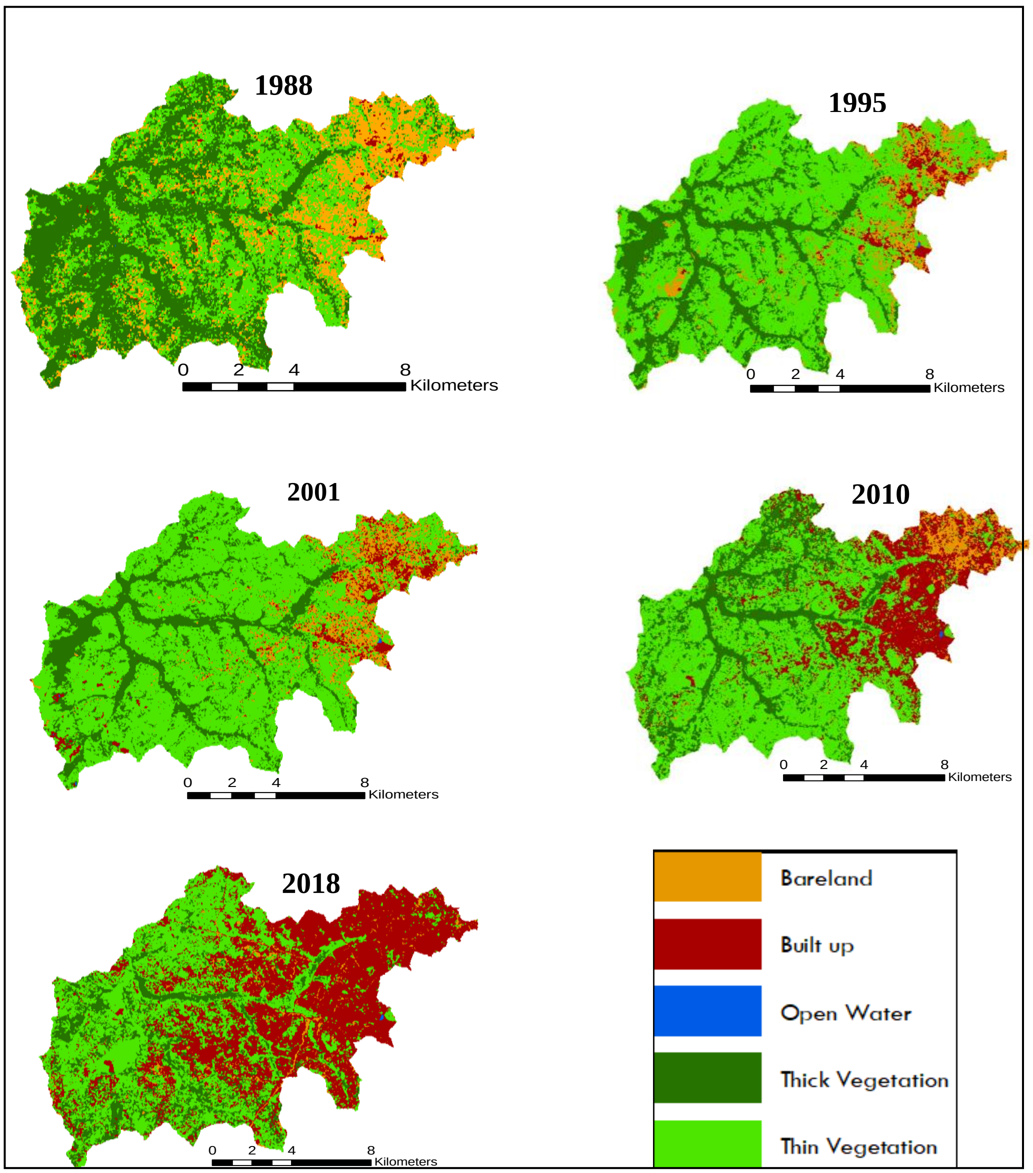

Figure 4.1 Classified land cover maps of 1988, 1995, 2001, 2010 and 2018

4.1.2 Accuracy Assessment

To use, GIS tools to estimate the lost areas covered by different activities, accuracy assessment was done using a point-based approach as described in section 3.11 above. This was aimed at assessing the accuracy of the map classes (bare land, cultivated land, thick vegetation and thin vegetation) with one or more evaluation points representing each map class. The map represents vegetation types using one or more polygons per type as described in details in section 3.11 above. Table 4.1 below presents the accuracy results of the classified images for the different time periods.

Table 4.1: Results for accuracy assessment

Sensor	Acquisition date	Classified image	Over all accuracy (%)	Kappa Statistics (%)
Landsat-4-MSS	12/3/1988	1988	78	72
Landsat-5-TM	19/01/1995	1995	93.3	92
Landsat-7-EMT+	27/11/2001	2001	87	83
Landsat-5-TM	28/01/2010	2010	86.6	83
Landsat 8	3/2/2018	2018	92.2	90

The overall accuracies of all images was within allowable limits hence giving a good result for remote sensing image based analysis as also given in Herold *et al*., (2005).

4.1.3 Land cover distribution

4.1.3.1 Catchment area

Basing on the results presented in section 4.1.1 and 4.1.2, the areas in hectares occupied by the different land cover classes over the different years were computed. Results are as shown in the table 4.2 below.

Table 4.2: Land cover distribution in catchment between 1988 - 2018

Class	Area_Ha(1988)	Area_Ha(1995)	Area_Ha(2001)	Area_Ha(2010)	Area_Ha(2018)
Bare land	5998.17	4904.07	5482.9	2346.42	1938.82
Built up	329.29	886.17	1214.46	8886.03	15869.48
Open Water	2.76	4.35	7.59	7.77	4.66
Thick Vegetation	13659.4	10199.54	8930.7	8014.93	5234.22
Thin Vegetation	11660.05	15655.54	16014.01	12394.5	8602.48
Total	**31649.66**	**31649.66**	**31649.66**	**31649.66**	**31649.66**

The catchment area within the study area is equivalent to 31,649.66 Hectares. The table showed that there was a consistent reduction in thick vegetation area from 1988 to 2018. Whereas there was increasing trend in built up and thin vegetation areas from 1988 to 2018.

Basing on the results presented in section 4.1.3.1, the percentage land cover distribution in wetland was computed as shown in table 4.3 below.

Table 4.3: Percentage land cover distribution in the wetland

Class	(%) 1988	(%) 1995	(%) 2001	(%) 2010	(%) 2018
Bare land	18.95	15.49	17.32	7.41	6.13
Built up	1.04	2.8	3.84	28.08	50.14
Open Water	0.01	0.01	0.02	0.02	0.01
Thick vegetation	43.16	32.23	28.22	25.32	16.54
Thin vegetation	36.84	49.47	50.6	39.16	27.18

Results in table 4.3 above indicated that there was a consistent decline in percentage land cover distribution in the thick vegetation to the expense of other land use classes.

4.1.3.2 Wetland area

In this study, the area covered by each land cover was calculated using the data on the wetland boundary within the catchment extracted from the 1994 wetland boundary layer.

The wetland area within the study area is equivalent to 4,656.29 Hectares. The land cover distribution of wetland is presented graphically in **Figure 4.2**.

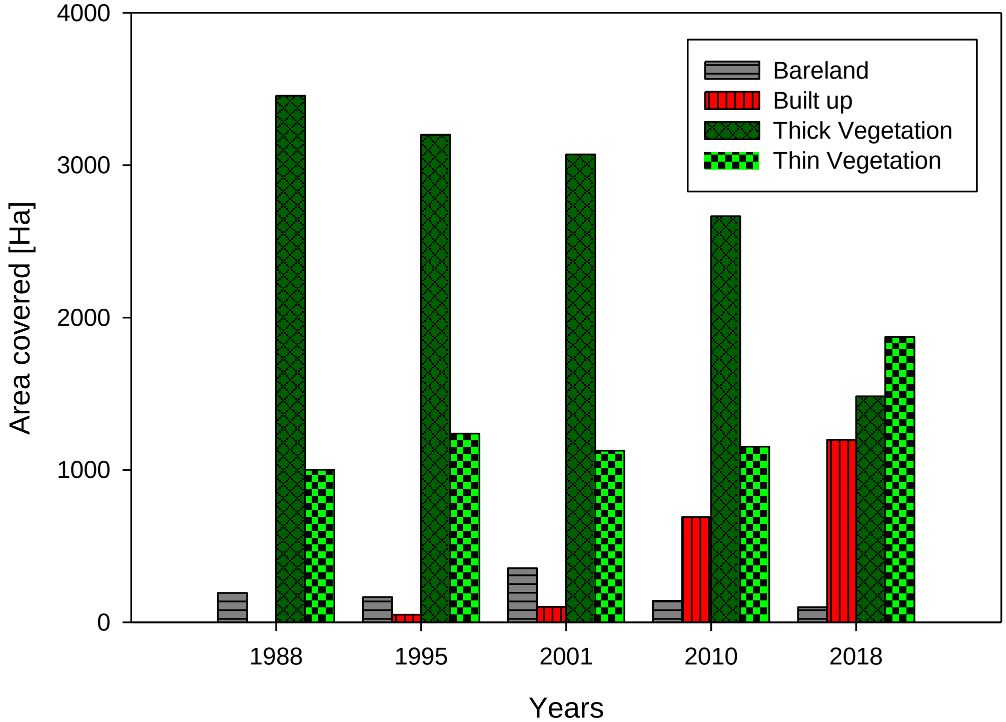

Figure 4.2 Land cover distribution in the wetland over the years.

Over the study period (1988 – 2018), thick vegetation progressively lost its area to other land use types namely; Bare land, built up area, and thin vegetation. Built up area progressively increased over the years with thin vegetation taking over thick vegetation in 2018.

4.1.4 Change detection

4.1.4.1 Catchment area

From the observed changes in figure 4.3, there were no areas that changed from built up to any other land cover class. This is because it is unlikely for developers to break down buildings to replace them with other uses for example a football pitch.

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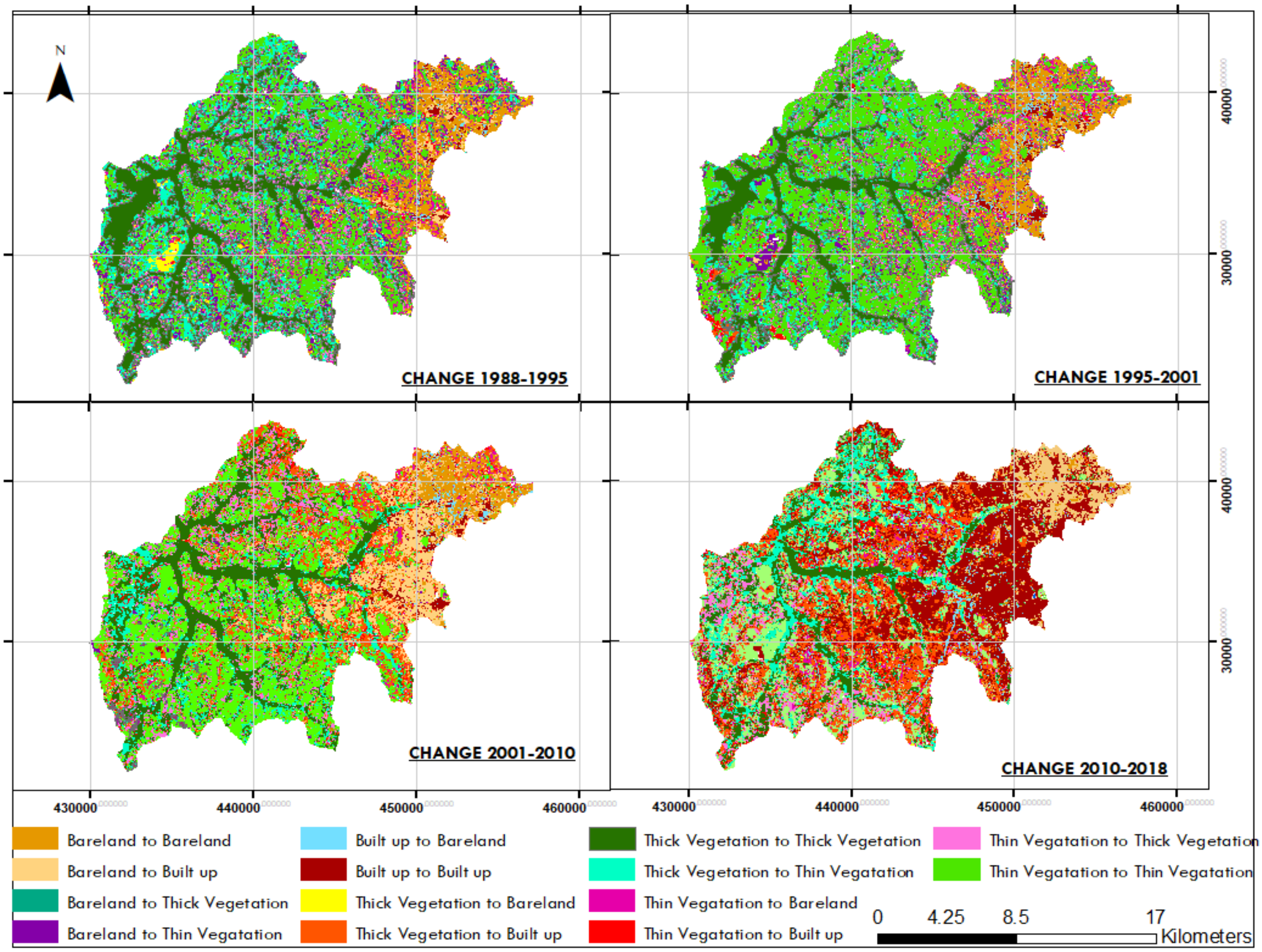

Figure 4.3: Change within catchment area.

4.1.4.2 Wetland area

Within the wetland area, there is a significant drop in the thick vegetation areas over the years. The areas which remained thick vegetation are represented using dark green colour. There is also an evident increased extent of the built-up areas represented with maroon within the wetland (figure 4.4).

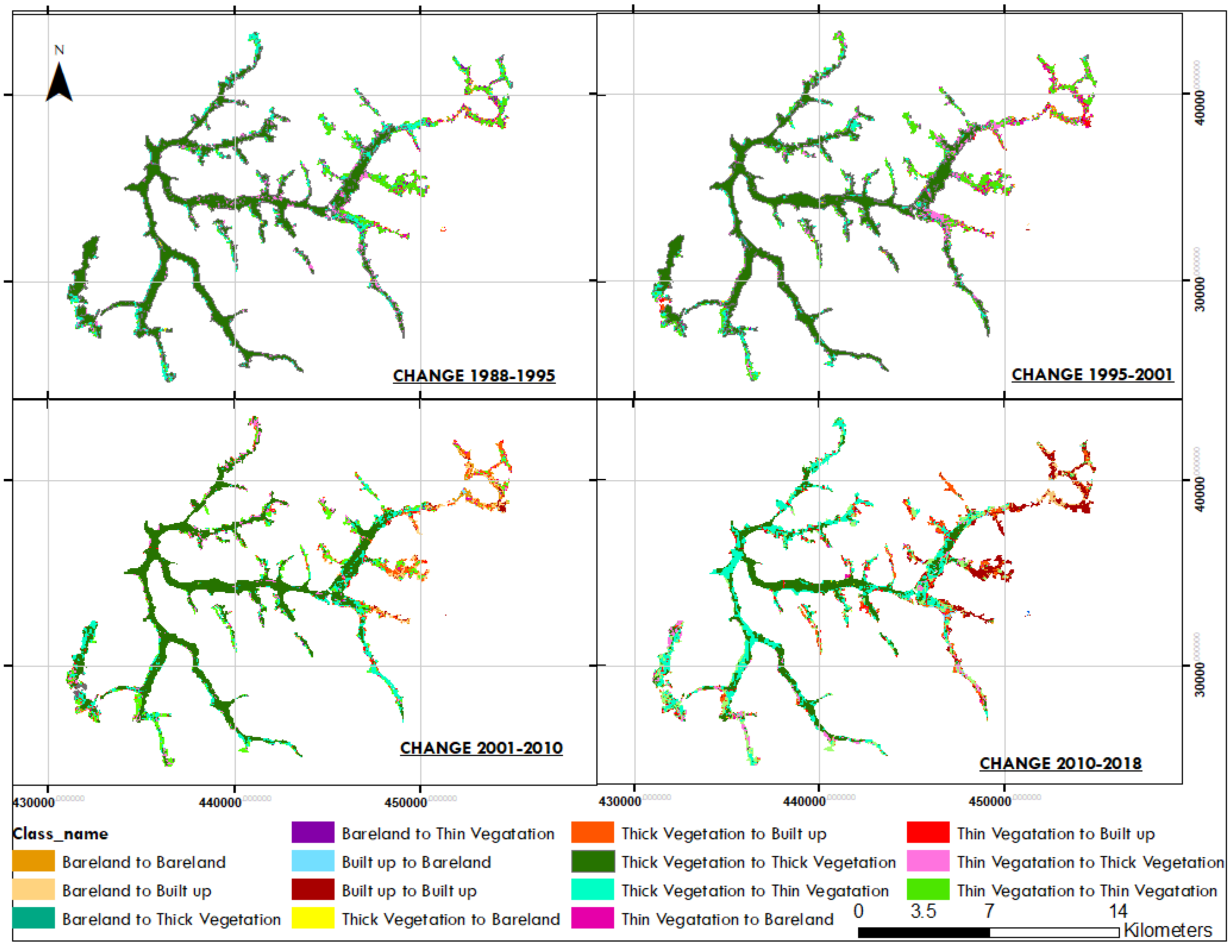

Figure 4.4: Change within the wetland.

4.1.4.3 Percentage change in wetland area

Deeper analysis of change detection in wetland was by computing percentage change in areas over the study periods. Figure 4.5 further shows change detection in the Wetland. In 1988 – 1995, the percentage change in bare land and thick vegetation was negative. The same change was more pronounced in 2010 – 2018 where original wetland area in form of thick vegetation was lost to build up and thin vegetation.

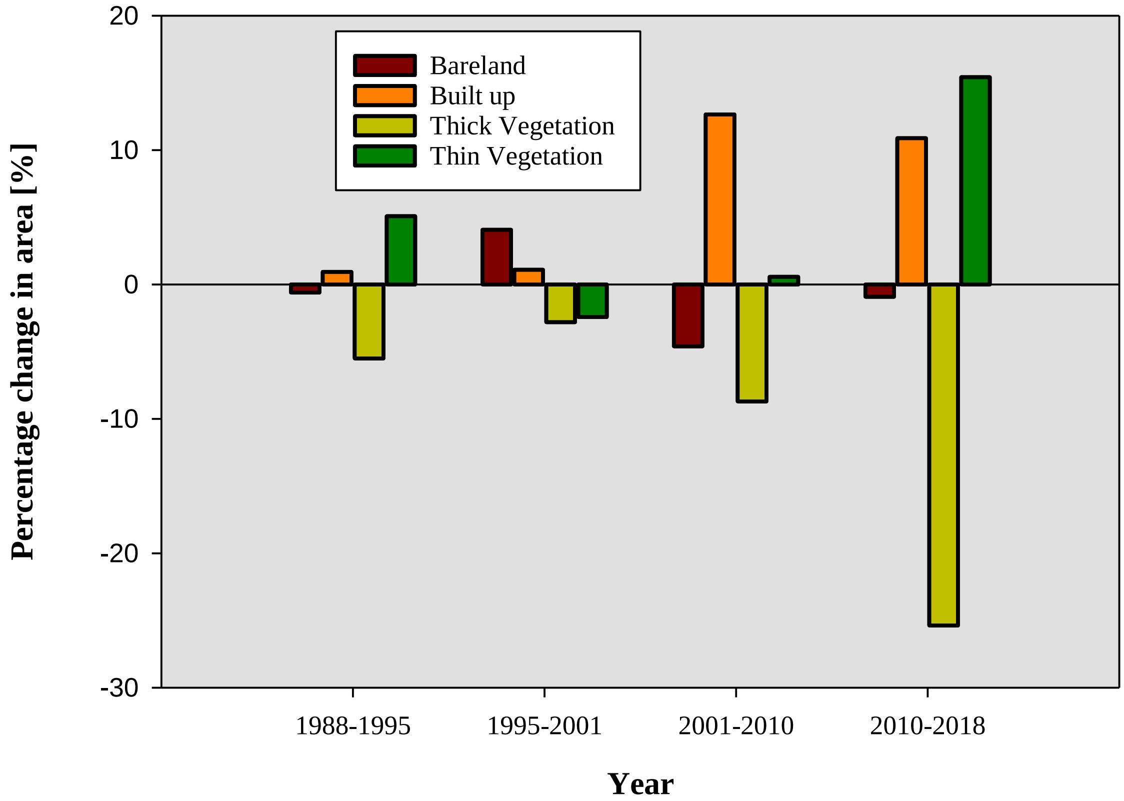

Figure 4.5 Gains and losses in wetland area

4.2 To relate carbon stocks below ground and above ground vegetation biomass across different degradation levels of wetland

4.2.1 Above ground vegetation biomass

Above ground biomass (AGB) was obtained based on the following formula.

$$AGB\ Total\ dry\ weight\ \left(\frac{g}{m^2}\right)$$

$$= \frac{Total\ fresh\ weight\ (g)\ \times\ subsample\ dry\ weight(g)}{sub\ sample\ fresh\ weigh(g)\ \times\ samplearea\ (m^2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ equation\ 4.1$$

According to (Hairiah *et al*., 2001)

The above ground vegetation biomass was computed and results presented in table 4.4.

Table 4.4 above ground biomass of the different wetland degradation levels

Degradation levels	Total fresh weight (g)	Average fresh weight/g of sub samples (g)	Average Dry weight/g of sub samples (g)	*AGB (g/m^2)
Thin vegetation	317.43	105.81	26.88	80.64^a
Cultivated	479.58	159.86	30.45	91.35^b
Thick vegetation	590.74	196.91	50.88	152.64^c

*AGB (Above Ground Biomass), sample area of quadrant = $1m^2$

Means followed by the same number are not significantly different (P>0.05; F=0.048)

Above ground biomass of the sites varied from 80.64 g/m^2 to 152.64g/m^2 and the highest value of above ground biomass was recorded at the thick vegetation wetland site followed by cultivated area and thin vegetation area which accounted for 91.35 g/m^2 and 80.64g/m^2 respectively (table 4.4).

4.2.2 Soil carbon stocks in relation to the above ground biomass

In this study, the soil carbon stocks generally had a high positive but insignificant correlation with the aboveground vegetative biomass (r = 0.8731, p = 0.1269). Figure 4.6 below shows the percentage organic carbon and percentage aboveground biomass against the various wetland degradation levels.

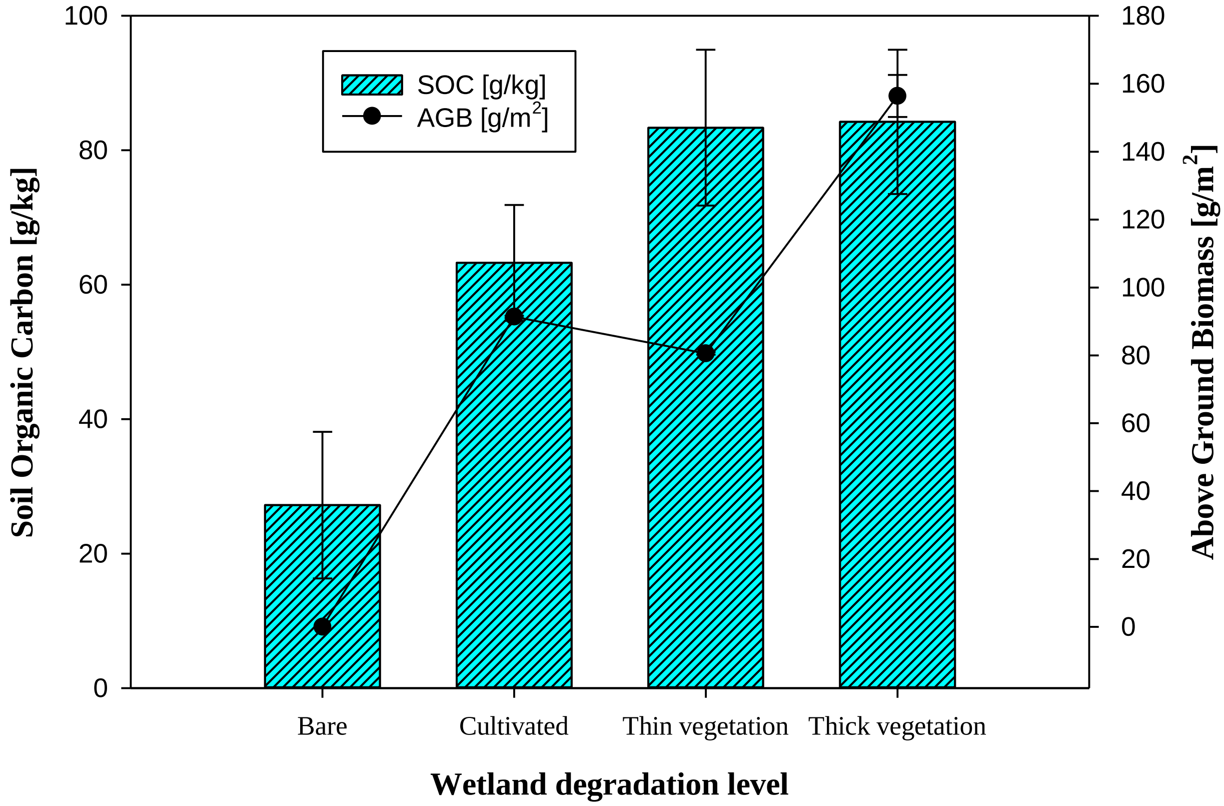

Figure 4.6 Soil carbon stocks in relation to the above ground biomass

As the aboveground biomass increases from bare, thin vegetation, cultivated to thick vegetation wetland, the soil carbon content also increases. The cultivated area, compared to the thin vegetation area, had a higher aboveground biomass and yet a lower soil organic carbon. The bare site had no aboveground biomass and hence had the lowest soil carbon stocks.

4.3 To establish the relationship between selected soil physico-chemical parameters and soil carbon stocks

4.3.1 Selected soil physico-chemical parameters

Pysico-chemical parameters are known to have an impact on soil organic carbon stocks, and some have been highlighted to be more important. Based on this, the relationships between the following physico-chemical parameters and organic carbon (OC) were studied and these included N %age, Av. P (mg/kg), Ca (Cmoles/kg), Mg (Cmoles/kg) and Temperature (^{0}C) among others.

4.3.1.1 Nutrients P and N

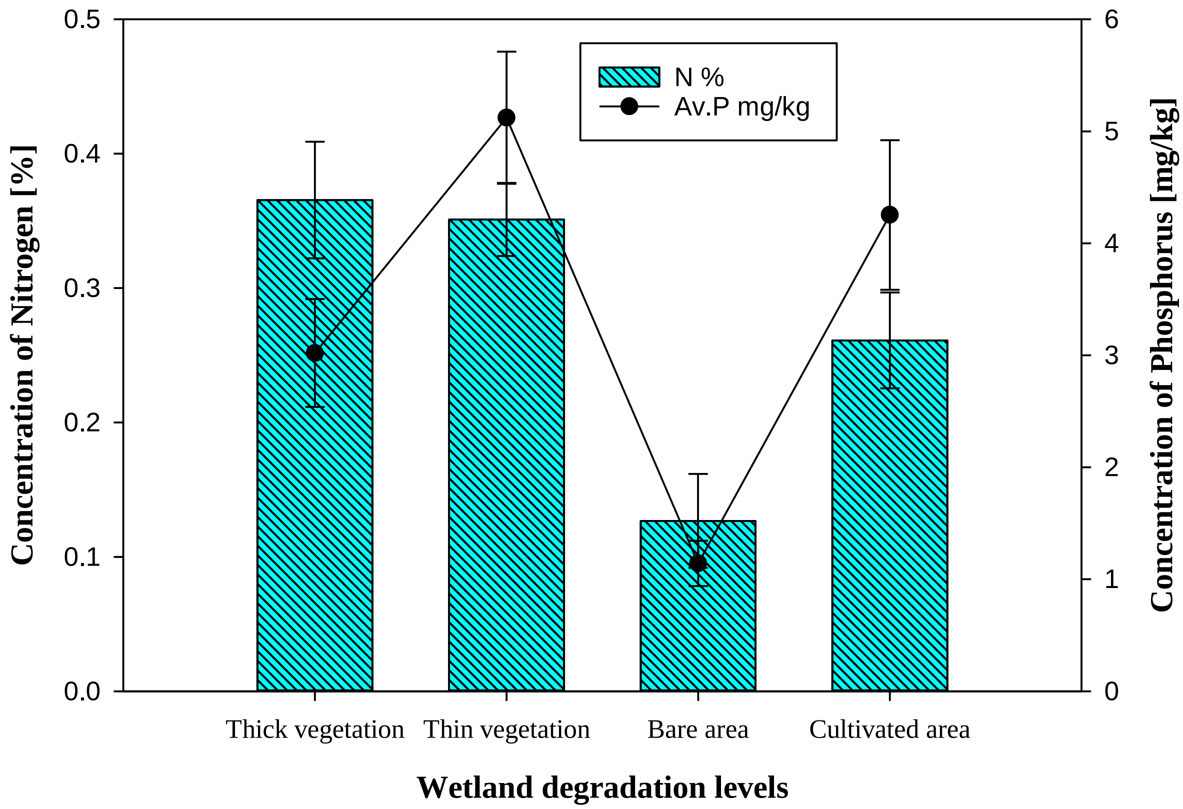

Figure 4.7 Soil N and P across the wetland degradation levels.

Thick vegetation of the wetland had the highest mean percentage of nitrogen (0.366±0.052) whereas bare land had the least mean percentage (0.127±0.0521). Thin vegetation had the highest mean of Av. P (5.121±0.507 mg/kg) and bare ground had the lowest (1.141±0.507 mg/kg).

4.3.1.2 Temperature and pH

Bare ground had the highest mean of temperature recorded and undisturbed had the least temperature mean (21.778±0.589 and 16.667±0.589 ^{o}C respectively). Soil temperature increased as degradation level of the wetland increased (Undisturbed < Grass cut area < Cultivated < Bare). The highest pH mean value was recorded at Cultivated (5.989±0.351) and the minimum PH in the undisturbed wetland (5.133±0.351) as shown in table 4.5 below.

Table 4.5 Mean values of Temperature and pH across the wetland degradation levels

Degradation level	Temperature (^{o}C)	pH
Bare	21.778^{a}	5.922
Cultivated	18.667^{b}	5.989
Thin vegetation	18.111^{ab}	5.344
Thick vegetation	16.667^{abc}	5.133
LSD	1.204	0.718
P-Value	<0.001	0.051
Standard error	0.589	0.351

Means followed by the same number are not significantly different (P>0.05; F=0.051)

4.3.1.3 K, Mg, Na and Ca

Calcium in the degradation levels varied from 7.099±0.440 to 6.063±0.440 Cmoles/kg with cultivated having the highest mean and undisturbed with the lowest respectively. Means for Mg vary from 1.247±0.188 to 1.754±0.188 Cmole/kg with cultivated having the highest and grass cut area the lowest. There was no significant difference in potassium and sodium amongst the different wetland sites.

Table 4.6 Mean values of K, Na, Ca and Mg in the study sites.

Degradation level	K	Na	Ca	Mg
Bare	0.467	0.119	6.993^{b}	1.674^{b}
Cultivated	0.376	0.109	7.099^{a}	1.754^{a}
Thin vegetation	0.354	0.118	6.207^{abc}	1.247^{c}
Thick vegetation	0.406	0.101	6.063^{c}	1.420^{d}
LSD	0.204	0.062	0.890	0.384
p-value	0.726	0.928	0.049	0.042
Standard error	0.104	0.030	0.440	0.188

Means followed by the same number are not significantly different ($P>0.05$; $F=0.49$)

4.3.1.4 BD and Ksat

The soil BD and Ksat were not significantly different between the wetland degradation levels. However, the thick vegetation had the highest Ksat (6.116±4.590 mm/hr) while Bare land had the lowest Ksat value (1.480±4.590 mm/hr). The highest BD was observed in cultivated area (1.356±0.029 g/cm^3) followed by thick vegetation (1.350±0.029 g/cm^3), thin vegetation (1.333±0.029 g/cm^3) and then Bare area (1.322±0.029 g/cm^3) as shown in figure 4.8 below.

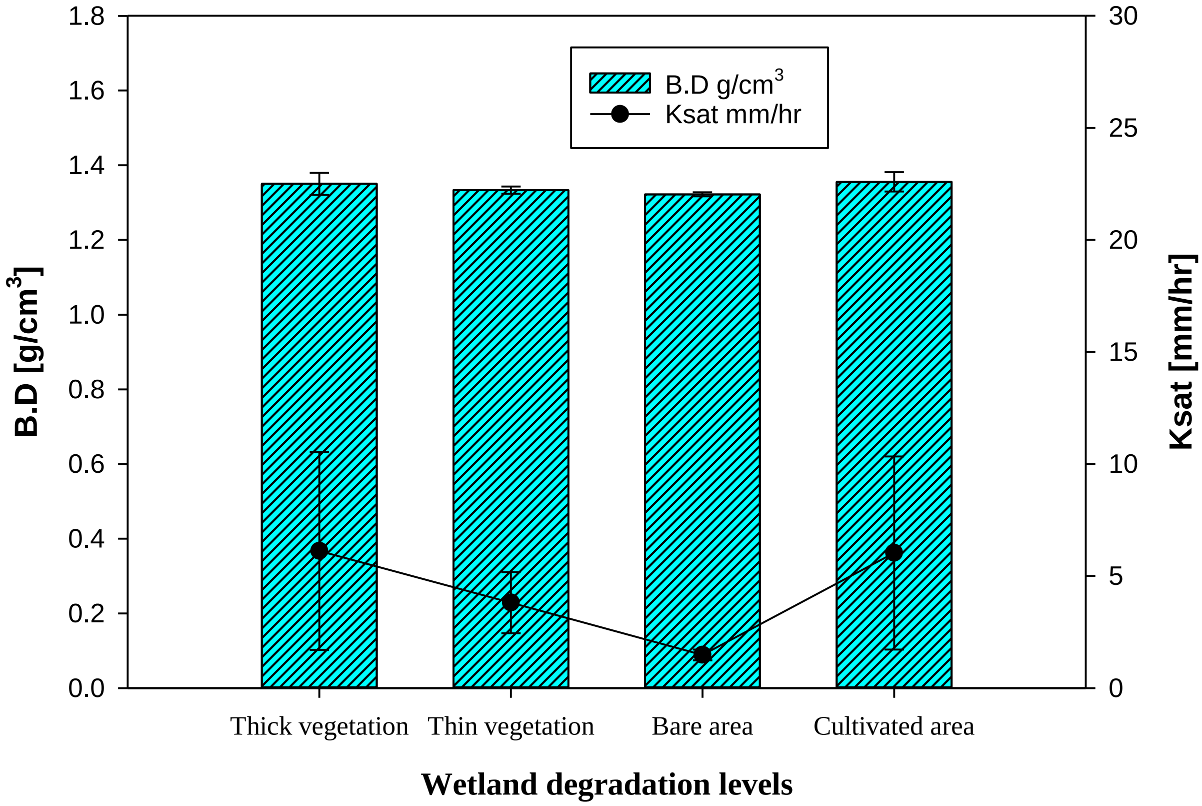

Figure 4.8 Soil BD and Ksat across the different wetland degradation levels.

4.3.2 Correlation analysis between carbon and selected physico-chemical parameters

The correlation between soil carbon and selected physico-chemical parameters was analyzed using SPSS software and results are presented in table 4.7 below to establish which physico-chemical parameters have a significant correlation (relationship) with carbon at 5% level of significance.

Table 4.7 showing correlation between carbon and selected physico-chemical parameters

Parameter	Pearson Correlation coefficient (r)	P-value
PH	-0.12	0.50
OM (%)	1.00	0.00*
N (%)	0.87	0.00*
P (mg/kg)	0.62	0.00*
K (Cmoles/kg)	-0.13	0.47
NA(Cmoles/kg)	0.04	0.80
Ca (Cmoles/kg)	-0.09	0.59
Mg (Cmoles/kg)	-0.03	0.84
Sand (%)	-0.08	0.63
BD (g/cm3)	0.08	0.66
Clay (%)	0.00	0.99
Silt (%)	0.05	0.79
KSAT (mm/hr)	0.09	0.59
Temp (^{o}c)	-0.33	0.05

*correlation is significant

Results in table 4.7 above indicated that OM, N and P are significant and positively correlated with carbon at 5% level of significance since all their p-values(0.00*,0.00*,0.00*) respectively are less than 0.05 and their correlation coefficients (1.00, 0.87, 0.62) indicated positive relationships between C and OM, N and P. Other variables like temperature, had a negative correlation while others like Clay were not correlated at all.

4.3.3 Regression analysis between carbon and selected physico-chemical parameters

After running a correlation analysis as shown in table 4.6, the above findings revealed that OM, N and P are the only variables with a significant correlation ($p<0.05$) with C at 5% level of significance.

A step wise regression was run since stepwise regression using SPSS automatically in background does multiple regression a number of times, each time removing the weakest correlated variable **(**physico-chemical parameter) and at the end leaving the variables that best explain the dependency between C and OM, N and P.

Therefore, a stepwise regression analysis was run using SPSS to determine which of the following (OM, N and P) had the greatest effect on C. Table 4.8 indicates that these 3 variables (OM, N and P) fully explain the variation in C, as indicated by R^2-value(1.000) which is interpreted at 100% indicating full dependency of C on OM,N and P and this is significant at 5% level of significance since the p-value (0.00327) is less than 0.05($p<0.05$).

Table 4.8 shows variation in C as indicated by R^2 value

R	R Square	P vale
1.000 [a]	1	0.00327

To determine which among OM, N and P has the greatest effect on C, the step wise regression produced the results in table 4.9 below starting with the variable which has the most significant effect (OM) and then excluding the variables with the weakest effect (N and P).

Table 4.9 shows the most significant variable on C

Parameter	Coefficient	P value
Constant	0	0.001
OM	0.58	0

The table 4.9 shows that the Coefficient for OM (0.580) indicates that a unit increase in OM will on average lead to a 0.58 increase in C and this is significant at 5% level of significance since the p value(0) is less than 0.05 ($P<0.05$). OM therefore, had the most significant effect on C.

The table 4.10 shows the variables that SPSS excluded automatically while running a stepwise regression as having the weakest effect on C.

Table 4.10 shows a stepwise regression analysis on OM, N and P

Nutrient	Coefficient	P value
N	0.055	0.753
P	0.235	0.175

The table 4.10 above indicates that a stepwise regression analysis excluded N and P because their effect on C was not significant as shown by the P-Values (0.753 and 0.175) respectively which are greater than 0.05 at 5% level of significance. Thus N and P indeed have the weakest effect on C.

4.4. To determine carbon sequestration potentials across different degradation levels of wetland.

Carbon sequestration potentials

4.4.1 Plant organic carbon

The plant organic carbon content of the study sites varied from 176.3 g/m^2 to 299.3 g/m^2. Highest mean plant organic carbon content was obtained in the thick vegetation site followed by thin vegetation, and finally cultivated area (sweet potatoes) where plant organic carbon was 287.1, 229.5 and 191.8 g/m^2, respectively (Figure 4.9). The bare site did not have any data because it did not have plants on it.

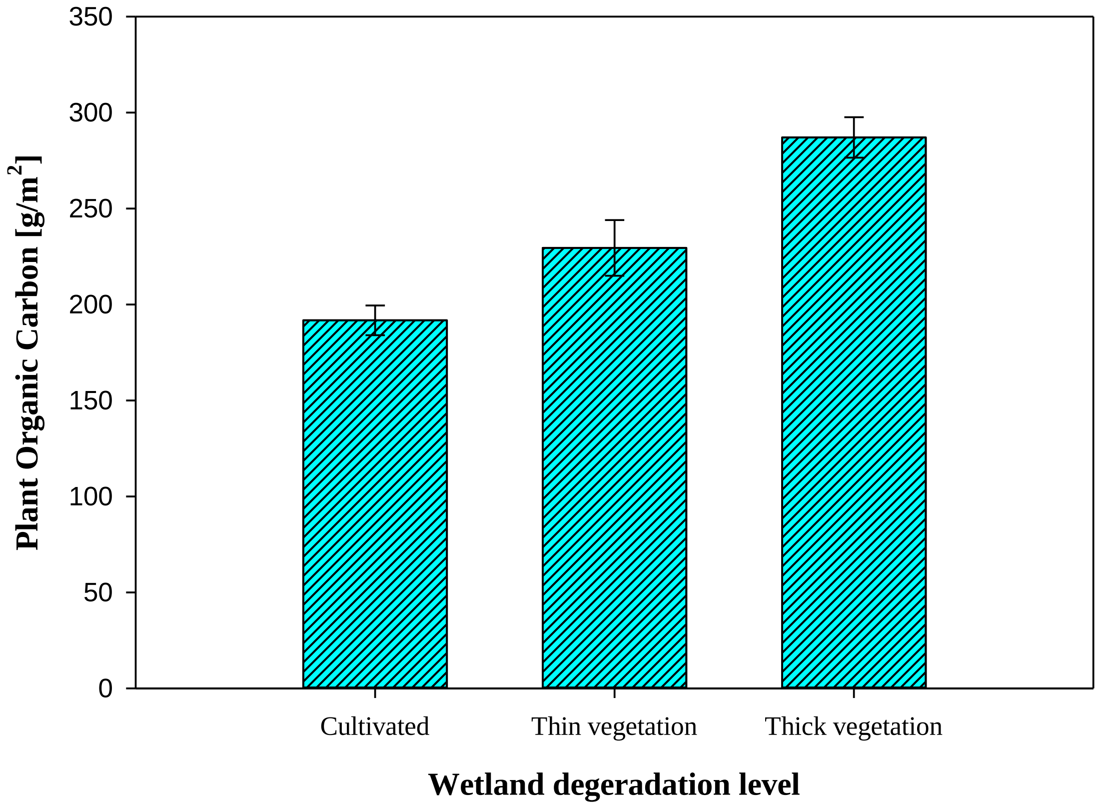

Figure 4.9 Mean aboveground plant carbon content of different wetland degradation categories.

4.4.2 Soil organic carbon

The mean organic carbon content showed a gradual increase from bare land, cultivated, grass cut area to undisturbed area. The highest mean organic carbon content (g/kg) was obtained in the thick vegetation wetland area which was about 84.2 g/kg, followed by grass cut area, cultivated area and bare land which contained 83.4, 63.3 and 27.2 g/kg respectively, (Figure 4.10).

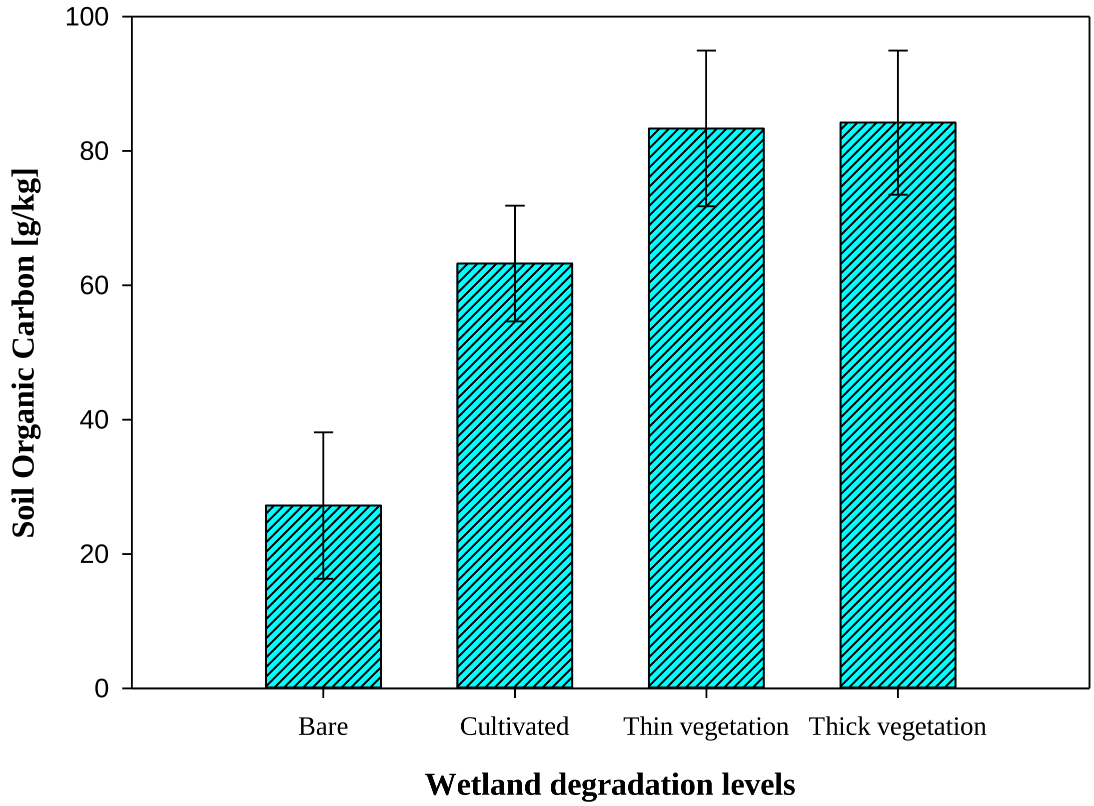

Figure 4.10 Mean soil organic carbon content of different wetland categories.

The analysis of variance showed that there was a significant difference in the organic carbon stocks/content between the different wetland degradation levels ($p<0.05$) much as thin vegetation area and thick vegetation area did not have any significant difference in organic carbon content (Figure 4.10). The thick vegetation wetland had the highest organic carbon content because of the very good and healthy stand of vegetation cover during plant sampling period and also due to the fact that the soil is intact so the sequestered carbon is not exposed to factors that releases them from the soil.

4.4.3 Calculating carbon sequestration potential

To calculate the total carbon stock per unit area of sampling unit, the sum of carbon stocks found in plant and soil were determined. The amount of carbon sequestered in the soil from the different degradation levels was calculated using formula according to Pearson *et al., (*2005) provided in equation 3.3 in section 3.8 above. The results are presented in table 4.11 below.

Table 4.11: Carbon sequestration potentials in soil

levels of degradation	OC(g/kg)	B.D (kg/m^3)	Depth (m)	C (tons/ha)	**CO_2 equivalent
Bare area	27.18	1322	0.45	161.69^a	592.86^a
Cultivated area	63.26	1356	0.45	386.01^b	1415.37^b
Thin vegetation area	83.37	1333	0.45	500.09^c	1833.66^c
Thick vegetation area	84.23	1350	0.45	511.70^c	1876.23^c

Means followed by the same number are not significantly different (P>0.05; F<0.001)

Likewise, the amount of carbon sequestered in the plant from the different degradation levels was calculated using formula according to Pearson *et al., (*2005) provided in equation 3.4 in section 3.8 above. The results are presented in table 4.12 below.

Table 4.12: Carbon sequestration potentials in plants

Level of degradation	OC (g/m^2)	C (t/ha)	**CO_2 equivalent
Cultivated area	191.8^a	1.92^a	7.04^a
Thin vegetation area	229.5^b	2.3^b	8.43^b
Thick vegetation area	287.1^c	2.87^c	10.52^c

Means followed by the same number are not significantly different (P>0.05; F<0.001)

Finally, the total carbon sequestered in each land use type in the wetland was calculated in the form of CO2 equivalent (i.e. ton CO2 equivalent) following Zerihun *et al*. (2011). Results are presented in table 4.13 below.

Table 4.13: Sum of carbon stocks in plants and soil and their CO_2 equivalent

Wetland degradation level	Sum C (t/ha) in soil and plants	Sum**CO_2 equivalent (Tons) in soil and plants
Bare area	161.69[a]	592.86[a]
Cultivated area	387.93[b]	1422.41[b]
Thin vegetation	502.39[c]	1842.1[c]
Thick vegetation	514.57[c]	1886.77[c]

**CO_2 equivalent = C (tons/ha)*44/12 (zerihun et al., 2011)

Means followed by the same number are not significantly different (P>0.05; F<0.001)

The amount of sequestered carbon in tons/ha in the wetland was highest in the thick vegetation wetland (514.57 tons/ha) and lowest in the bare area (161.69 tons/ha) as shown in table 4.13 above. There was a significant difference ($p<0.001$) in the carbon stored between the wetland degradation levels. CO_2-equivalent was used to quantify the amount of carbon sequestrated in the form of carbon dioxide in the atmosphere. The CO_2-equivalent for bare land, cultivated land, thin vegetation area, and thick vegetation area was: 592.86, 1,422.41, 1,842.1, and 1,886.77 t/ha, respectively as shown in table 4.13 above. There was a significant difference ($p<0.001$) in the carbondioxide equivalent between the wetland categories. Figure 4.11 describes how the sequestered carbon relates with its carbondioxide equivalent.

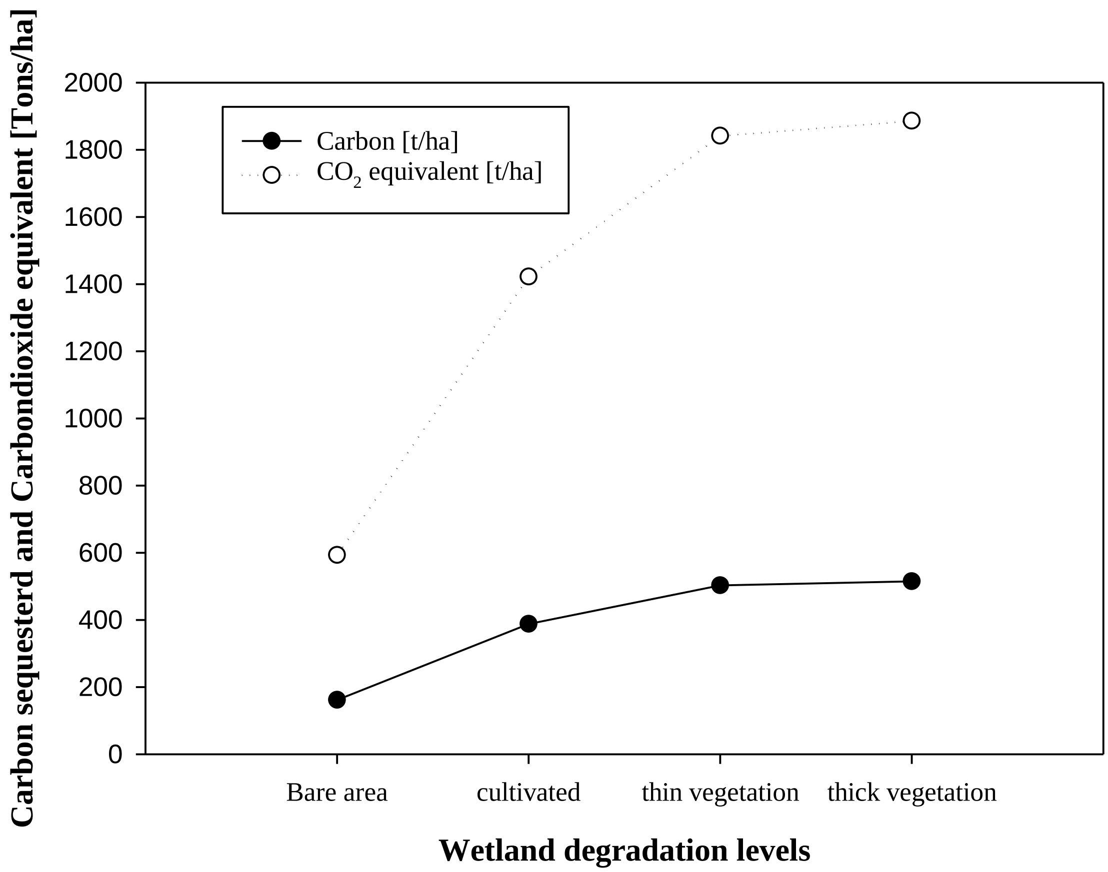

Figure 4.11: carbon sequestration potential and carbon dioxide equivalent trend in tons/ha

Similar to the trend of total organic carbon in the soil, the amount of CO_2-equivalent sequestrated in the thick wetland was more than double the amount of CO_2-equivalent sequestrated in bare land.

4.4.4 Yearly carbon sequestration potentials of different Land use land cover types

Yearly carbon sequestration potentials of selected land use land cover types in Lubigi wetland are presented in figure 4:12 below.

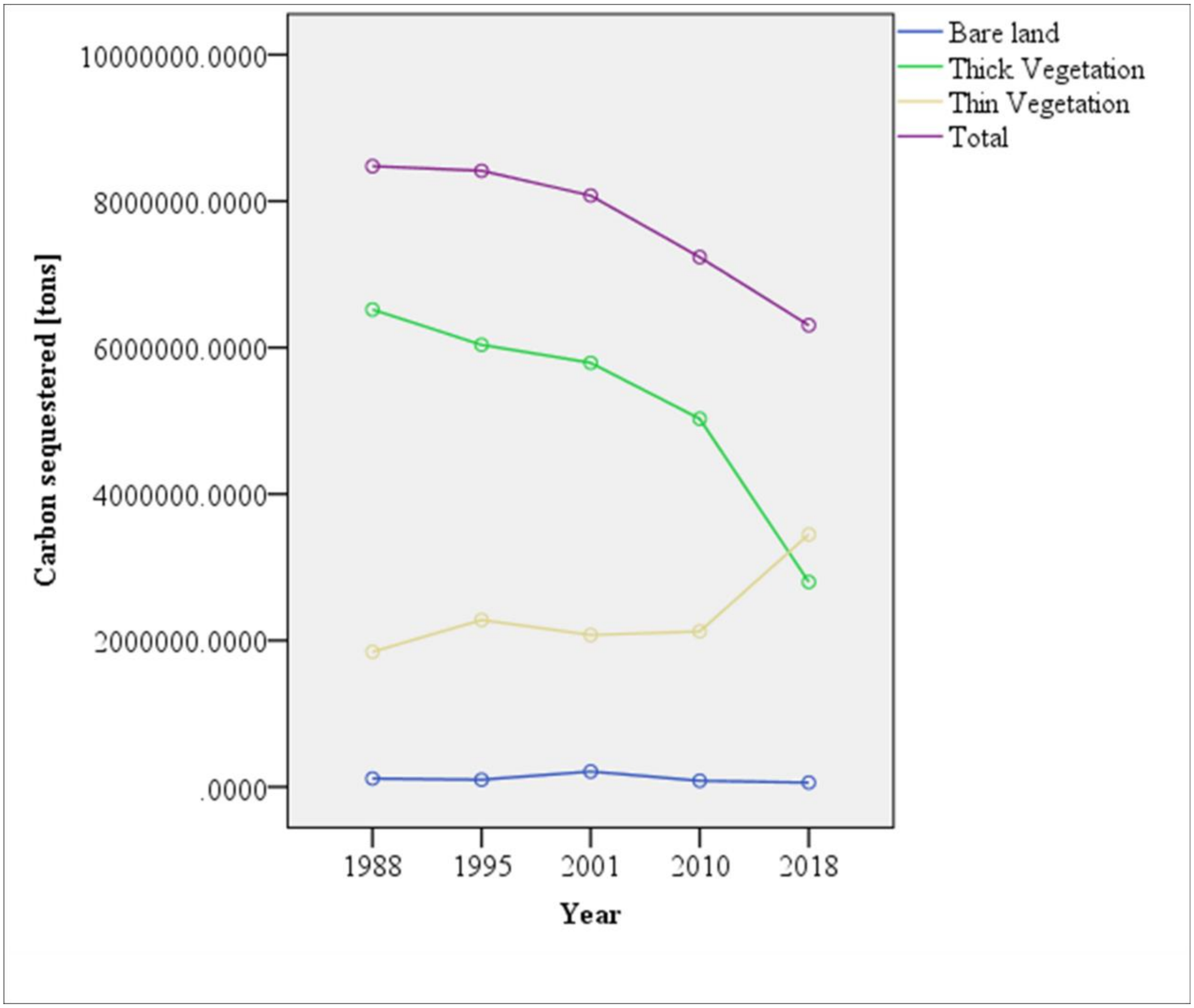

Figure 4:12 Yearly carbon sequestration potentials of different Land use land cover types

Total carbon sequestered in all the three wetland degradation levels progressively declined from 1988 to 2018 as a result of the degradation of the wetland. There was equally, a progressive decline in carbon sequestered by the thick vegetation over years compared to the thin vegetation and bare land. Thin vegetation sequestration potential rose up from year 2010 to 2018 whereas that of the bare land was more or less a flat trend.

4.5 Results from interviews of respondents

4.5.1 Demographic characteristics of respondents

In this section, some of the findings about the demographic characteristics of the respondents are provided.

4.5.1.1 Respondents place of origin

Respondents were requested to name their places of origin, and the results were presented in table 4.14 below.

Table 4.14: Place of origin of the respondents

Place of origin	Frequency	Percent	Cumulative Percent
Busega	4	12.9	12.9
Kaboja	2	6.5	19.4
Kyengera	1	3.2	22.6
Namungoona	16	51.6	74.2
Masanafu	2	6.5	80.6
Nabweru	1	3.2	83.9
Bwaise	1	3.2	87.1
Kalerwe	3	9.7	96.8
Kawala	1	3.2	100
Total	**31**	**100**	

Results in table 4.14 indicated that a big percentage of respondents were from Namungoona.

4.5.1.2 Age of respondents

The table 4.15 below presents the age of the respondents.

Table 4.15: Age of the respondents

Age (Years)	Frequency	Percent	Cumulative Percent
10-19	7	22.6	22.6
20-29	10	32.3	54.8
30-39	9	29	83.9
40-49	5	16.1	100
Total	**31**	**100**	

Results in table 4.15 indicated that most of the respondents were 20-29 years followed by 30-39 years. So, generally, majority of respondents were youth.

4.5.1.3 Respondent's level of education

Respondents were asked to give their education status and figure 4.13 below indicated their responses.

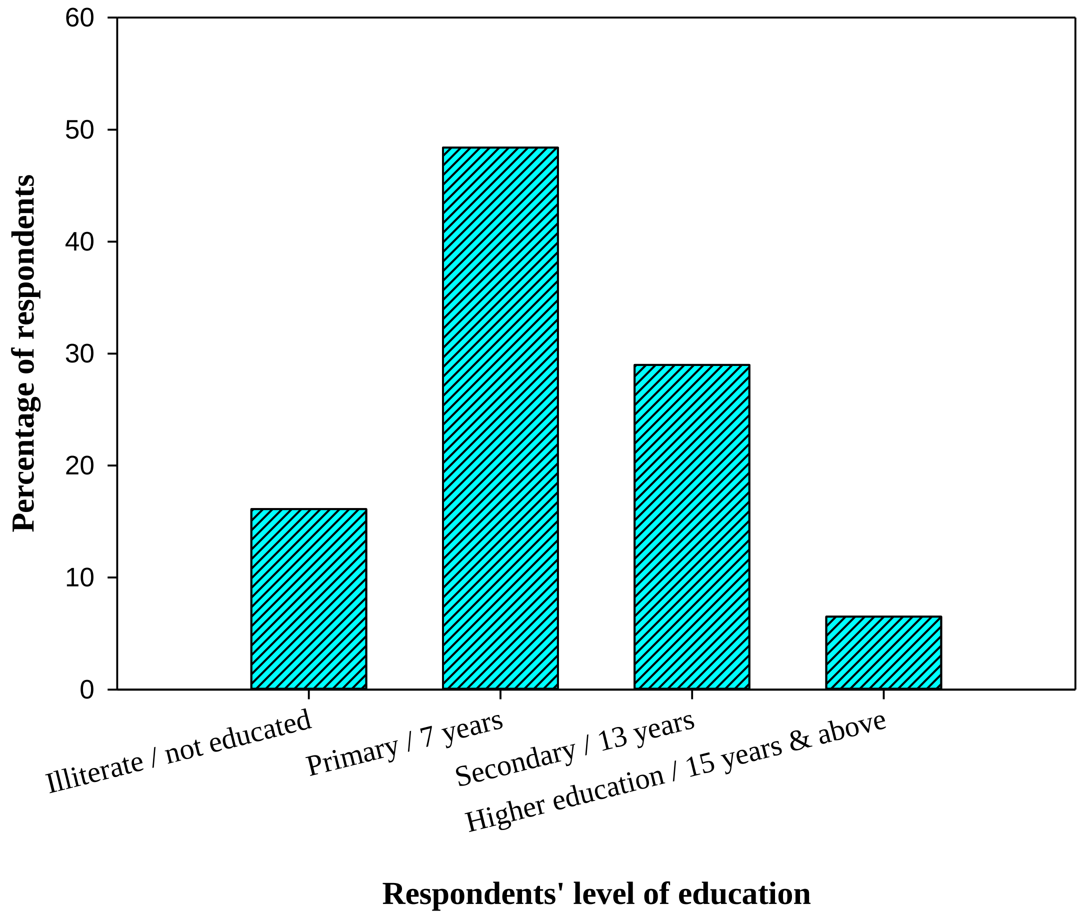

Figure 4.13: Respondent's level of education

Results in figure 4.13 showed that majority of the respondents were primary drop outs followed by secondary drop outs.

4.5.1.4 Respondents' source of money

Respondents were asked to mention the source of their money they use to sustain themselves and the results were presented in table 4.16 below.

Table 4.16: Respondents' source of money

Source of money	Frequency	Percent	Cumulative Percent
Selling food	5	16.1	16.1
Car washing	1	3.2	19.4
Other business	1	3.2	22.6
Job salary	1	3.2	25.8
Tree seedling sales	3	9.7	35.5
Harvesting livestock grass	17	54.8	90.3
Harvesting papyrus	2	6.5	96.8
Harvesting livestock grass and papyrus	1	3.2	100
Total	**31**	**100**	

The results in table 4.16 indicated that the majority of respondents obtained their money from harvesting grass for feeding livestock. In fact, the researcher saw many vehicles frequenting the place to pick grass.

4.5.2 Respondents' land use types in Lubigi wetland

Respondents were asked to mention what kind of land use activities they do or see in Lubigi wetland and their responses were summarized in figure 4.14 below.

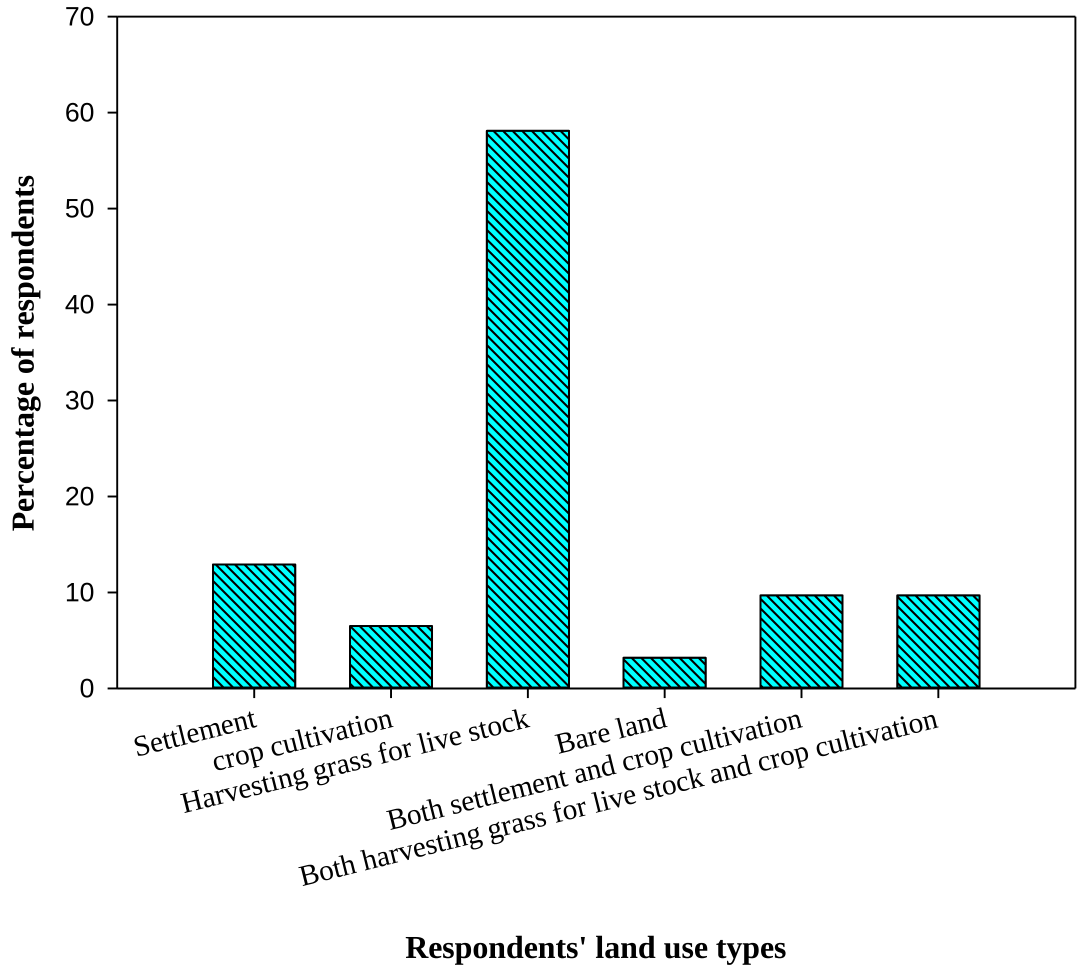

Figure 4.14: Respondents' land use types in Lubigi wetland

Is it clear from figure 4.14 that harvesting grass for livestock feed is the main economic activity being done in Lubigi wetland. This is being done mainly by the youth.

4.5.3 Factors that facilitate the respondents' entry into Lubigi wetland

Respondents were asked to give factors that favour people's entry into Lubigi wetland and their responses were summarized in figure 4.15 below.

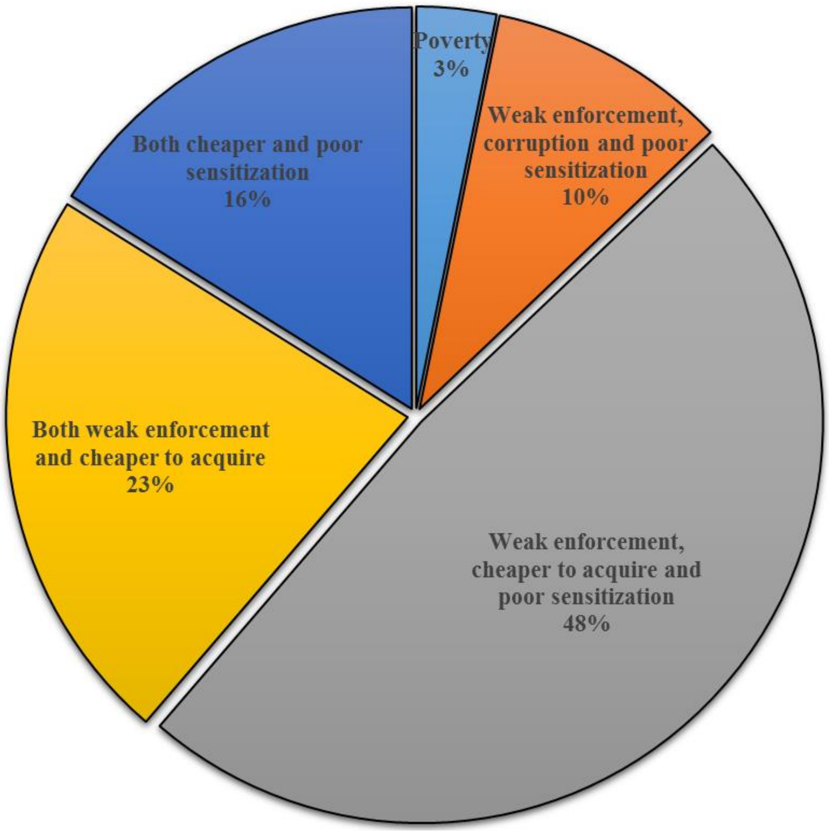

Figure 4.15: Factors that facilitate the respondents' entry into Lubigi wetland

Results in figure 4.15 indicated that 48.4% reported Weak enforcement, cheaper to acquire and poor sensitization of people. This was followed by 22.6% who reported both weak enforcement and cheaper acquisition of land as facilitating factors.

4.5.4 Recommendations for conserving Lubigi wetland

Respondents were asked to list key recommendations for conserving Lubigi wetland, and their responses were summarized in table 1.17 below.

Table 1.17: Recommendations for conserving Lubigi wetland

Recommendations for conserving Lubigi wetland	Frequency	Percent	Cumulative Percent
Sensitize public on wise wet land use, fight corruption and avoid double standards in application of law	5	16.1	16.1
Enforcement of law and sensitize the public on wise wet land use	3	9.7	25.8
Enforcement of law and provide jobs to the youths	4	12.9	38.7
sensitize public on wise wet land use and avoid double standards in application of law	3	9.7	48.4
Provide jobs to the youths	10	32.3	80.6
Enforcement of law	6	19.4	100
Total	**31**	**100**	

Results in table 1.17 indicated that 32.3% of the respondents requested government to provide jobs to the youth in order for them to get off Lubigi wetland. These were followed by the 19.4% respondents who called upon government to enforce law to protect Lubigi wetland. Additional 16.1% called for government to sensitize public on wise wet land use, fight corruption and avoid double standards in application of law.

CHAPTER FIVE: DISCUSSION OF RESULTS

5.1 Spatial and temporal trends in land use and land cover changes (LULCC)

5.1.1 Lubigi catchment area

The percentage coverage of each land cover class over the years was computed as shown in **Table 4.3.** Built up areas to increase up to 50.14 percent of the study area in 2018 all at the expense of other cover classes. This is because it is expected that people clear the thick and thin vegetation areas for construction of buildings and most of the bare land areas will also be developed to build up as reported by UNRA, (2011). There was a significant loss of Thin vegetation by 11.44% (50.60 -39.16) between the period 2001-2010. The coverage of thin vegetation dropped further by 11.98% between the period 2010-2018. Thick vegetation reduced from 43.16% in 1988 to 16.54% in 2018 as reported in HRNJ-UGANDA, (2010). There is a slight increase in the water areas probably because the vegetation that was covering it has been cleared and this water appeared open.

5.1.2 Lubigi wetland area

From Figure 4.5, there is a significant loss of thick vegetated areas which increased up to 25.38% in 2018. In the period 2001-2010, thick vegetation mostly lost to built up area; similar trends were reported by UNRA, (2011) and World Bank, (2015). The extent of thin vegetated area increased in 2018, this is probably because the originally bare land areas redeveloped their green cover and the thick vegetation areas were being cleared for cultivation purposes within the wetland area. Similar trend of results were obtained by studies done by Baker *et. al*., (2007) when studying wetland change detection using Landsat images. Results from the respondents' interview corroborated these findings by acknowledging wetland area loss over the years mostly through cutting of vegetation and construction of buildings.

5.2 The relationships between carbon stocks below and above ground vegetation biomass across different degradation levels of wetland

5.2.1 Soil organic carbon in relation to above ground biomass.

The amount of aboveground vegetation cover can greatly influence the soil organic carbon contents and eventually the carbon sequestration potentials (Tesfau, 2016). In this study, there was a significant positive correlation ($p<0.05$) between soil organic carbon content and aboveground biomass. The study by Junbao *et al*. (2013) showed that, the inputs of plant litter to the soil was correlated positively ($p<0.01$) with soil organic carbon content. Generally, as aboveground biomass (g/m^2) increased, soil organic carbon content (g/Kgm) also increased. Highest value of soil organic content was found in the thick vegetation wetland where the aboveground vegetation biomass was also highest and the lowest value was found in the bare site where no vegetative biomass was observed as shown in figure 4.6. Studies conducted by Eid and Shaltout (2013) and Tesfau (2016) supports the results found in this study when they found a positive correlation between soil organic carbon and above ground biomass. The observed results were due to the fact that vegetation biomass affects the relative amount of carbon that eventually falls to the surface of soil from the shoots (Jobbagy and Jackson, 2000). The cultivated wetlands had a higher biomass compared to thin vegetation area as shown in figure 4.6 yet it had a lower soil organic carbon content (g/kg). This was because the cultivated crop (sweet potatoes) has a good cover per unit surface area and yet a low contribution to the soil organic carbon in terms of litter fall and decomposition.

5.2.2 Plant carbon content in relation to soil carbon stocks

Carbon stocks increases from bare land (no above ground data) to cultivated area, thin vegetation area and to thick vegetation area for both below and above ground. Therefore, as the below ground carbon stocks increases, the above ground carbon stocks also increase from bare area, cultivated area, thin vegetation area to thick vegetation wetlands. The thick vegetation area had the highest above ground carbon stock (287.1g/Kgm) and below ground carbon content (84.2g/Kgm), (figure 4.9 and figure 4.10 respectively) because of the very good and healthy stand of vegetation cover (above ground vegetation biomass) during plant sampling period. This was also due to the fact that the soil is intact so the sequestered carbon is not exposed to factors that releases them from the soil, while the bare land has the lowest below ground/soil carbon stocks (27.2g/Kgm) because the area lacks vegetation to trap and in cooperate the carbon into the soil. These findings are in line with those of Tesfau, (2016) and Howe, (2009) who found that the highest mean plant and soil organic carbon content was obtained in the least impacted site (thick vegetation area) followed by moderately degraded wetland site.

5.3 To establish the relationship between selected soil physico-chemical parameters and soil carbon stocks

Temperature and pH

Soil Organic Carbon (SOC) related positively and negatively to different soil parameters. There was a negative correlation between OC and temperature ($r = -0.33$, $p=0.05$). Other studies conducted in wetlands also corroborate the present study and found negative correlations between SOC and temperature (Jobbagy and Jackson, 2000; Tesfau, 2016). As temperature of the soil decreases, SOC content increases since lower temperature limits decomposition by affecting soil microbial activities leading to accumulation of organic matter (Franzluebbers *et al*., 2001; Zsolt *et. al*., 2014). On the other hand, when sites are cleared of their vegetation, and become dry, the ensuing temperature rise can affect SOC highly, but when sites are saturated with water and have enough vegetation cover the variation in temperature can be buffered and there will be no more effect on the stored organic carbon (Villa, 2014). As the study area is located in a tropical zone, the effect of temperature on the soil organic carbon could be considerably high although some previous studies on tropical wetlands suggested that the presence of vegetation as a source of carbon together with a stagnant hydrology are the most important factors for maximizing carbon storage (Jones and Humphries, 2002; Bernal, 2008; Bernal and Mitsch, 2012; Bernal and Mitsch, 2013; and Villa, 2014). Soil pH was also negatively correlated with SOC in this study (r = -0.12, p=0.50) just like soil temperature because the increase in pH can enhance mineralization of SOC by stimulating soil microbes (Guangyu *et al*., 2010) although it is not a major factor which can affect SOC (Wang *et al*., 2011).

Soil N and P

Soil N had a strong positive relationship with soil organic carbon (r =0.87, p = 0.00). This is because both are produced from mineralization of organic matter and 10% of humus is nitrogen (Bill, 2014). This result is in line with those of Gebeyehu and Soromessa (2018) who suggested that the contribution of organic carbon is significantly high for nitrogen improvement as evidenced by the correlation analysis (r = 0.911). Land management for improvement of organic matter (including land degradation control) has thus an opportunity to increase soil nitrogen. Soil available P also significantly and positively correlated with soil OC (r = 0.62, p = 0.00). There is some evidence that organic matter in the soil can inhibit the conversion of available phosphorus to forms that are unavailable to plants. One explanation is that organic matter coats the surfaces of minerals that can bond tightly to phosphorus. Once these surfaces are covered, available forms of phosphorus are less likely to react with them (Bot and Benites, 2005).

Soil BD and Ksat

Soil bulk density and saturated hydraulic conductivity did not have any significant relationship with the soil organic carbon in all wetland degradation levels in this study ($r = 0.08$, $p = 0.66$ and $r = 0.09$, $p = 0.59$ respectively). Some studies however presented different results. Gebeyehu and Soromessa (2018) for example found a strong negative relationship between soil bulk density and organic carbon ($r = -0.898$) and elaborated that soil bulk density determines organic matter change that is, a decrease in BD leads to increase in the soil OC. Lado *et al*. (2004) found greater Ksat in columns of aggregates and attributed the increased Ksat to less slaking under saturated conditions. In their study, greater aggregate stability was attributed to higher OC levels. In this study however, no evidence is available to support the argument that higher organic carbon content can improve soil Ksat.

Soil K, Na, Ca and Mg

K, Ca and Mg negatively and insignificantly related with soil organic carbon while sodium had a very low positive relationship with soil organic carbon in this study (table 4.5). Findings by Kavdir *et al.,* (2004) also indicated no significant relationship between Na and soil OC ($r = 0.213$, $p>0.05$). Sapek (2013) found a significant negative correlation between OC and Ca ($r = –0.38$, $p<0.05$) and OC and Mg ($r = –0.55$, $p<0.01$) concentrations. One explanation given for this was due to sorption of these elements in soil. According to Hossain (2014), the correlation coefficient for organic carbon content and potassium is positive and non-significant ($r = 0.558$).

In this study however, K negatively related to the soil organic carbon content which means an increase in the soil organic carbon content is accompanied by a decrease in the soil potassium content.

5.4 To determine carbon sequestration potentials across different degradation levels of wetland.

5.4.1Plant organic carbon content

The highest mean plant organic carbon content was obtained in the thick vegetation site followed by thin vegetation area, and finally cultivated area (sweet potatoes) where plant organic carbon was 287.1, 229.5 and 191.8 g/m^2. This was expected as thick vegetation wetland areas are good in terms of aboveground vegetation composition due to lesser disturbances compared to the other sites. Thin vegetation area had significantly higher organic carbon than cultivated area due to the ability of the grasses to reduce the carbon deficit and sequester carbon through higher root productivity compared to crops. In the same way, wetlands and ponds can sequester large amounts of carbon because decomposition is greatly reduced in waterlogged soils from lack of oxygen; this can actually result in carbon gains that exceed the deficits resulting from past land use.

SOC levels result from the interactions of several ecosystem processes, of which photosynthesis, respiration, and decomposition are key. Photosynthesis is the fixation of atmospheric CO_2 into plant biomass. SOC input rates are primarily determined by the root biomass of a plant, but also include litter deposited from plant shoots. Soil carbon results both directly from growth and death of plant roots, as well as indirectly from the transfer of carbon-enriched compounds from roots to soil microbes. For example, many plants form symbiotic associations between their roots and specialized fungi in the soil known as mycorrhizae, in this association the roots provide the fungi energy in the form of carbon while the fungi provide the plant with often-limiting nutrients such as phosphorus (Ontl *et al*., 2012).

Decomposition of biomass by soil microbes results in carbon loss as CO_2 from the soil due to microbial respiration, while a small proportion of the original carbon is retained in the soil through the formation of humus, a product that often gives carbon-rich soils their characteristic dark color. These various forms of SOC differ in their recalcitrance, or resistance to decomposition. Humus is highly recalcitrant, and this resistance to decomposition leads to a long residence time in soil. Plant debris is less recalcitrant, resulting in a much shorter residence time in soil. Other ecosystem processes that can lead to carbon loss include soil erosion and leaching of dissolved carbon into groundwater. When carbon inputs and outputs are in balance with one another, there is no net change in SOC levels. When carbon inputs from photosynthesis exceed carbon losses, SOC levels increase over time.

5.4.2 Soil organic carbon content

Results in figure 4.6 showed that the highest mean organic carbon content (g/kg) was obtained from thick vegetation wetland area which was about 84.2 g/kg, followed by thin vegetation, cultivated area and bare land which contained 83.4, 63.3 and 27.2 g/kg respectively. Mean organic carbon content showed a gradual increase from bare land, cultivated, thin vegetation area to thick vegetation area. The low organic carbon content on the bare land could be due to the decreased fallout from vegetation (Khresat *et al*., 2008), lower carbon inputs because of less biomass carbon return on harvested land, accelerated water erosion and livestock grazing (Islam and Weil, 2000). In addition, soil organic carbon decomposition is accelerated due to the provision of better aeration (Masto *et al.*,(2008), Since bare land is not physically protected, this exposes organic matter and thereby accelerating its loss. Ultimately, the lower organic matter content on bare lands will lead to a reduced nutrient holding capacity.

The high organic carbon content obtained from the thick vegetation wetland area can be attributed to the presence of very good and healthy stand of vegetation cover during plant sampling period. The vegetation stand on the thick vegetation wetland leads to the accumulation of soil organic matter from the litter fall of the aboveground biomass and the presence of flooded soil in the areas. Fresh water wetlands are significant carbon sinks due to high productivity and water logged conditions (Bernal and Mitsch, 2012). Carbon sequestration potential may be determined by an understanding of both the historic SOC stocks under natural vegetation prior to conversion to other uses and the influences of those land uses on carbon loss. Land uses and management that reduce carbon inputs or increase losses compared to natural vegetation result in reductions in SOC over time, creating a soil carbon deficit relative to the levels of carbon that previously existed in the soil. This deficit represents an opportunity to store carbon from conversions in land use and management when those changes result in either increased inputs or decreased losses of carbon (Ontl *et al*., 2012).

These results as shown in table 4.11 were in conjunction with those of Larry and Macha (2007); who found out that soil is the largest pool of sequestered carbon provided that the integrity of the vegetation cover is maintained, soil disturbance is avoided and soil erosion is prevented. The mean organic carbon difference in the gradient from bare land, cultivated, thin vegetation area to thick vegetation area can be attributed to many factors like climatic condition, topographic condition, biological activity, biomass condition, sedimentation rate, land management, and socioeconomic condition of the area (Mitra *et al.*, 2005). Climate change though not a major focus of this study is also a contributing factor for the reduction of organic carbon in the wetlands as increasing temperature causes an increase in organic matter decomposition rate. It is believed that whenever temperature increases by 10^0C, the decomposition rate of carbon doubles (Gebrekidan, 2014). Therefore, climate change can have significant impact on the reduction of carbon stock in wetlands. However, thick vegetation wetlands are still the largest store of soil carbon stocks per unit area in the study area. Findings of this study were also in agreement with the work of Gebrekidan (2014) who reported a significant difference in total carbon content among undisturbed, sedimented, semi-disturbed and agricultural lands in Wetlands of Fogera Plain, North West Ethiopia. According to him, the lowest carbon content was found in soils of sedimented wetland and the highest total organic carbon content was in soils of undisturbed wetlands.

5.4.3 Carbon sequestration potential

The study shows that the carbon sequestration potential and the carbon dioxide equivalence increases from bare, cultivated, thin vegetation to thick vegetation wetland (Figure 4.11). This result of the analyses showed that if wetlands are well conserved and kept intact, that is, as thick vegetation, more than 1,886.77 tons of CO_2 can be sequestered from the atmosphere, unlike the bare lands that only sequestered 592.86 tons of CO_2. The results obtained by Kassa *et al.*, (2015) are similar to these ones when they found a higher amount of carbondioxide being sequestered in intact wetlands compared to cultivated wetland. This is because changes such as converting wetlands to grazing and cultivation land by draining and clearing the wetland biomass could result in loss of stored carbon to the atmosphere (Saunders *et al.*, 2014). The low carbon sequestration potential in the bare sites was due to no carbon inputs because of no biomass carbon return on the land and accelerated water erosion (Islam and Weil, 2000). Compared to bare sites which had no vegetation biomass, cultivated wetland had higher carbon sequestration potential because the plants grown could enhance fixation of atmospheric carbon dioxide (Kassa *et al*., 2015; Tesfau *et al*., 2016).

Climate changes in the undisturbed/thick vegetation wetlands caused by greenhouse warming are expected to alter processes related to carbon storage in wetlands. Higher temperatures which increase primary production also increase decomposition rates in wetland soils and this will increase organic matter availability and hence organic carbon (Chmura *et al*., 2003). Carbon fixation under wetland anaerobic soil conditions provides unique conditions for long-term storage of carbon into histosols (Whiting and Chanton, 2001). Thick vegetation wetland also tend to form a very productive ecosystem consisting of many different plant species which accumulate large amounts of organic matter in the soil, functioning as significant carbon sinks.

5.5 Lubigi wetland status and management as per reports from the community

About 94% of the respondents agreed that there is already a change in land use land cover in Lubigi wetland. The original thick papyrus has been changing to thin vegetation, bare land, built up and cultivated land over years. 77.4% of the respondents reported that most change in land use land cover for Lubigi wetland occurred between 2010 and 2018 and this result in fact agrees with objective one of this study where satellite image analysis revealed that most land use change in Lubigi wetland occurred during the same period. More so, reports by KCCA (2014) and World Bank (2015) corroborate these findings when they reported massive destruction of Kampala’s wetlands by government development programs and community encroachment. As many respondents as 87% agreed that the local community was the leading encroacher in Lubigi wetland. When asked whether they supported to change wetland to other land uses, the answers varied. 45.2% said they did not support any change in wetland use, followed by 12.9% who strongly not support any change. Some respondents (41.9%) said that they supported any change of land use of the wetland urging that population was high and there is limited land to plant food crops. In contrast, Tesfau (2016) found out that only 16.98% of the interviewed respondents of Lake Ziway in Ethiopia believed that wetlands should be converted in to other land use types so as to meet the need of the highly increasing population, especially the landless youths for cultivable land, and the need for high production in the fertile soils of the wetland. Lubigi wetland being in the urban centre, its conditions are different from those of Lake Ziway which is located in the local area.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

6.1.1 To determine spatial and temporal trends in land use and land cover changes (LULCC) in Lubigi wetland from 1988 to 2018.

Both Lubigi wetland and its catchment have been progressively declining in area. This is due to rapid construction of roads, homesteads, markets, sewers, cutting of grass for livestock, cultivation among others. By 2018, most of the remaining area was converted into thin vegetation and built up areas.

6.1.2 To relate carbon stocks below ground and above ground vegetation biomass across different degradation levels of wetland

Thick vegetation wetlands are the best places for storage of both aboveground plant carbon and soil organic carbon. Where the above ground vegetation biomass was higher, so was the carbon content below ground. This is due to the better status of the wetland in terms of vegetation cover, hydrology, soil conditions, and reduced levels of human disturbances.

6.1.3 To establish the relationship between selected soil physico-chemical parameters and soil carbon stocks.

Soil organic carbon content was positively correlated with above ground biomass and soil moisture whereas soil temperature showed significant negative correlation. Where temperature increases, SOC decreases, thus heavily degraded sections of wetland with less moisture and high temperature have low SOC.

6.1.4 To determine carbon sequestration potentials across different degradation levels of wetland.

Wetland sites with a better vegetation cover and soil conditions have the best carbon sequestration potential. Compared to plants, soil is the largest pool of sequestered carbon provided the above ground vegetation is kept intact. Therefore, Lubigi wetland has been losing its carbon sequestration potential over years due to wetland degradation.

This study has also revealed that communities around Lubigi wetlands try as much as possible to improve their livelihoods through maximum utilization of wetlands, however, in the process they end up contributing to carbon emissions.

6.2 RECOMMENDATIONS

It is highly recommended that:

1. The Ministry of Water and Environment should stop wetland degrading activities especially cutting grass for livestock to allow wetland undergo full restoration. This can be done through enforcement of law.
2. Government should come up with alternative sources of income (jobs) to support the youth who are currently actively engaged in cutting grass for livestock. This may include registering all wetland users and providing alternative land for them to plant grass or some other business.
3. The Ministry of Water and Environment should enforce wise wetland use that allows sufficient regeneration time and space for the wetland's sustainability. This can be done through training and general sensitization of the community on wise wetland use options.
4. Special attention should be given to protect all wetlands in the country so as to enhance their capacity to sequester carbon and thus mitigate climate change.
5. The Ministry of Water and Environment and Non-Governmental Organisations should empower the local community to be the managers of the wetland by providing appropriate incentives and community wetland management leadership.
6. Parliament should consider allocating more money to the Minsitry of Water and Environment to support wetland management activities in Lubigi and country wide.
7. Government should cancel all land titles given illegally in Lubigi wetland.

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APPENDICES

Appendix 1: Questionnaire

KYAMBOGO UNIVERSITY

FACULTY OF SCIENCE

DEPARTMENT OF BIOLOGY

MASTER OF SCIENCE IN CONSERVATION AND NATURAL RESOURCE MANAGEMENT 2017/18

QUESTIONNAIRE FOR RESPONDENTS LIVING/USING LUBIGI WETLAND

You have been selected as one of the respondents in this research. The purpose of this exercise is to collect data on factors that have affected the potential of carbon sequestration in Lubigi wetland. Please kindly spare part of your precious time to answer these questions as accurately and honestly as possible. The information you will give will be treated with utmost confidentiality and only used for this study.

1.0 BIO DATA

1.1. Place of origin

[ ]

1.2. Gender

Female [ ] Male [ ]

1.3. Age Group: (Tick)

Below 20 years	20-29 years	30-39 years	40-49 years	50-59 years	Above 60 years

1.4. Status/Position/ Designation/occupation:

1. Peasant farmer
2. Civil servant
3. Business man

1.5. Education level

illiterate	Primary	Secondary	High education	

1.6. Marital status:

Single ☐ Married ☐ Divorced ☐

1.7. State No. of biological children

☐

1.8. State No. of dependants

☐

1.9. What is the main source of money for supporting your family?

1. Growing Crops
2. Keeping livestock
3. Car washing
4. Selling tree seedlings
5. Salary
6. Other

2. LAND USE LAND COVER CHANGE DATA

2.1. In which year did you acquire this land?

2.2. What was the original vegetation/cover on this section of the land before you started using?

1. Bare ground
2. Food crops
3. Thin/grass vegetation
4. Thick/Intact Papyrus
5. Other……………………………………………………………………………....

2.3. What purpose do you currently use this land for?

1. Growing crops
2. Animal keeping/grazing/harvesting grass for livestock
3. Settlement
4. Commercial buildings
5. Others………………………………………………………………………………

2.4. What is the size of land in acres that you own/use? (Break as per land use where possible)

2.5. Please select among the options below how you obtained this land:

1. Bought
2. Inherited from parents/clan
3. Provided by government to settle
4. Obtained on your own (without any authorization)
5. Leased or temporarily hired from some one

2.6. Do you agree that Lubigi wetland is currently being changed into other land use types?

1. **Yes** 2. **No**

2.7. If your answer for Q 2.7 above is yes, which year did the most land use change/wetland degradation occur?

1. 1988 -1995
2. 1995 - 2001
3. 2001 -2010
4. 2010 -2018

2.8. Select only ONE category of people whom you think are the leading encroachers on Lubigi wetland?

1. Local community
2. Government workers in charge of wetland management
3. Untouchable public figures in Army, Politics, Business, etc who act above the law

2.9. Give the various land use types commonly seen in Lubigi wetland area?

1. Crop cultivation

2. Settlement

3. Bare land

4. Built/converted area

5. Other…………………………………………………………………………………

2.10. Do you support the idea of changing Lubigi wetland to other land use types? (tick the most appropriate box)

1. Strongly support

2. Support

3. Not support

4. Strongly not support

2.11. If your answer to No. 2.12. Above is either 1 or 2, then give two (2) main reasons why you support the idea of land use changes in wetlands?

1. Free land for cultivation
2. Free land for settlement
3. Support urban development and industrialization
4. Other ………………………………………………………………………………

2.12. If your answer to No. 2.12. above is either 3 or 4, then give two (2) main reasons to support your answer.

1. Biodiversity conservation

2. Protect climate

3. Control floods

4. Water quality

2.13. In your own view, what have been the main 3 factors that have facilitated people to enter into Lubigi wetland to change its land cover?

1. High population

2. Weak enforcement of wetland protection laws

3. Cheaper to acquire

4. Poor sensitization of public on conservation of wetlands

5. Corruption and contradicting government directives

2.14. In your own experience, is there any change observed in the local climate today as compared to the past years in Uganda?

1. Yes ☐ 2. No ☐

2.15. If yes, what do you think wetland degradation has led to?

1. Increased temperature
2. Variability in rainfall patterns
3. Excessive drought
4. Increase in flooding in areas surrounding wetlands

5. Other…………………………………………………………………………………………

2.16. Are you aware that Lubigi wetland is protected by law?

1. Yes ☐ 2. No ☐

2.17. Please give 2 key recommendations to government indicating what it should do to restore and then sustainably conserve Lubigi Wetland.

a) --

b) --

THANK YOU FOR YOUR TIME

Appendix 2: Photo galary

(1) Thick vegetation area: Charles Odeke Augering to get soil sample after collecting vegetation.

(2). Thin vegetation area: Cutting grass is the order of the day by the community

(3). Thin vegetation area: Locating quadrat before soil and grass is collected

(4). Cultivated area: Collecting soil and vegetation samples from sweet potato site.

(4).Bare area: demonstrating how soil sample was collected. No vegetation collected.