THE ECONOMIC AND ECOLOGICAL TRADE-OFFS OF WETLAND CONVERSION FOR DEVELOPMENT PROJECTS: THE CASE OF THE KAMPALA–MUKONO CORRIDOR

BY

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ABSTRACT

Wetland diminution for development projects (DPs) in the Kampala–Mukono Corridor (KMC) continues to pose threats to the socio-economic and ecological benefits of wetlands because decision-makers and wetland users at various levels often have insufficient knowledge of these benefits. This situation has resulted in unsustainable development decisions that accord little weight to wetlands and have allocated many of them to DPs. In order to inform decision making for optimal development in the KMC, the present study analysed the spatial and temporal wetland loss to DPs, estimated the economic value of the KMC wetlands, and assessed the environmental consequences of wetland conversion for DPs.

Sets of ortho-rectified and cloud-free multi-temporal Landsat MSS (1974) and Landsat TM/ETM+ images (30m) for 1986, 2006, and 2013 were analysed in a spatial and temporal framework. The 79m Landsat image (MSS) of 1974 was resampled and later filtered with subsequent 30m images using a majority filter method. An unsupervised classification approach was employed to characterize the wetlands and associated DPs. The classified DPs and wetland cover types were validated by reference to topographical maps (sheets) of 1974 at a scale of 1:50,000 obtained from Uganda Lands and Surveys, apriori knowledge and Google earth images corresponding to the same spatial and temporal frames. The IDRISI Selva-based Markov Chain model was employed to model future wetland loss to DPs. The Total Economic Valuation Approach (TEV) was employed to quantify selected use values of wetland economic benefits using the market price, replacement cost and contingent valuation techniques. The ecological implications of wetland loss focused on soil organic carbon (SOC) and hydrological impacts in the KMC wetlands. The estimated SOC was assessed with climatic data in order to infer the implication of SOC loss for local climate variability. The manual wet chemistry/oxidation method by Walkley-Black (1934) was adopted to estimate SOC in various wetland cover types. Hydrological impact assessments focused on water quality analysis in various wetland cover types, with major parameters being total nitrogen (TN), total phosphorous (TP) total dissolved solids – (TDS) and total suspended sediments (TSS). Hydrologic flow data parameters across the different wetland cover types in the KMC focused on water level, speed, stream width, and bed load.

Results from analysis of the spatial-temporal wetland change revealed that by 2013 the KMC wetlands had lost almost half (47%) of their 1974 areal coverage, with 56% of this loss resulting from conversion to DPs. It is projected that 26% of the KMC wetlands will be lost to more DPs by 2040. Wetland loss is attributed to intensified economic activity and preference of Kampala as an industrial zone, weakness in the previous spatial planning of Kampala, and the general lack of information flow to various institutions involved in the establishment of DPs.

The KMC wetlands provide a flow of economic benefits at a minimum approximated value of US$ 3,418 / ha / per year. It is revealed that a great deal of these economic benefits (88%) accrues to the local subsistence level in the form of livelihood products, incomes, and employment benefits. The 56% wetlands loss to DPs in the KMC by 2013 brings the minimum economic value lost to US$ 19,311,700 in the sampled wetlands, and projections of future wetland loss put the minimum economic loss at US$ 48,368,118 by 2040. Continuous degradation of these wetlands means serious economic costs to the government and local communities, as reflected in high replacement expenditures for wetland services, foregone incomes, subsistence livelihood support and alternative employment.

The highest carbon (C) sinks were identified in forest swamps, palms, thickets and wetlands converted to agriculture, which accounted for 25% of the KMC wetlands by 2013, while the lowest total soil organic carbon (TSOC) range occurred in converted wetland cover types (converted wetlands to industrial and settlements) that occupied 47% of the study area. A general decrease in SOC sequestration from 1974 to 2013 across the KMC wetlands is identified, with the lowest C pool registered in 2013. The dwindling SOC banks are considered to be partly responsible for varying climate and related feedbacks on wetland benefits in the KMC. The hydrologic impacts of wetland loss are felt mainly in converted wetland cover types, in the form of compromised water quality, with increased nutrient pollution and TSS. These all create negative impacts on wetland hydrological services, particularly filtration, flood attenuation, recharge and discharge benefits, all of which have profound effects on biodiversity.

There is an urgent need to reduce the scale of wetland diminution in the KMC. This will be achieved if mitigation and conservation measures are undertaken. Mitigation measures should include a revision of development plans, user sensitization on wetland economic values and enforcement of regulatory mechanisms. Conservation strategies should involve the use of economic incentives and disincentives which include: a revision of historic property rights to regulate wetland use, performance bonds or subsidies for environmentally friendly activities and taxes, fees or fines for unacceptable levels of degradation and tradable permits that utilise the concept of ‘wetland banks’ to ensure no further loss of the KMC wetlands to DPs. Future research should focus on modelling the response of wetland ecosystems to multiple threats and management interventions, and on a feasibility study of wetland restoration options and the implications for local people’s livelihoods in the KMC.

DECLARATION

I, **HANNINGTON WASSWA** (Student number: 211173886) hereby declare that this thesis for the degree of PhD (Environmental Geography) is my own work, composed and written by myself. It has never been previous presented anywhere for assessment of any academic award or published in any peer reviewed journal. All materials used from other sources are duly appreciated and properly acknowledged.

5th/November/ 2018

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LIST OF ACRONYMS

Acronyms		**Meaning**
C	:	Carbon
DGGCS	:	Department of Geography, Geo-Informatics and Climatic sciences
DPP	:	Development Physical Plan
DPs	:	Development Projects
DSOER	:	District State of Environmental Report
DV	:	Direct Value
EIA	:	Environmental Impact Assessment
EV	:	Economic Value
GHGs	:	Greenhouse gasses
GIS	:	Geographic Information Systems
GoU	:	Government of Uganda
HIA	:	Hydrological Impact Analysis
IUCN	:	International Union for Conservation of Nature
IV	:	Indirect Value
KMC	:	Kampala Mukono Corridor
MEA	:	Millennium Ecosystem Assessments
MNR	:	Ministry of Natural Resources
NBS	:	National Bureau of Statistics
NEMA	:	National Environmental Management Authority
NMU	:	Nelson Mandela University
NRM	:	National Resistance Movement
OC	:	Organic Carbon
OV	:	Optional value
SOC	:	Soil Organic Carbon
SOCA	:	Soil Organic Carbon Analysis
SOCD	:	Soil Organic Carbon Density
SUPRE	:	State of Uganda’s Population Report
TDS	:	Total Dissolved Sediments
TEV	:	Total Economic Value

TN	:	Total Nitrogen
TP	:	Total Phosphorous
TSS	:	Total Suspended Sediments
UBOS	:	Uganda Bureau of Statistics
UGX	:	Ugandan Shilling
UIA	:	Uganda Investment Authority
UNMA	:	Uganda National Meteorological Authority
USGS	:	United States Geological Survey
WID	:	Wetland Inspection Division
WRI	:	World Resources Institute
WTP	:	Willingness to pay

CHAPTER ONE

General Introduction

1.1 Background

Revamping Uganda's economic sector and diversifying economic production that hinged solely on agriculture in the early 1960s has been a major focus since the inception of the current NRM government in 1986 (Kataata, 2003). This inspired the development of the Uganda Investment Authority (UIA) in 1991, with a mandate to attract, promote and facilitate investment in order to realize economic growth and infrastructural development. In fulfilment of this obligation, the UIA allocates land to potential investors to establish Development Projects (DPs). However, amidst limited strategic locations, especially around Kampala, many DPs have ended up infringing upon wetlands (Kataata, 2003).

This situation arose because wetlands are perceived to have little or no economic value (Schuyt, 2005). Yet they are considered to be among the earth's most productive ecosystems, performing a wide range of services in the hydrological and chemical cycles (Barbier *et al*., 1997) and possessing notable economic value (Schuyt, 2005; Brander *et al.*, 2006; Xu *et al*., 2011). According to MEA (2005), these services include production services (production of plants, water, soils, and animals); regulation services (climate regulation, mitigation of storms and floods, erosion control, control of pests and diseases, and the regulation of rainfall and water supply); and cycling/supporting services (nutrient cycling, nitrogen fixation, carbon sequestration and soil formation).

The general lack of adequate information and knowledge about these complex ecosystem functions of wetlands and the benefits they generate for society, coupled with the fact that no formal markets exist for their services to humanity, means that wetlands are significantly undervalued by society (Newcome *et al.*, 2005). This diminishes the gross value inherent in them and certainly obstructs the translation of their full social and environmental benefits (goods and services) in a way that will ensure optimal decisions for a sustainable future. For this reason, wetland conservation is not seen as a convincing alternative by economic decision-makers, who often opt to convert their lands, or the water that feeds them, to extensive industrial or residential functions (Barbier *et al*., 1997).

The Kampala–Mukono Corridor (KMC) shares this challenge of DPs, particularly in the form of large industrial companies and slum/semi-slum housing and agriculture (Byaruhanga and Ssozi, 2012) that have encroached on wetlands like Nakivubo, Namanve, and Kinawataka. These perceived development options have led to the conversion of wetlands to various forms of economic development, with expected serious and irreversible environmental consequences for carbon sequestration and wetland hydrological functions, which will adversely affect human welfare. Studies on wetlands in Kampala and the neighbouring urbanizing areas (see Emerton *et al*., 1998; Lwasa, 2010) provide evidence of increased flood frequencies, increased runoff and siltation, disruption of water sources, pollution and associated effects on ecosystem biodiversity, all resulting from wetland conversion for industrial, settlement and agricultural uses.

It is the poor rural areas which tend to bear the brunt of the impact on ecosystem degradation, since many of them heavily depend on wetland goods and services. Yet they are the least able to mitigate the consequences of such ecosystem change (Newcome *et al*., 2005; SUPRE, 2012). Consequently, wetland diminution is likely to make their lives vulnerable to the loss of subsistence agricultural opportunities and alternative income-generating activities. In urban areas, the consequences of wetland loss are reflected in their reduced ability to perform life-supporting regulatory services, most importantly revealed in their reduced ecological functionality in terms of moderating environmental conditions through stabilizing climate, reducing the risk of weather events, droughts, floods, poor air and water quality, loss of native biodiversity and the subsequent decline in the flood mitigation role (Newcome *et al*., 2005).

Economic valuation is one tool that aims at investigating public preferences for change in ecosystem goods and services. Although it has not been applied in many places, it provides a means of quantifying the direct and indirect benefits that people derive from wetlands, highlights the importance of ecosystems to policy makers, and informs management, planning and practice about resource conservation options and optimal allocation (Karanja *et al*., 2001; Boyer & Polasky, 2004; Schuyt, 2005; Crossman & Bryan, 2009; Moran *et al*., 2010; Satlhogile *et al*., 2011; de Groot *et al*., 2012).

In the present study, the economic value accruing from wetland conservation is estimated in terms of monetary worth, and the ecological implications of KMC wetland development options are described. These will serve as major inputs for highlighting the potential economic and ecological trade-offs of wetland conversion for DPs, while raising awareness of the relative importance of the KMC wetlands to policy makers.

1.2 Statement of the problem

Wetlands resources are an asset due to the ecological goods and services they provide (Acharya, 2000; Schuyt, 2005; Brander *et al*., 2006). Over 80% of Uganda's population adjacent to wetland areas relies directly on these wetlands for their livelihood needs (Turyahabwe *et al*., 2013a). Yet these important ecosystems are both degrading and shrinking, with much of their land increasingly being converted to DPs, particularly industrial estates, agriculture, and residential slum and semi-slum developments (UNEP, 2009). This results in a decline in wetlands' functioning and resilience, and in their ability to provide ecosystem services to humanity. A clear understanding of the extent of human dependence on ecosystem services and the ecological implications of wetland conversion is essential for sustainable development.

Previous studies point to anthropogenic factors as the major drivers of wetland loss, particularly government development policies, rising poverty, and lack of awareness (Wegener, 2001; Joshi *et al*., 2002; Kataata, 2003; Schuyt, 2005; Owino & Ryan, 2005). This is exacerbated by the high population growth rate of 3.03 percent (UBOS, 2014) and pressure for industrial expansion (UNEP, 2009). Ironically, Uganda is a country with good environmental resource management policies and functional environmental monitory and regulatory agencies, like the National Environmental Management Authority (NEMA) and the Wetland Inspection Division (WID); but it is also true that these policies are minimally implemented (Rwakakamba, 2009). As a country, Uganda has lost about 11,268 km^2 of wetlands, down from 37,575 km^2 (15.6%) in 1994 to about 26,308 km^2 (10.9%) in 2009. This represents a loss of 30% of the country's wetlands (Kakuru *et al*., 2013).

Despite the diminishing wetland coverage, few studies have been done to investigate the spatial and temporal changes in the KMC wetlands (Mafabi, 2003). Previous studies have largely focused on the direct consumptive wetland economic benefits and how they affect human welfare (Emerton *et al*., 1998; Karanja *et al*., 2001; Maclean *et al*., 2003; Schuyt 2005; Kakuru *et al*., 2013;

Turyahabwe *et al*., 2013; Nsereko, 2010). There is a need to monitor the wetlands on a landscape scale in order to understand the spatial and temporal changes as well as the implications for ecological functioning. Such assessments will enhance our understanding of the impacts on ecological sustainability and help to direct efforts to improve wetland integrity in development decision making.

1.3 Overall aim of the study

The present study aims to estimate the potential economic value of the KMC wetlands and to assess the environmental consequences of wetland conversion for DPs, in order to inform optimal development decision making.

1.4 Specific objectives of the study

The specific objectives of the study are:

1. To establish the extent of wetland loss to DPs over the four decades 1974 – 2013 and also project future wetland loss to DPs. This objective is achieved by examining the spatial and temporal trends in wetland cover change of the KMC wetlands for the period 1974 to 2013. Based on observed wetland cover change trends during the observation period, projection of future wetland loss to DPs was done using the Markov Chain projection model.

2. To estimate the economic value (EV) of conserving the KMC wetlands. To achieve this objective, the economic value of wetland benefits was quantified and its implication for people's livelihoods assessed. This also provided a major input into estimating the environmental costs of wetland loss to DPs in the KMC.

3. To assess the carbon sequestration and hydrological impacts relating to wetland diminution by DPs. This objective is achieved by estimating the spatial and temporal variations of soil organic carbon storage among different wetland cover types. The results were compared with climatic data for Kampala in order to assess the implications of soil organic carbon loss for local climate variability. Remotely sensed Landsat MSS, TM and ETM+ images of the KMC wetland cover types and related SOC stocks were used to estimate SOC storage changes across the different wetland cover types. The hydrological implications of wetland loss to DPs were based on testing water quality levels in the KMC wetland cover types.

The main parameters considered for this analysis included: chemical nutrient concentration (Total nitrogen - TN, Total phosphorous - TP and Total dissolved solids - TDS), total suspended sediments (TSS) and related hydrologic flow data (water level, speed, stream width, and bed load).

1.5 Research questions

1. What is the extent of wetland loss to DPs over the four decades 1974 – 2013 and what are the projected wetland losses in the next 27 years (to 2040)?
2. What is the economic value (EV) of conserving the KMC wetlands?
3. What are the carbon sequestration and hydrological impacts related to wetland diminution for DPs in the KMC?

1.6 Scope of the study

This study was carried out in the wetlands of the KMC, focussing on the economic and ecological trade-offs of wetland conversion for DPs from 1974 to 2013, as well as on projected future wetland loss. An economic valuation of the KMC wetlands was undertaken in which the use values – i.e. the direct and indirect benefits accruing from wetland goods and services – formed the basis for assessing economic trade-offs. The ecological impacts were assessed through analysing carbon sequestration and the hydrological impacts of wetland diminution.

1.7 Study area

This section describes the study area with respect to the major aspects of location, geology and topography, climate, hydrology, soils, flora and fauna, ethnicity and land tenure/land use. The description of the study area is relevant to the ‘results-based’ chapters (except the chapter titled “Economic Implication of Wetland Conversion to Local People’s Livelihoods: The Case of the Kampala-Mukono Corridor (KMC)” The description is, therefore, not repeated for the other results-based chapters.

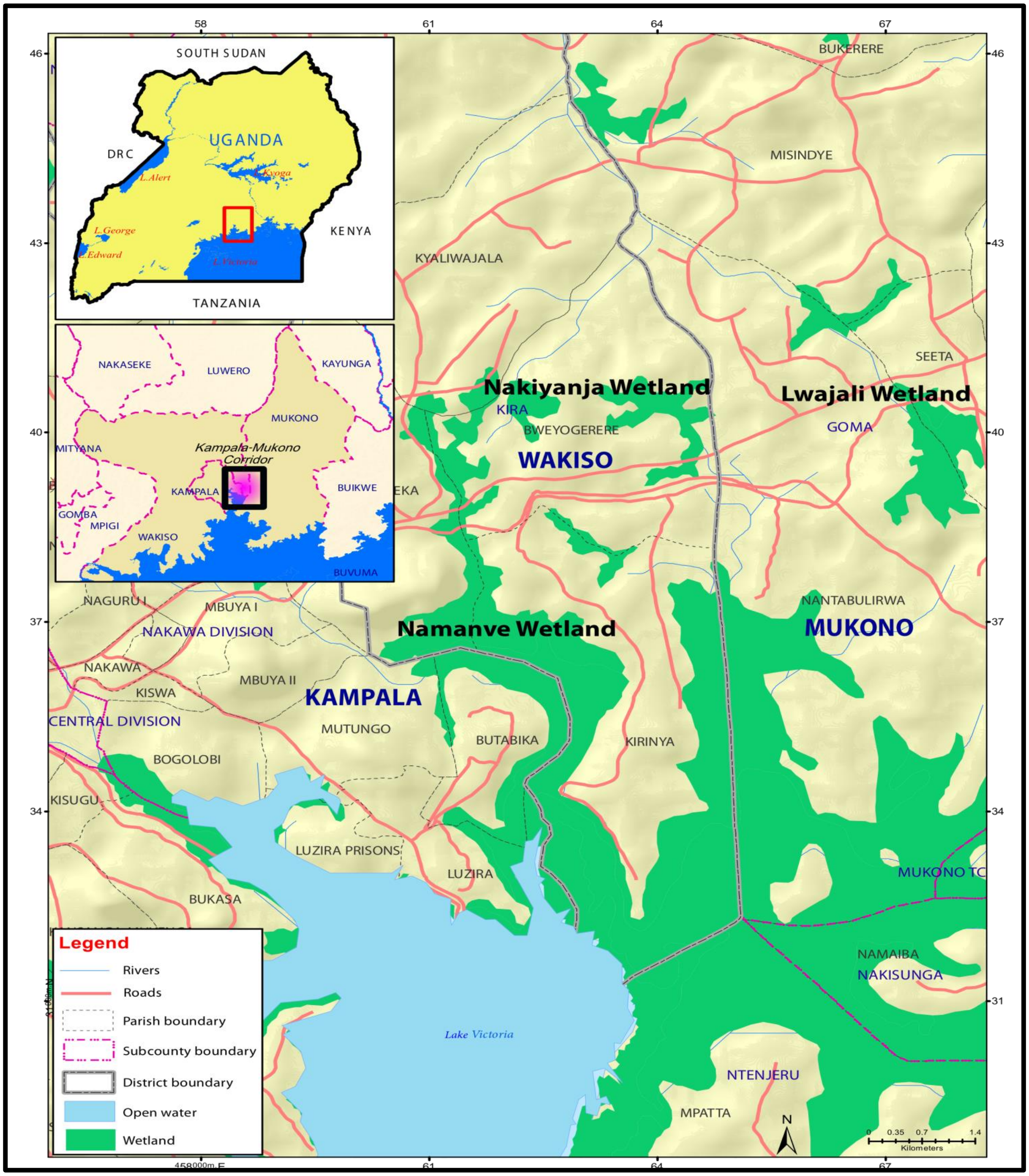


Figure 1.1: Map of Uganda showing the location of the sampled wetlands in the KMC

1.7.1 Hydrology

The KMC is drained by numerous streams, including Lwajjali, Nakiyanja, Kasota, Namanve and other sub-tributaries of the River Sezibwa. Most of these drain northwards through River Sezibwa into Lake Kyoga, yet due to variations in topography, some streams drain southwards through the small valleys into Lake Victoria. The northerly flow of streams dominates the area's drainage, especially in Mukono. This is due to the gentle relief in the northern side and a great deal of undulations to the south of the KMC. Collectively, these rivers provide good quality water to millions of people in the KMC villages (Musoke, 2001), and the neighbouring districts of Wakiso, Nakasongola, and Luweero. Unfortunately, Kampala streams have not escaped the city mayhem of pollution. They are heavily polluted with domestic and industrial wastes that end up in Lake Victoria through channels which drain the city (Kansiime & Bruggen, 2001; Byaruhanga & Ssozi, 2012).

1.7.2 Location of the Kampala-Mukono Corridor

The KMC is located on the northern shores of Lake Victoria in Uganda (Figure 1.1), between 0°23' 56.22"N 32°42' 51.22"E, 0°23'48.66"N 32°35'20.79"E, 0°16'04.07"N 32°42'49.38"E and 0°016'16.05"N 32°35'03.16"E. This area is an elongated corridor adjacent to the districts of Kampala and Mukono, with an estimated surface area of 199 km^2. The area occupies part of the valley slopes and plateau zones of central Uganda, ranging between 1000 and 1300 m.a.s.l. (NEMA, 1996). The surrounding environments are highly populated and the main activities include trade and urban agriculture, especially on the Kampala side. This fades away towards Mukono, where rural settlements are punctuated with agriculture, agroforestry and peri-urban trading.

1.7.3 Geology and topography

The study area is associated with the paleoproterogenic Buganda-Toro basement complex (1800 – 2000 m.a.s.l.). It also shares a portion of the granitic metamorphic rocks of the Achaean shield of central Uganda. These rocks are deeply weathered and not exposed at the surface (Malick, 2004). The geological conditions reflect a Precambrian-Paleozoic sedimentary cover sequence and associated alluvium lacustrine deposits, which are responsible for the formation of numerous wetlands and flood plains in this area (NEMA, 2002). The area is characterized by gently undulating hills surrounded by a network of valleys. These are covered by wetlands that are drained by a number of streams (NEMA, 1996). The elevation ranges between 1000 - 1500 m.a.s.l. (NEMA, 2006).

1.7.4 Climate

The KMC lies in the tropical climatic zones of central Uganda. The climate of this entire region is influenced by a broad range of factors, notably proximity to Lake Victoria, altitudinal variations, wind systems (south-east and north monsoon winds), vegetation and human activities (BakamaNume, 2010). The rainfall pattern is bimodal, with the wettest period being March to May and September to November, while the dry season falls from December to February. The mean annual rainfall is 2100mm, with sunny intervals most of the year (NEMA, 2002) and extensive cloud cover. Temperatures range from 14.5^0 C to 28^0 C, with humidity and wind patterns displaying comparatively small variations throughout the year (NEMA, 2010).

1.7.5 Soils

The KMC soils fall in the Buganda quaternary complex (Malick, 2004). The predominant areas are underlain by ferralitic soils of sandy and clay loams, which have high to medium fertility with relatively good porosity (Kamanyire, 2000). Various soil types envisaged in this category include shallow, murram-based lithosols, reddish and free-draining hillside latosols, brown to grey and black clay loams and sticky valley clays (Banage, 1999). In a few scattered virgin areas free from human induced degradation, particularly in Mukono, these soils have supported tropical forest vegetation, while productive subsistence agriculture thrives in areas where indigenous forest cover has been cleared.

1.7.6 Flora and fauna

The vegetation of the study area reveals a forest/savannah mosaic characterized by patches of dense forest in the south and grasslands in the north (NEMA, 2002; NEMA, 2004). However, in Kampala much of this vegetation has been cleared for settlement, agriculture and industrialization. Wetland vegetation comprises papyrus swamps, *Typha miscanthus, Hyparrhenia* species, some *Cyperaceous* and creepers. Swamp forest tree species include *Pseudospondias Microcapar, mitrogyra* species, *Tarbementana, Ficus spp, Bridelia micrautha* and *Phoenix reclinata* while shrub vegetation consists of several edible plants such as *psidium guava* and *afromonium augustifolium*. Many of these species are utilized by the local community for food, fuel, building materials, medicines and raw materials for crafts. Information provided by local farmers and forest guards points to sightings of warthogs, monkeys, mongoose, cane rats, bush bucks, sitatunga antelopes (*Tragelaphus spekei*), and civets (Musoke, 2001). Over 100 bird species associated with forest and papyrus swamps have also been noted (Mukoome, 2009).

1.7.7 Ethnicity

KMC is situated in the Kingdom of Buganda, one of the ancient African monarchies recognized in Uganda. The dominant ethnic group is the Baganda, with whom a mixed ethnic community is associated. This is because the area lies close to the cosmopolitan capital city (Kampala). Most of the residents are natives of the area, while small portions are immigrants who have recently settled in the area. These communities include Banyankole, Bakiga, Basoga, Banyarwanda, Basamya, Bagisu and Ateso (Malick, 2004).

1.7.8 Land tenure / land use

The predominant land tenure systems in the study area are mailo land and leasehold (Malick, 2004). Presently, the study area supports small-scale scattered subsistence farms, mainly growing bananas, cassava, sweet potatoes, sugar cane, yams, cabbage, etc. Cash crops like tea and coffee exist in small stands, with privately owned woodlots comprising eucalyptus trees lying north of the extensive Namanve estate. Some sections of the KMC wetlands are utilized for sand mining and brick making activities, while the rest have small pockets of upcoming industrial nodes which are gradually transforming the KMC into an industrial corridor (Lwasa *et al.*, 2005). Other areas are densely populated with mainly low-income housing, particularly informal semi-slum residential housing, while there are other associated uses such as cultivation, waste disposal and business sites for local manufacturing artisans - *jua kali*.

1.8 Structure of the thesis

The thesis is structured into seven chapters: the general introduction, the literature review, the methods chapter, and three results-based chapters (4–6), laid out in publication (journal article) format. The methods sections for the results-based chapters are built into the main methods chapter. The last chapter provides a synthesis of the preceding chapters, conclusions and recommendations.

1.8.1 Chapter One: General Introduction

Chapter one introduces the topic investigated in the study. The problem statement, research objectives, research questions and the scope of the study are presented. The chapter concludes with a description of the study area in terms of location, geology and topography, climate, hydrology, soils, flora and fauna, ethnicity, and land use.

1.8.2 Chapter Two: Literature Review

This chapter presents a review of related literature on the nature and extent of wetlands in Uganda, major DPs in wetland areas and the factors responsible for the undervaluation of wetlands in development decisions. Aspects of wetland valuation procedures are also presented, as well as methodological approaches to assessing the environmental impacts (carbon sequestration and hydrological impacts) associated with wetland change.

1.8.3 Chapter Three: Materials and Methods

Chapter Three presents the research design and methodology. This chapter describes the methods used to establish the extent of wetlands lost to DPs, and to ascertain the economic value of wetland goods and services. The chapter ends with a presentation of the methodology employed in assessing the environmental impacts (carbon sequestration and hydrological impacts) of wetland loss and the methodological limitations.

1.8.4 Chapter Four: A spatial and temporal assessment of wetland loss to Development Projects: The case of Kampala–Mukono Corridor wetlands in Uganda

This chapter presents the spatial and temporal trends in wetland loss to DPs and related land use changes in the KMC between 1974 and 2013. A projection of future wetland loss to DPs in the KMC is also presented. The chapter highlights the major drivers of wetland diminution and the ecological implications of wetland loss for optimal development decision making aimed at mitigating continuing wetland diminution in the KMC.

1.8.5 Chapter Five: Economic implications of wetland conversion for local people's livelihoods: The case of Kampala–Mukono Corridor wetlands in Uganda

This chapter presents the wetland benefits of the KMC and the economic value of the KMC wetland benefits. A distribution analysis of wetland economic values for stakeholders and the implications of their loss is also presented. The chapter concludes with identification of suitable economic measures for sustainable wetland management.

1.8.6 Chapter Six: Assessment of the carbon sequestration and hydrological impacts related to wetland diminution in the Kampala–Mukono Corridor wetlands in Uganda

The chapter assesses the carbon sequestration and hydrological impacts associated with wetland diminution for DPs. An assessment of the spatial variations of SOC stocks in the KMC wetland cover is made. The implications of the KMC wetland cover changes for SOC and local climate variability are described. The chapter concludes with an assessment of the hydrological impacts of wetland loss to DPs based on water quality and flow data analyses.

1.8.7 Chapter Seven: Synthesis

This chapter presents a synthesis of the other chapters, bringing together the various strands of the study. A conceptual model of the factors responsible for wetland diminution and a framework for optimal development decision making in the KMC wetlands is developed. Conclusions and recommendations are made and future research directions are proposed.

CHAPTER TWO

Literature Review

2.0 Introduction

In this chapter, case studies in the remote sensing of wetland change, valuation of ecosystems, factors responsible for the undervaluation of wetlands in development decisions, the nature of wetland values, wetland valuation procedures, and related limitations are presented. The chapter also presents a review of carbon sequestration in wetlands and implications for climate variability, methods for the restoration and enhancement of carbon sequestration in wetlands, and methodological approaches in estimating SOC. It concludes with a review of wetland hydrological assessments and a presentation of the evolution and impacts of wetland hydrological alterations.

2.1 Application of remote sensing in wetland assessment

Traditionally, wetlands were delineated through the use of ground surveys, which later proved to be difficult and time consuming (Yasouka *et al*., 1995). The use of remote sensing technology was developed to provide cost and time-effective solutions to mitigate the challenges posed by ground surveys (Goldberg, 1998). To date, remote sensing technology has been widely used in wetland change due to the fundamental role it plays in wetland conservation (Romsho, 2004; Xu *et al*., 2011) and its ability to supply information about the extent of the wetlands, the nature of its resources, its general characteristics (Lyon & Carthy, 1995; Xu *et al*., 2010), and patterns and drivers of wetland change (Xu *et al*., 2011).

Although some wetland studies have used radar data (Bourgeau-Chavez *et al*., 2001; Alsdorf *et al*., 2001) as well as LIDAR (MacKinnon, 2001), the majority of wetland-related studies have concentrated on Landsat TM, MSS, SPOT, and airborne CIR images (Sugumaran *et al*., 2004). This study opted for Landsat MSS, TM/ETM$^+$ images because they are the first and oldest forms of remotely sensed land satellite images, having been used to scan the earth's surface since 1972 (Ozesmi & Bauer, 2002), and therefore given the time scale of the study, it is the best to provide information on the wetlands and development projects that dates back to the period between 1974 and 1980. Another advantage is the low cost of their acquisition. This choice has been supported by Sugumaran *et al*. (2004), who conclude that Landsat imagery remains a valid choice for large-scale wetlands mapping projects, especially with the added capability of the panchromatic band.

Most of the early studies classified wetland images through visual interpretation of aerial photographs (Sugumaran *et al*., 2004). However, with time, unsupervised classification or clustering became the most commonly used method of delineating wetlands (see Naugle *et al*., 1999; Dechka *et al*., 2002; Kingsford & Thomas, 2002; Ruan *et al*., 2008; Zhang *et al*., 2011), together with the Maximum Likelihood supervised classification algorithm (Özemi, 2000). According to Zhang *et al*. (2016) the ISODATA algorithm is one of the most widely used in unsupervised classification of remote sensing images, especially where there is limited prior knowledge of available data (see Ruan *et al*., 2008; Zhang *et al*., 2016). It is however noted that these classification methods are associated with low accuracy percentages (30-60), which have often been increased through the use of multi-temporal and ancillary data (Özemi, 2000). Other commonly used algorithms include K–means, MNF (Minimum Noise Fraction), and Spectral Angle Mapper (SAM).

Hodgson *et al*. (1987) and Wilcox (1995) suggest that wetlands are best delineated with images acquired in spring when the water table is high enough to facilitate growth of wetland aquatic macrophytic vegetation. Despite having similar views, Sano *et al*. (2007) claim that the best images are acquired in the dry season, to overcome the constraints introduced by cloudiness and enable excellent image interpretation. In this regard the present study concentrated on images acquired on the eve of the dry period for the study area. Other classification work has been undertaken through the use of multi-sensor assessments, hyper spectral data, neural networks and ancillary data (Houhoulis & Michener, 2000), which comprise a problem-solving tool for distinguishing spectral similarities, especially in wetlands forests and agricultural areas (Nguyen & Pham, 2016).

2.2 Valuation of ecosystems in development decisions

Ecosystems provide a range of services that are of fundamental importance to human well-being, for health, livelihood and survival (Costanza *et al*., 1997; Millennium Ecosystem Assessment (MA), 2005). These services include (1) the production of resources for humans, like food, water, raw materials for building and clothing; (2) regulation services: they regulate ecological processes that contribute to a healthy environment such as climate regulation, mitigation of storms and floods, erosion control, control of pests and diseases, carbon sequestration and the regulation of rainfall and water supply; (3) carrier functions: the provision of space for activities like human settlement, cultivation and energy conversion; and (4) information functions, in terms of which ecosystems contribute to mental health by providing scientific, aesthetic and spiritual information (de Groot, 1992). Yet despite these important services, global ecosystems and biodiversity continue to decline at unprecedented rates (de Groot *et al*., 2012), and this includes a decline in wetland functioning, resilience and ability to provide ecosystem services to humanity (Elmqvist *et al*., 2012). As observed by de Groot *et al*. (2012), the threats of ecosystem loss are expected to be greater in the context of climate change and the ever-increasing human consumption of resources. There is a need to express the true value of ecosystems and the related costs of their loss to humanity, in order to preserve the integrity of ecosystems in development decision making.

The monetary valuation of ecosystem services dates back to the early 1960s, but received wide attention after the publication of Costanza *et al*. (1997). Since then there has been steady growth in ecosystem valuation studies (Gomez *et al*., 2010; Muradian *et al*., 2010). Given the ecological, socio-cultural and economic dimensions of the importance of ecosystems and biodiversity to human society, economic valuation remains an important tool in raising awareness and conveying this to decision-makers (de Groot *et al*., 2012). In view of the limited funds to finance active ecosystem management, as already indicated in the case of Nakivubo wetland in Uganda (Emerton *et al*., 1998), information on monetary valuation is fundamental in generating the funds needed for sustainable conservation and the utilization of ecosystem services (Farley & Costanza, 2010; Leimona, 2011). Coupled with this is the fact that monetary valuation assists with determination of the extent to which compensation should be paid for the loss of ecosystem services (Payne & Sand, 2011).

Quantifying ecosystem service value in monetary units is also essential in guiding understanding of user preferences and the relative value that the current generation places on ecosystem services (Moran *et al*., 2010; Satlhogile *et al*., 2011; de Groot *et al*., 2012). However, as noted by Newcome *et al*. (2005), this value is often premised on the level of ecosystem benefits perception, where the indirect benefits are not usually recognized. This information failure and lack of recognition leads to ill-informed decisions on ecosystem management, which contributes to the continuing rapid loss, conversion and degradation of these ecosystems (de Groot *et al*., 2006).

The Millennium Ecosystem Assessment (MEA, 2005) identifies wetlands as the most threatened type of ecosystem, with more than half their world coverage having disappeared since 1900

(Barbier, 1993). In Uganda, despite the contribution of wetlands toward national economic development, their full economic value is not adequately understood or appreciated (NEMA, 2001). Their importance is usually associated with direct consumptive values like the extraction of useful materials. This obstructs the recognition of essential life-supporting processes, including stabilization of the hydrological cycle and microclimates, protection of riverbanks, nutrient and toxin retention, and sewerage treatment (UNDP, 2009). It is a perception that contributes to the continuing rapid loss, conversion and degradation of wetlands. It is estimated that 2,376.4km^2 of wetlands in Uganda had been converted for agriculture, industrial and related activities by the year 2000 (NEMA, 2000). Additionally, preliminary studies from the Biomass Study Unit of the NFA (2008) indicate that in 2005, Uganda's wetland cover as a proportion of the total land area had reduced to 11 percent.

Efforts to preserve and create wetland ecosystems depend on the recognition of their ecological as well as their economic value. In Uganda, only a few wetland valuation studies have been undertaken, and these typically focus on individual wetlands rather than a broader regional scale assessment (economic valuation of Nakivubo wetland estimated UGX 2 billion per year [Emerton *et al*., 1998]; the valuation of Pallisa district at US$ 10,861/ha/year [Karanja *et al*., 2000]; the valuation of Bushenyi wetlands at US$ 10,226/ha/year [IUCN, 2004]; and the value of non-use wetland benefits: water recharge and flood control, at US$ 7.1 million and 1.7 billion, respectively [Kakuru *et al*., 2013]. Other related case studies include: Provisioning services of Ga-Mampa wetlands in South Africa at US$ 900/ha [Adekola *et al*., 2012]; Consumptive value of Nyando wetlands in Kenya at US$ 62,500/ha/year [Oduor *et al*., 2015]; Provisioning services of Lesotho wetlands at US$ 220/ha [Lannas & Turpie, 2009]). Additionally, it is only in very few cases that wetland valuations have focused on the Total Economic Value and the benefits of both marketed and non-marketed services of wetlands (de Groot *et al*., 2006), which is itself contributing to the under-valuation of wetlands and resulting in their rapid conversion and degradation. As noted by UNDP (2009), the consideration of both the marketed and non-marketed values of wetland ecosystem services lead to a greater estimation of the total economic value of unconverted wetlands.

2.3 Wetland types

Wetlands occupy only about 6.5% of the world's land area (Constanza *et al*., 1997). In Africa, these ecosystems are estimated to comprise between 1% and 16% of the continent's total area.

According to UNEP (2009), the largest wetlands in Africa include the Okavango Delta, the Sudd in the Upper Nile, the wetlands of Lake Victoria and Lake Chad, and the floodplains and deltas of the Congo, Niger and Zambezi rivers. In Uganda, wetlands occupy 13% of the land area, which is ~30,000 km^2 (Hartter & Ryan, 2010), including areas of seasonally flooded grassland, swamp forest, permanent flooded papyrus, grass swamp and upland bog (Baguma, 2001).

According to Schuyt (2005), there is no universally agreed wetland classification scheme. Wetlands have been classified on the basis of their water sources, nutrients, hydrological regimes, soil type and vegetation structure. The differences between these classifications are attributable to the region and the reasons for which the classification is made (Roggeri, 2013). Roggeri (2013) identifies two important wetland classification schemes: classification according to geomorphological units (sources of water and nutrients), and ecological classifications based on vegetation structures. The former classification distinguishes (1) alluvial lowlands, which are fringing floodplains, inner deltas and coastal delta floodplains; (2) small valleys, including headwater lowlands and small overflow valleys; (3) lakeshore wetlands on the shores of a deep lake, and (4) depressions – wetlands in river and lake systems and isolated depressions. The ecological classification units include periodically flooded ecosystems (flooded forests, flooded grasslands and seasonal shallow lakes and water bodies), swamps and marshes (herbaceous swamps, swamp forests and peat swamps), and shallow lakes and water bodies (natural ponds, oxbow lakes and lagoons). The National Biomass study of Uganda has adopted these approaches to map Uganda’s wetlands at district level, based on visual interpretation of SPOT imagery and giving rise to a classification scheme presented in Appendix L.

2.4 Undervaluation of wetlands in development decisions

Although wetlands are an important source of natural resources producing goods and services that have economic value (Acharya, 2000; Schuyt, 2005; Brander *et al*., 2006; Daniels & Cumming, 2008; Ozyavuz, 2011), they have continuously been encroached upon and their land allocated to DPs in the name of development. This scenario has been attributed to a combination of factors including the nature of wetland values, information failures, lack of consistency in policy interventions, inadequacies of historic wetland property regimes, the public nature of some wetland resources, complex land ownership, and political interference.

The nature of wetland values has been cited by many scholars as a major reason for the undervaluation of wetlands in development decisions (Turner *et al*., 2000; Boyer & Polasky 2004; Schuyt, 2005). As demonstrated by Barbier *et al*. (1997), the support provided by many wetland services is largely indirect, which means that key wetland services are not captured in the open market. Such market failures have contributed to the undervaluing of wetland services (particularly the ecological services) in development decisions, which has conspicuously contributed to wetland conversion in favour of projects that seem to yield greater economic benefits (Schuyt, 2002; Pascual *et al*., 2010; de Groot *et al*., 2012). Additionally, information failures – arising from the difficulty of quantifying most ecosystem services in terms comparable to human-made assets – contribute to structural limitations on the ability of economic data to provide a comprehensive picture of ecological value in decision-making processes. This all contributes to the undervaluation and subsequent degradation of wetlands for other uses that appear to have more, and more immediate, economic benefits (Costanza *et al*., 1997).

As substantiated by Schuyt (2002), Stuip *et al*. (2002), Boyer and Polasky (2004), Turpie *et al*. (2010) and de Groot *et al.* (2012), information failures regarding both spatial relationships and the consequences of land use, water management, pollution and infrastructure development derive from a fundamental lack of understanding of the magnitude of values that may be associated with wetlands. This is partly a consequence of the complexity and invisibility of spatial relationships among groundwater, surface water and wetland vegetation (Turner *et al*., 2000). Consequently, two camps of wetland stakeholders with differing claims on wetland functions are created. In many cases, advocates of wetland protection are dwarfed by those who desire the economic gains to be made from wetland conversion. This is because the latter group of actors literally consider wetlands to have little or no economic value (Turner *et al*., 2000; Emerton, 2000; Brander *et al*., 2006). Consequently, such opportunity costs are perceived by decision-makers to exceed the benefits of wetlands (Oglethorpe & Miliadou, 2000).

Continuous wetland degradation is also blamed on the inadequacies of historic property regimes that are based on traditional wetland uses, making it difficult to cope with modern wetland uses (Adger & Luttrell, 2000; Turner *et al*., 2000; Maclean *et al*., 2003). However, even where such property rights have been well defined, the wetlands provide off-site benefits that are not appreciated by the resource owner, owing to their invisibility of their economic value and associated market failure (Turner *et al*., 2000). This limits owners' motivation to maintain wetlands, as the private benefits to be derived do not reflect off-site social benefits.

Despite the existence of laws and policy regulations in Uganda, (the National Wetland Policy of 1995, the National Environmental Management Policy of 1995 and the Environmental Impact Assessment Resolutions of 1998), the discrepancy between policy formulation and the reality of implementation underscores the problem of wetland conservation (Matovu, 2006; Rwakakamba, 2009). The alarming rate at which wetland resources are being depleted means that the above laws are not being enforced effectively, due to poor design and little community participation. This is exacerbated by certain policy interventions (Aryamanya, 2011; Kakuru *et al*., 2013). According to Lung'ayia and Kenyanya (2001), such interventions are a function of the fact that previous environmental policies seemed to be inadequate in meeting the challenges posed by high population growth and related activities, and as such they end up ignoring the needs of various stakeholder groups in the wetlands. As demonstrated by Muganwa (1995), the National Wetland Policy of 1995 forbids the leasing of wetlands to any person or organization for whatsoever reason (Section 7.6 - ii). But the Uganda Land Commission has often leased wetlands (Kiyimba, 2013), while the UIA and the NEMA have also been cited as issuing operational permits in wetland areas.

Institutional constraints also manifest in EIA compliances. According to Kataata (2003), various wetlands in Kampala were zoned in 1972 for industrial development, yet impact assessment as a prerequisite for project development only started in 1995. Consequently, by the time environmental policy came into being, most of the developments had been started or completed. Currently, adherence to EIA by project developers is perceived as a new requirement and an expensive exercise. The result is that agreement or compromise is difficult to reach, particularly with big investors, in the context of the government's liberal policy to attract as many investors as possible for economic growth (Ecaat, 2004; Lwasa, 2004). In cases where development projects have been subjected to mandatory EIA, follow-up of recommended mitigation measures is often not done, which has further exacerbated wetland degradation (Kataata, 2003; Umar, 2010). However, contrary to previous spatial development plans, government is now considering the cancellation of all wetlands titles on public land acquired after 1995. This move will contribute immensely to the protection and conservation of wetlands from the impacts resulting from development activities.

The public nature of some wetland ecological services, biological resources, and amenity values also underpins wetland values in development decisions (Barbier *et al*., 1997; Stuip *et al*., 2002; De Blaeij *et al*., 2011). The valuable wetland services which collectively benefit all individuals are often considered as monetary bounties of nature that are "free of charge". This makes it difficult to exclude other individuals from these public services. As stated by Barbier *et al*. (1997), such a scenario makes it difficult to collect payments for the service. Coupled with the absence of enforceable property rights (Turner *et al*., 2000), devaluation and subsequent unrestricted depletion of the resource is the inevitable result.

In urban areas, particularly Kampala, wetlands are seen as the cheapest areas for industrial development (UNEP, 2009; Aryamanya, 2011); hence many are converted for industrial and associated uses. This is exacerbated by the complexity of land ownership in Uganda. Although the government recognizes the conservation of wetlands (Article 237/ 2(b) of the Uganda Constitution, 2006), little attention is paid to matters of ownership, especially those pertaining to Mailo land ownership in the Buganda region (Aryamanya, 2011). Consequently, land owners in the wetlands see no need for their conservation. Moreover, it has been shown that private land owners are capable of degrading their lands for production more extensively than the government or communal owners (Ostrom, 1999).

Political inference is also compromising wetland conservation (Namakambo, 2000; Apunyo, 2008; Moses, 2008; Gumm, 2011). Although wetlands in Uganda are held in trust by the central government or local government for the common good of the people of Uganda, it is these very institutions that have in many cases turned out to promote their abuse (Apunyo, 2008). Indeed, although the government has in the past institutionalized environmental planning and management, with supporting legislation and regulations, many wetlands have been degraded at the hands of the very institution that is supposed to be a watchdog (Busuulwa, 2001; Aryamanya, 2011). This has mainly been through the construction of infrastructure/highways, water treatment plants and industrial developments (Gumm 2011). The government has encouraged the drainage of swamps by way of reclaiming them for agriculture and related activities, while in western Uganda, wetlands were leased to dairy farmers who drained them and replaced their natural vegetation with pasture (Apunyo, 2008).

Recent examples of wetland abuse have included cases where local authorities have been the very violators of this institutional provision. Central and local authorities have indicated that they converted wetlands for the sake of providing their communities with economic growth opportunities to fight poverty (Aryamanya, 2011).

2.5 Nature of wetland values

Economic values are in this context described as monetary measures of the benefits or costs of environmental change, based on people's willingness to accept that environmental change (Wills, 1997). Regardless of the type, wetlands provide an array of goods and services which hold value for humanity (MEA, 2005; Schuyt, 2005). According to De Groot (1992) and Turner *et al*. (2000), wetland services are derived from wetland ecological and physical functions and, therefore include storm buffering, flood attenuation, sediment retention, together with a broad spectrum of climatologic, biological and social cultural services (Brander *et al*., 2006; Emerton, 1998). Additionally, wetlands provide ecological processes vital in enhancing the extraction of natural resources such as water, fish and other edible animals, wood and energy, together with natural surroundings for recreation activities (Barbier, 1993; Acharya, 2000; Oglethorpe & Miliadou, 2000). In general, wetland services have been categorized into hydrological, geochemical and ecological services (Turner *et al*., 2000). The value of natural resources is, however, exclusively perceived in terms of extractive products: the raw materials and physical products that they generate for human consumption (UNDP, 2009). As Schuyt (2002) points out, these direct uses represent only a small portion of the total value of wetlands. Following Krutilla (1967), a number of scholars have used the Total Economic Value (TEV) approach as a framework within which to express the full range of socio-economic values of wetland resources, categorizing them into use and non-use values (see Table 2.1) (Costanza *et al*., 1997; Schuyt, 2002; IUCN, 2006).

Table 2.1: Classification of Total Economic Value for wetlands

Use values			**Non-use values**
Direct use value	**Indirect use value**	**Option and quasi-option value**	**Existence value**
Production and consumption of goods such as: • Fish • Agriculture • Fuel wood • Recreation • Wildlife harvesting • Peat/energy	*Ecosystem functions and services such as:* • Nutrient retention • Flood control • Storm protection • Groundwater recharge • External ecosystem support • Micro-climatic stabilization • Shoreline stabilization, etc.	*Premium placed on possible future uses or applications such as:* • Potential future uses (as per direct and indirect uses) • Future value of information	*Intrinsic significance of resources and ecosystems in terms of:* • Biodiversity • Culture heritage • Bequest values

Source: Adapted from Emerton (1998); IUCN (2006)

Direct Value (DV) relates to the physical use of resources such as wild fish capture, timber, firewood, etc. Indirect Value (IV) refers to ecosystem services such as watershed protection, carbon sequestration, water quality attenuation and supply. Option Value (OV) refers to future economic options such as industrial, pharmaceutical or recreational applications. Barbier (1997) and Ruzzier (2010) suggest that, if an individual is uncertain about the future value of a wetland but believes that the wetland’s conversion may have irreversible consequences, there may be a quasi-option value to be derived by delaying the development activities. In this regard, delaying DPs in the KMC wetlands in the face of ongoing economic transformation policies ought to be the best alternative for a sustained flow of wetland ecological and economic services. The Existence Value implies the intrinsic worth, regardless of use, such as biodiversity, landscape, aesthetics, heritage, bequest and culture (IUCN, 2006; Kyophilavong, 2011). This is a form of non-use value that is extremely difficult to measure (Barbier, 1997; De Groot *et al*., 2006), because it involves subjective valuations by individuals in respect of both current and future use. It is for this reason that the present study will concentrate on selected components of use value, particularly the direct and indirect use values.

An important sub-set of this Existence or Intrinsic Value is the Bequest Value, which results from individuals placing a high value on the conservation of wetlands for future generations (Barbier, 1997; Oglethorpe & Miliadou, 2000; Petrics & Russo, 2006). This value may be high among local populations currently using the wetlands, since they would like to see their way of life in conjunction with the wetlands, passed onto to their heirs and future generations.

2.6 Valuing wetland ecosystems

2.6.1 Monetary valuation techniques for wetland goods and services

The importance of wetlands to human society must be assessed in order to make intelligent decisions regarding their use and management (de Groot *et al*., 2006). As highlighted by Turner *et al*. (2000), quantifying wetland conservation benefits serves to facilitate improved social decisions in the wetland protection versus development conflict. Economic valuation involves estimating how much purchasing power people would be willing to give up, if they were forced to make a choice for a wetland resource (Ramachandra & Rajinikanth, 2004; King *et al*., 2006). Various methods are used to value wetlands ecosystems. These valuation techniques are categorized as revealed preference, stated preference and benefit transfer.

2.6.1.1 Revealed preference approaches

Revealed preference methods uncover value estimates of non-market goods based on observation and people's actual behaviour, in the face of real choices (Fujiwara & Campbell, 2011). The valuation methods in this category include the market price method, the hedonic pricing approach, the production function and travel cost models, and damage cost avoidance (Ruzzier, 2010).

The market pricing method is regarded as the simplest and most straightforward way of quantifying the economic value of wetland benefits (Emerton, 1998; Ramachandra & Rajinikanth, 2004; Miththapala, 2008). It is used to estimate the economic value of ecosystem products for which markets exist (Figure 2.1). In this regard, the individual values of selected wetland products are determined by observing people's preferences and willingness to pay (WTP) for them at a price offered in the market. However, the market price method is conditioned by assumptions that wetland goods are sold through a perfectly competitive market; where there is full information about wetland goods, identical products sold, with no taxes or subsidies levied (Emerton, 1998; Ruzzier, 2010); where wetlands provide goods that have only direct use to man with stable undistorted prices through time, and where producers and consumers enjoy a surplus after supplying and purchasing wetland goods. The present study adopted the market price method, since the KMC wetlands generally offer similar goods to local communities which are traded in the open market, with readily available market information.

The basic premise of the market price method in valuing ecosystem goods traded in the open market is the use of a standard technique of estimating the consumer and producers' surplus for every good to be valued, which is summed to obtain the total economic surplus or net economic value for the selected goods. The consumer surplus reflects the maximum amount that consumers are willing to pay for a good, minus what they actually pay, while the producer's surplus is measured by the difference between revenues to producers from a particular good and the total variable costs (King *et al*., 2006). However, estimation of the producer's and consumer's surpluses is premised on certain data requirements, such as time series data on quantity demanded at different prices. Much of this data can be collected through the use of questionnaires and direct observation (Ruzzier, 2010; Oduor *et al*., 2015).

The travel cost is used to estimate the value of recreational benefits generated by ecosystems (Ghaemi & Panahi, 2011). It assumes that the value of the site and its recreational services is reflected in how much people are willing to pay to get there. The basic premise of this method is that the time and travel cost expenses that people incur to visit a site represent the price of access to the site. However, because it depends heavily on market inputs like visitation rates, estimates of travel costs and certain socio-economic characteristics of visitors, this method becomes cumbersome to use, especially for grass root organizations (Alvarez & Larkin, 2010; Musamba *et al*., 2012). Owing to the fact that the KMC wetlands are not widely utilized for recreation, the present study opted not to quantify recreation wetlands benefits.

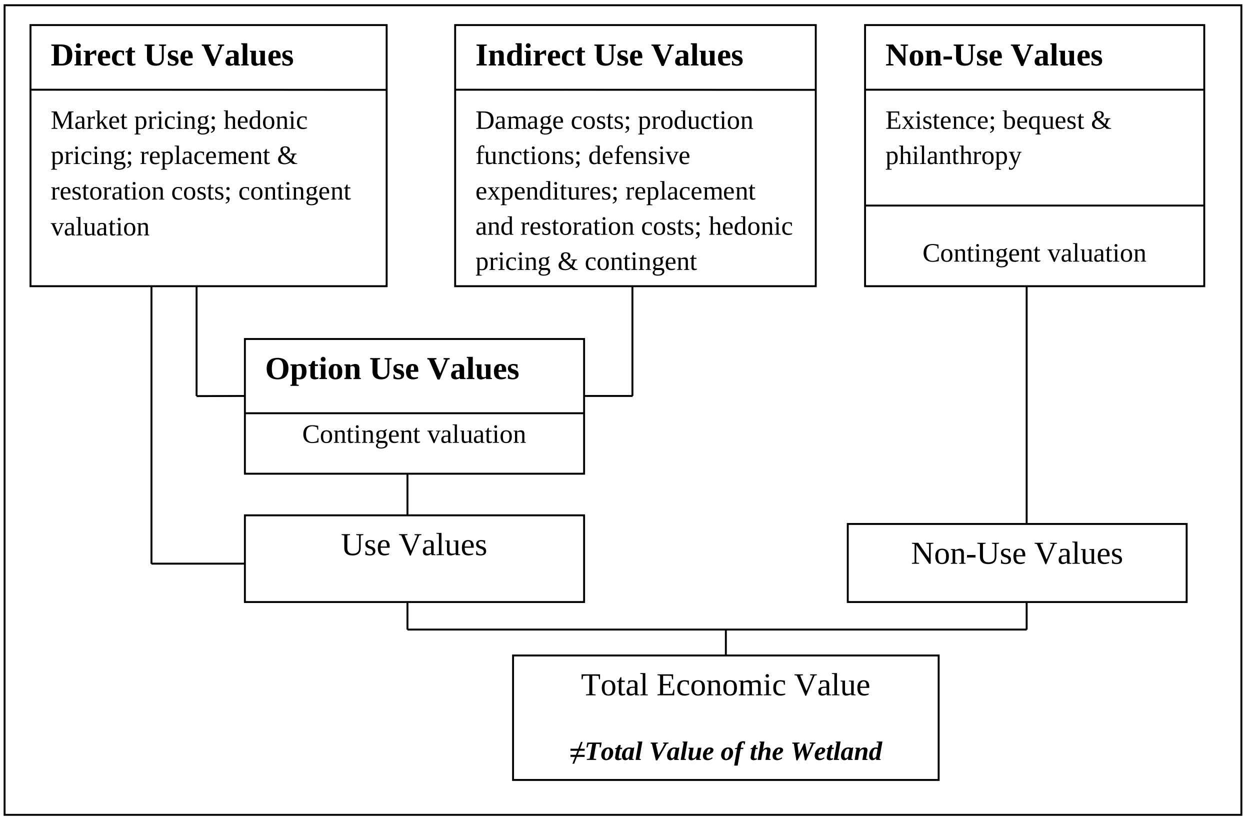


Figure 2.1: Monetary valuation techniques for different wetland values. Source: Adapted from De Groot *et al*. (2002)

Hedonic pricing/revealed preference is used to estimate the value of environmental amenities that affect the prices of marketed goods (King *et al.*, 2006). This method utilizes the assumption that the consumer's satisfaction is dependent on the characteristics of the market commodity that is used to determine the consumer's WTP (Mahan *et al.*, 2000). For example, the method attempts to identify how much of a property differential is due to a particular environmental difference between two properties and hence how much people are willing to pay for the improvement in environmental quality (Turner *et al.*, 1994). In the context of the present study, hedonic pricing can be used to estimate people's WTP for the improved quality of wetland goods like water, bearing in mind that wetlands provide water filtration services.

The replacement cost approach/damage cost avoidance approach looks at the cost of avoided damages resulting from lost ecosystem services or the cost of providing substitute services, which is used as a measure of the benefit of restoring that natural asset (King & Mazzotta, 2010).

Although this information may be useful to decision makers, the method does not provide a true measure of EV. This is mainly because it does not rely on price, which is thought to be a true indicator of EV (King & Mazzotta, 2010). Despite this, the replacement cost approach will be useful to the present study in valuing wetland services in terms of indirect use value, particularly the replacement cost of water purification services initially provided by the KMC wetlands free of charge.

The production function approach estimates the economic value of environmental products or services that contribute to the production of commercially marketed goods (King & Mazzotta, 2010). It focuses on the indirect relationship that may exist between a particular non-market environmental good or service and the production of a marketed good (Ozdemiroglu *et al*., 2006). The Dose Response technique is an example of this approach. This is based on the relationship between an environmental good and its perfect substitute. For example, the benefits of the water cleaning capacity of wetlands can be estimated by the avoidance of expenditure on water cleaning facilities (Schuyt, 2002). The opportunity cost method simply estimates the benefits of an activity that causes environmental degradation, so as to indicate the environmental benefits if the activity does not take place (Turner *et al*., 1994).

2.6.1.2 Stated preference approaches to environmental valuation

Stated preference methods of environmental valuation rely on the researcher's asking direct questions about a respondent's willingness to pay or accept compensation for changes in environmental quality. This approach utilizes two main basic methods: the contingent valuation method and the choice modelling approach (Ruzzier, 2010). The method directly ascertains the consumer's willingness to pay for a change in the level of environmental good, based on a hypothetical market (Hanley & Barbier 2009; Brander *et al*., 2006). The method can be used to evaluate both use and non-use values (King *et al*., 2006). However, this method may be cumbersome, owing to the difficulties respondents experience in dealing with multiple complex choices or rankings (Ruzzier, 2010).

2.6.1.3 Benefit transfer approach

Benefit transfer measures economic values by transferring the existing benefit estimates from studies already completed for another location or issue (King & Mazzotta, 2006). Adjustments are made for differences between the environmental characteristics of the site to which values are to be transferred, known as the ‘policy site’, and those of the site at which the original data was collected, known as ‘study site’ (Hanley & Barbier, 2009). The technique aims at providing decision makers with a monetary valuation of environmental goods and services in a cost-effective and timely manner, since original valuation studies are both expensive and time-consuming (Hanley & Barbier, 2009). The present study employs the benefit transfer method to value specific wetland benefits when obliged to by limited financial resources and time constraints.

2.6.1.4 Understanding the step by step wetland economic valuation procedure

Economic valuation relates to the practice of attaching a price to qualitatively investigated economic values. Various scholars have developed numerous but closely-related, integrated steps in approaches to wetland valuation (see Emerton *et al*., 1998; De Groot *et al*., 2006; Kyophilavong, 2011). In all of these approaches, the major steps in wetland valuation involve defining the scope of wetlands to be valued, identifying and categorizing wetland values, selecting costs/benefits to be valued, choosing appropriate valuation methods, and data collection. A distribution analysis of wetland values can be made at this stage and the entire process is concluded by the identification of economic measures for sustainable wetland management (Karanja *et al*., 2001).

The first step in the wetland valuation process is to define the scope of the wetlands to be valued. This is because wetlands are complex systems in terms of spatial distribution, type and resource utilization. It is, therefore, important to define the type of wetland and the boundaries of what is to be valued (Kyophilavong, 2011). Thus, a sample of wetlands with distinctive resource utilization activities from the KMC is determined and delineated, and subsequent analysis is based upon this. This is corroborated by Oduor *et al*. (2015) in their related study of Nyando wetlands, in which a selection of the scope of wetlands to be valued was made because wetland communities are not homogeneous in terms of wetland utilization, socioeconomic values attached, and development concerns and threats.

Definition of the wetland scope is followed by making an inventory of the different goods and services that the wetland yields (Lannas & Turpie, 2009; Kakuru *et al*., 2013). This provides an overview of the wetlands' resource potential (Emerton *et al*., 1998; De Groot *et al*., 2006). According to Kakuru *et al*. (2013), selection of these wetland goods is based on the potential of a resource to meet basic needs, the number of users harvesting the resource, various resource uses and the likelihood of obtaining sufficient quality data to enable the computation of monetary values. The concept of Total Economic Value (TEV) provides a useful framework for achieving this, by categorizing wetland goods and services according to their use and non-use value (Schuyt, 2005; de Groot *et al*., 2010). The result of this is a listing of benefits according to their direct use, indirect use, option value and existence value. The present study employs this framework in categorizing wetland goods and services, focusing on the direct and indirect use values.

The third step in the valuation process involves making a decision about which wetland goods and services to value (de Groot *et al*., 2006; Oduor *et al*., 2015). This is done mainly because it is rarely possible to value all goods and services associated with wetlands, due to time constraints and difficulties in obtaining data (Karanja *et al*., 2001). The selection of goods and services is based on a number of criteria, ranging from consideration of the most important goods and services for a given wetland, to selecting only those goods and services that can realistically be valued (Barbier *et al*., 1997). Since it was realistically impossible to value all wetland goods and services, the present study only concentrated on four direct use wetlands goods: thatch, clay, water and crops; and two indirect use wetland services: flood attenuation and water purification.

Having chosen which type of goods and services are to be considered, it then becomes necessary to identify which techniques will be applied in order to calculate their economic value (Karanja *et al*., 2001; Ajibola, 2014). The result of this is a listing relating wetland benefits to economic valuation methods. Figure 2.1 identifies the most commonly used wetland valuation methods associated with different wetland valuation functions. These techniques are discussed in Section 2.6.1.1. However, selection of these techniques depends on the nature of the good in question, length of time for the study, and the resources available for the entire exercise (Boyd & Wainger, 2003). For goods that are traded in the open market, the market pricing technique may be used (Barbier *et al*., 1997; Karanja *et al*., 2001; Oduor *et al*., 2015), while those that are not traded in the open market may be valued through other methods such as the contingent replacement cost

(Costanza *et al*., 1997), hedonic pricing, or travel cost (Kakuru *et al.*, 2013) among others. The present study employed the market price method to value the KMC wetlands, based on wetland goods with direct use value, since all of them are traded in the open market. The replacement cost method was employed to value the indirect use values of wetland services, and due to inadequate resources and time, this method was only used to value water purification. The contingent valuation method was employed to value flood attenuation owing to the availability of market information and easy estimation of values in a hypothetical market.

When valuation techniques have been identified, it becomes necessary to think about how economic values will be expressed (Karanja *et al*., 2001; Ramachandra & Rajinikanth, 2009), which calls for the identification of economic value indicators. Various studies have considered income, profits, and returns as the main measures of economic value (MEA, 2005; Schuyt, 2005). As elaborated by Karanja *et al*. (2001), Lannas and Turpie (2009), Oduor *et al*. (2015), there is a wide range of economic measures that can provide estimates of wetland value, such as total returns, cash income, subsistence values, returns to labour, and to land, as summarized in Table 2.2. The annual value of wetland-based activities to households in Lesotho wetlands was evaluated in terms of average gross, net, and cash household incomes (Lannas & Turpie, 2009). These indicators were adopted by the present study. In this regard, the focus rested on the Net Cash Income, Subsistence Consumption Value and the Gross Value as indicators of economic value, in order to provide estimates of total returns to income, subsistence value and returns to land for the selected goods and services.

Table 2.2: Indicators of wetland economic value (Adapted from Karanja et al., 2001)

Economic indicator	**Description/expression**
The gross value (for both goods and services)	How much the goods and services are worth overall.
Net value (for all goods)	The use value of the goods, less costs of producing or harvesting them.
Net cash income (for marketed goods only)	Cash income earned from sales of goods, less cash costs of harvesting them
Subsistence consumption value	Value to household consumption of goods
Returns to labour (for all goods)	How much goods are worth per day spent on harvesting/using them
Returns to land (goods clearly linked to specific land areas)	How much goods linked per hectare of land required to produce them

Having identified the indicators of EV, it becomes crucial to specify data needs for valuation. According to Karanja *et al*. (2001), Ramachandra and Rajinikath (2004), and IUCN (2011), this detailed listing of the exact data required to calculate different wetland values provides the basis for deciding on the ways in which information will be collected, and how calculations will be expressed in comparable units of time, area, and weights or volume, in order to reflect selected indicators of economic value. At the same time, seasonal or other variations in amounts of wetland goods harvested, produced or sold (prices) and other factors must be considered. These data considerations are a feature of comparable studies (see Karanja *et al*., 2001; Kakuru *et al*., 2013; Oduor *et al*., 2015). The present study considered a range of data needs for wetland valuation. These comprised prices, amount harvested per unit area or sold, as well as the input needs to harvest, process and market goods, the input's lifetime, and labour requirements per unit output.

In specifying this data, time and units of measurement are crucial frames of reference that must be considered if valuation figures are to make any sense or be comparable with other alternatives, which in this perspective are the costs of wetland protection or other alternative decisions in line with wetland management (Miththapala, 2008). Such units of time may include how much is collected, processed, or sold per month/year. The units of volume of weights may include, bundles, kilograms, etc. In some cases, it was also possible to relate volumes of use to specific land areas, especially at the harvesting stage, or for different groups of people. The present study adopted the use of similar units of volume or weight for the valuation of goods, while hectares were considered as specified land areas in estimating the units of volume. A detailed list of the data requirements in valuation studies is presented in Table 2.3.

After wetland values have been quantified, the distribution of wetland values between different stakeholders can be assessed (Barbier *et al*., 1997; Emerton, 1998; Reed *et al*., 2009). This involves determining the type and level of benefits and costs accruing to different stakeholders and to different activities, the outcome of which facilitates the determination of who gains and who loses, and by how much, from the selected wetlands. Ruzzier (2010) points out that a distribution analysis is critical for predicting which stakeholder groups are likely to support a change in the management of an environmental resource and which are likely to oppose it. Hein *et al*. (2006) and Reed *et al*. (2009) identify local households, the private sector, government and the global community as the principle actors/stakeholders to be considered in wetland valuation.

Table 2.3: Data requirements for wetland economic valuation

Data requirements of unit of a good by unit of time.
For primary harvesters • Amount harvested • Proportion sold • Price sold at • Labour requirements for harvesting • Type and amount of equipment/inputs used • Cost of equipment/inputs • Life time of equipment • For some goods (crops) amount of land area to produce a given amount of good.
For artisans, households and traders • Amount produced • Proportion sold • Price sold at • Labour requirements • Equipment used (type) • Time spent selling products • Transport costs of goods for sale • Other market costs license, transportation cost • Cost equipment/inputs. • Lifetime of equipment. • Extent of the wetland

(Adapted from Karanja *et al*., 2001; Ramachandra & Rajinikanth, 2004)

The final stage in ecosystem economic analysis involves identifying economic measures for sustainable wetland management (Emerton, 1998; Ruzzier, 2010). This is mainly because management of these ecosystems and the groups upon which the burden of degradational costs rests require operational funds (Emerton & Muramira, 1999). Since valuation estimates the extent and distribution of wetland benefits and costs, it provides an insight into conservation, financing needs, and also identifies those actors who either benefit freely, or utilize wetlands resources at low cost, without being reprimanded for the harm they cause (Turpie *et al*., 2010). In turn, this enables policy makers to identify niches for capturing additional revenues, which can be redistributed to the groups who bear the costs associated with wetland conservation (Emerton, 1998).

2.6.1.5 Limitations to wetland valuation

As noted above in section 2.6.1, valuation is a useful tool for wetland conservation since it highlights a range of costs and benefits which have been ignored in the past by planners, policy and decision makers. It does, however, have a number of shortcomings and weakness. According to Emerton (1998), the following methodological issues and limitations should always be borne in mind when carrying out wetland valuation:

- The reality of wetland values is sometimes limited. They are rarely real values and often don’t exist in terms of concrete prices or income. They should, therefore, be seen as indicative estimates, which present a guide to what wetlands may be worth, for use in planning, policy and decision making (Hadley *et al*., 2011).
- Some wetland benefits will always be unquantifiable and immeasurable, because the necessary scientific, technical or economic data is not available, while other aspects which relate to human life or religious and cultural significance involve ethical considerations. For example, brick making, clay extraction or papyrus harvesting are designated as undesirable activities compared to others, since they are perceived as unsustainable utilization activities likely to lead to tremendous wetland modifications, despite the fact that they contribute greatly to human welfare. For such controversial reasons, it is no straightforward matter to value wetlands (Emerton, 1998).

2.7 Carbon sequestration in wetlands and implications for climate variability

Wetlands are optimum natural environments for sequestering and storing carbon (C) from the atmosphere owing to their anaerobic conditions (Mitra *et al*., 2005; Mitsch *et al*., 2013). Carbon is held in living vegetation as well as litter, peats, organic soils and sediments that have built up over the years. This makes wetlands critical in mitigating climate change and its effects on human welfare (Foster *et al*., 2012). It is estimated that 20–30% of the global soil carbon pool (i.e. 2,500Pg C) is stored in wetlands (Lal, 2008) that only occupy 5–8% of the earth’s land surface (Mitsch, 1986). However, wetlands also release carbon both through natural, seasonal changes and, more drastically, when their equilibrium is affected by human interference (Goreau & Mello, 2007).

The magnitude of storage depends on wetland type, size, vegetation, depth of wetland soils, groundwater and nutrient levels, pH, and other factors (Parish & Looi, 2011). Various studies have attempted to estimate carbon sequestration potentials according to wetland type. Based on regional scales, Bernal and Mitsch (2012) have reported that fresh water temperate wetlands (depressional) sequestered 317 ± 93g C m−2 yr−1, more ($P < 0.01$) than the riverine communities that sequestered 140 ± 16g C m−2 yr−1. In contrast, the humid tropical wetlands in Costa Rica accumulated 255g C m−2 year−1 for over 42 years (Mitsch *et al*., 2010). Saunders *et al.* (2007) carried out carbon estimates in similar/related regions of East Africa in which they realised that the papyrus (*Cyperus papyrus L.*) of East Africa had the potential to sequester approximately 0.48kg C m−2 y−1 while. In a later paper, Saunders *et al*. (2014) indicate that papyrus represents a significant C sink, where up to 88t C ha−1 is stored in the aboveground and belowground components. Other significant C sequestration estimates for different wetland types include the peat forest swamps which sequestered between 0.01 and 0.03 Gigatonnes of carbon annually (Sorensen, 1993), mangrove forests, with an average of 1,023 Mg carbon per hectare (Donato *et al*., 2011) while disturbed estuarine wetlands (e.g. in New South Wales, Australia) were noted to sequester higher levels (3900–5600 Gg C) owing to wetland rehabilitation works (Howe *et al*., 2009).

Despite these sequestration figures, wetlands are not managed as environmental capital worthy of protection and investment (UNDP, 2009). They are instead degraded for economic gains (Joshi *et al*., 2002) in response to demographic shifts, severe economic stress and information failures about their economic value (Huising, 2002; Schuyt, 2005). The loss of an existing wetland means not only the loss of that particular carbon sink, but also that the carbon in that wetland will be released, adding to the total carbon load in the atmosphere and thereby contributing to climate change (Lal, 2004; Foster *et al*., 2012). Scientists point to several factors that may affect wetlands, given the fact of carbon-driven climate change: increased carbon dioxide concentrations, a longer growing season due to increased temperature, increased water to some drier wetlands, decreased water and thus more vegetation in drier systems (Scholz, 2011).

The KMC is one region where human-induced wetland modification is bound to alter wetland cover and ecological stability, hastened by pressure for industrial and residential estate expansion (Mafabi, 2003; Byaruhanga & Ssozi 2012; Turyahabwe *et al*., 2013b). However, the literature on the complex and variable environmental consequences of wetland diminution as a result of DPs is still scanty (Saunders *et al*., 2007; Maltby & Barker, 2009). Studies have concentrated on analysing/modelling fundamental wetland functions for sustainable management, wetland inventories and economic valuations to develop adaptation strategies to climate change (see Nabulo *et al*., 2008; Mabasi, 2009; Kanyiginya *et al*., 2010; Lwasa, 2010; Turyahabwe *et al*., 2013a). Addressing this information gap for the KMC is critical for informed optimal decision making at national and local planning levels.

2.8 Restoration and enhancement of carbon sequestration

Restoring and increasing carbon sequestration in wetlands may involve measures such as the planting of coniferous, shrub, and forested wetlands, and creating seasonal wetlands that do not flood for long periods (Paul, 2008). It has also been suggested (see Megan & Nater, 2006; Bernal, 2012) that it is the continuously flooded parts of the wetland marsh systems that store most carbon. In association with these strategies, certain land use changes (including wetland restoration and protection) should be adopted as development priorities at the local, regional and state levels (Yang *et al*. 2010).

2.9 Methods of estimating SOC

A variety of methods exist for the estimation of soil organic carbon (SOC). Normally, SOC is measured by dry combustion at high temperatures in a dry furnace, with the collection and determination of evolutionary carbon through the use of automated analysers (Schumacher, 2002). It is also done through the wet chemical oxidation method, followed by titration of the remaining dichromate with ferrous ammonium sulphate or photometric determination of C_r^{3+} (Ellerbrock *et al*., 1999). The dry combustion method is considered the most precise and accurate procedure today, but the high cost of dry combustion equipment is a major limitation to many laboratories (Konen *et al*., 2002). The manual dichromate procedures are widely used for routine SOC determination where the purchase of an automated system cannot be justified, mainly because of the simplicity, rapidity and precision of the method compared to dry combustion (Nelson & Sommers, 1975; Kimble *et al*., 2000).

The first step with organic carbon (OC) determination by oxidation is heating with potassium dichromate solution ($K_2Cr_2O_7$) in sulphuric acid (H_2SO_4). This is followed by the estimation of the amount of potassium dichromate used for OC oxidation (as in Equation 2.1), evaluated by titration or photometric analysis (Ponomariova & Plotnikova, 1980; Nikitin, 1999; Filcheva & Tsadilas, 2002; Spiegel *et al*., 2007).

$$3C + 2KCr_2O_7 + 8H_2S0_4 = 2Cr_2(SO_4)3 + 3\ CO_2 + 2KSO_4 + 8H_2O \quad \text{Eq. 2.1}$$

The excess dichromate (Cr_2O_7) is titrated with ferrous ammonia sulphate solution (Fe $(NH_4)_2(SO_4)_26H_20$), and the Cr_2O_7 reduced during the reaction with the soil is assumed to be equivalent to the organic C present in the sample (Angelova *et al*., 2014). A combination of other related OC determination methods by oxidation frequently in use include: Walkley and Black (1934), Walkley-Black modified with external heating (Kalembasa & Jenkinson, 1973; Filcheva & Tsadilas, 2002). The present study employed the manual wet chemistry/oxidation method pioneered by Walkley & Black (1934). The justification for adopting this approach is provided in the Methods chapter.

2.10 Wetland hydrologic assessments

The formation, size, persistence and functions of wetlands are controlled by hydrological processes (Sun *et al*., 2002; Acreman & Miller, 2006; Mitsch, 1986). The hydrologic behaviour of a wetland can be characterized according to three hydrologic variables: the water level, hydro pattern and residence time (U.S. EPA, 2008). These three components are influenced and controlled by the hydrological inputs and outputs summarized in the wetland water budget (U.S. EPA, 2008; Thompson, 2012): see Equation 2.2 (A detailed version of the wetlands water budget is available in Maltby & Barker, 2009). The wetland gains and losses expressed by Equation 2.2 determine the net wetland storage term upon which hydrological parameters depend.

$$dS = P + Qi + Gi - E - Qo - Go \qquad \text{Eq. 2.2}$$

Where: dS = change in water storage

P = rainfall

E = evapotranspiration losses

Qi/Qo = surface groundwater inflow/outflow

Gi/Go = subsurface groundwater inflow

2.11 Evolution and impacts of wetland hydrologic alterations

The conservation of wetland hydrological functions results in a wide range of values, including groundwater recharge and discharge, flood attenuation and sediment stabilization (Zedler & Kercher, 2005). Alterations in catchment hydrology, including abstractions from surface and groundwater, impoundment/diversion of rivers and land use change or upstream developments, can have adverse impacts on the fragile wetland hydrologic behaviour. These impacts manifest through increased sediment production and transport, increased nutrient concentrations and loads, and changes in wetland flow velocities and storage volumes (U.S. EPA, 2008). Resulting from this are significant alterations in wetland processes, species composition and ecological functions (Acreman & Miller, 2006).

The construction of ditches, canals or channels increases wetland outflows and also alters the natural drainage and residence time through the wetland (Chabreck, 1988). These effects finally result in lowered groundwater levels with increased subsurface drainage (Querner, 2000). Drainage of fields for agriculture reduces surface water inflows (U.S. EPA, 2008; Blann *et al*., 2009; Westbrook *et al*., 2011), while wetlands with substantial macrophytic vegetation can increase hydrologic roughness, thus decreasing flow velocities (Tabacchi *et al*., 2000; Chadwick *et al*., 2002). Beneficial hydrologic wetland functions, such as flood attenuation and groundwater recharge, are usually compromised by the increased wetland loading, along with decreased retention and residence times (Chadwick *et al*., 2002).

Owing to their proximity to industrial incentive zones and exposure to the market forces of consumption, the KMC wetlands apparently constitute some of the few strategic locations suitable for allocation to DPs (Nyakaana & Sengendo, 2004), particularly industrial establishments, residential estates and agriculture (Gumm, 2011). However, literature on the hydrological impacts arising from development activities in wetlands is rather still scarce (Mafabi, 2003). Previous studies in Uganda have focused on biodiversity inventories to prioritize wetlands in need of biodiversity protection, and soil studies to assess the suitability of soils for agriculture and other uses (see Namakambo, 2000; Muwanga & Barifaijo, 2006; Nabulo *et al*, 2008; Kanyiginya *et al*., 2010), and economic valuations to enable informed decisions on wetland management options (see Emerton *et al*., 1998; Karanja *et al*., 2001; Maclean *et al*., 2003; Schuyt, 2005; Nsereko, 2010; Kakuru *et al*., 2013; Turyahabwe *et al*., 2013a). The hydrological implications of wetland diminution for sustainable development constitute a variable and complex topic that the present study intends to address.

2.11.1 Indicators of hydrological disturbance to wetlands

In response to prevalent wetland hydrological alterations, various approaches have been developed to determine wetland hydrological disturbances. According to Conly and Van der Kamp (2001), these approaches require extensive regional scale data, complemented by intensive measurements at given locations. According to Wilcox (1995), since plant communities respond to hydrologic/habitat alterations, observations of changing plant communities may be used to determine the effects of hydrologic disturbances that may not be easily understood. In conjunction with remote sensing technology, vegetation studies and water level monitoring are vital to understanding hydrological disturbances (see Shafroth *et al*., 2002; Cline & McAllister, 2002; Džubáková *et al*., 2015).

Stream environmental flow assessments have also been applied to monitor hydrological changes since particular aquatic organisms respond to changes in stream flows. This method has been applied in Turkey's wetlands, which are at considerable risk of biodiversity loss arising from changes in hydrological disturbances (see Gül *et al*., 2014). Richter *et al*. (1996) compares hydrological parameters using measures of central tendency and dispersion for given significant hydrologic parameters based on user-defined "pre-impact" and "post- impact" time frames. As indicated in the Richter et al. (1996) study, this method is usually intended to plan ecosystem management activities or measure progress towards conservation or restoration goals (see Kansiime *et al*. 2007).

Reid and Brooks (2000) have applied selected sensitivity indicators to determine wetland hydrological disturbances. In their study, a wide range of physical (wetland depth, wetland area), chemical (salinity) and biological (aquatic macrophytes and macro invertebrates) indicators are recommended, in association with information on other components of the ecosystem and how they relate to hydrology. Other studies have evaluated hydrologic disturbances by monitoring nutrient (Total nitrogen - TN, Total Phosphorous - TP, Sulphur - S) and sediment load (suspended sediments) (Brown & Krygier, 1971; McClain *et al*., 1998; Bruland *et al*., 2003; Stevenson *et al*., 2006). This method is premised on the fact that the hydrologic and water quality functions of wetland are all related to the wetland physical setting (Carter, 1996). The present study used a combination of these approaches, especially nutrient, chemical and flow-based approaches, to monitor hydrologic impacts of wetland conversion for DPs.

2.12 Conceptual framework

The economic and ecological trade-offs of wetland diminution for DPs is one of the major unresolved issues in environmental sciences. The present study seeks to fill this knowledge gap by assessing the economic potential accruing from wetland conservation in terms of its monetary value, and the ecological implications of the KMC wetland development options.

Figure 2.2 presents an integrated conceptual framework for assessing the economic and ecological trade-offs of wetland conversion for DPs in the KMC. As the schematic diagram in Figure 2.2 shows, development decision making in wetlands is anchored in the appreciation of wetland benefits, which include the economic and ecological benefits. These indirectly inform economic and ecological trade-offs. The economic valuation of wetland goods and services facilitates the assessment of economic trade-offs of wetland conversion for DPs using the Total Economic Valuation framework. The trade-offs include intrinsic economic value, alternative employment/income benefits, subsistence livelihood products and subsidized public expenditure on goods and services. The complex ecological trade-offs of wetland conversion for DPs are analysed from the perspective of key wetland ecological services, particularly carbon sequestration and hydrological services, utilizing the Soil Organic Carbon (SOC) and the Hydrological Impact Analysis (HIA) methodological approaches, respectively.

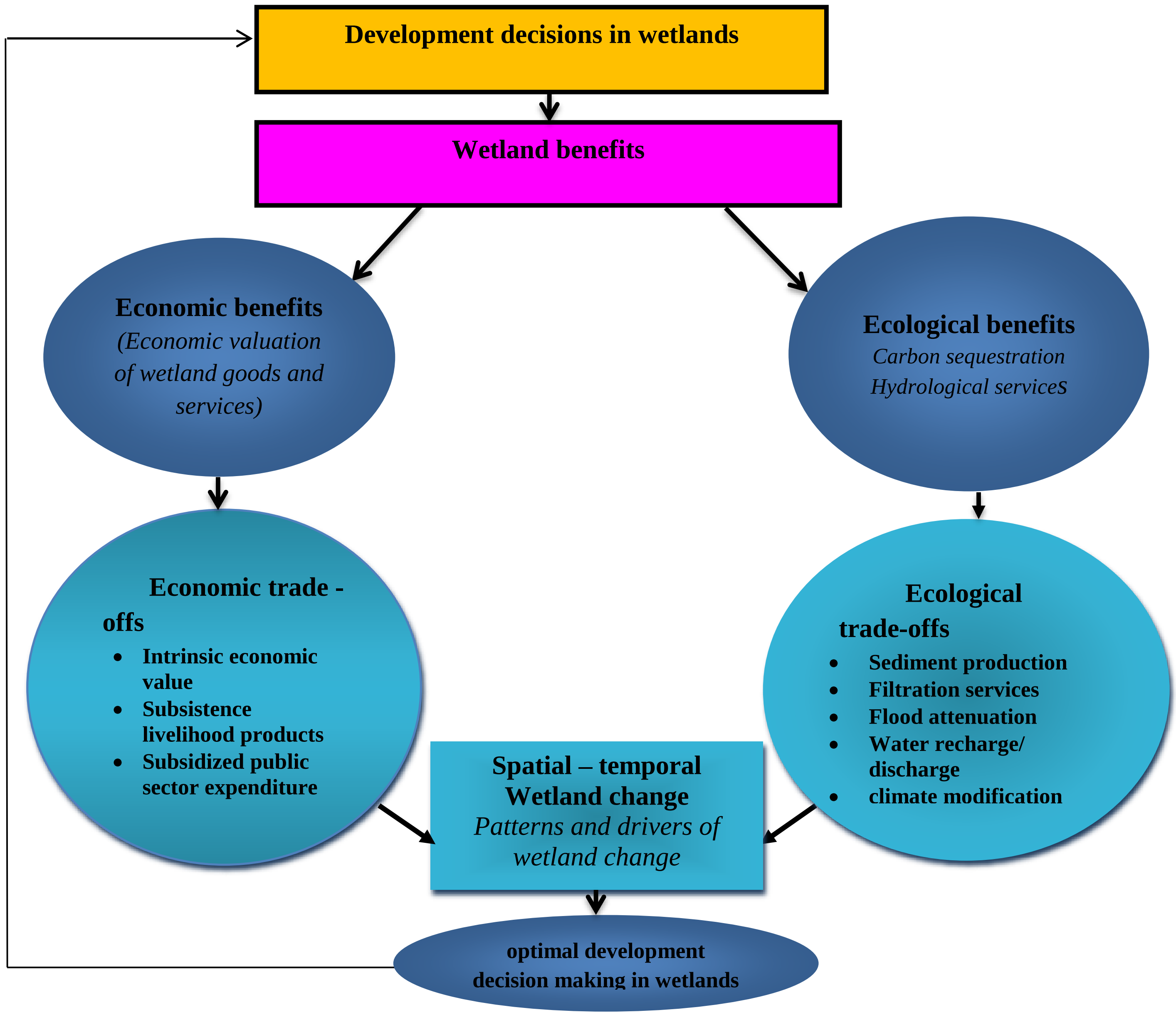


Figure 2.2: Conceptual framework for assessing the economic and ecological trade-offs of wetland conversion for DPs in the KMC

2.13 Summary

In summary, an assessment of the economic and ecological trade-offs of wetland conversion for DPs in the KMC provides a better platform for informed development decision-making in the wetlands. This chapter has reviewed the nature of wetland values, approaches to wetland valuation, and the undervaluation of wetlands in development decisions. A review of carbon sequestration in wetlands and its implications for climate variability, restoration and enhancement of carbon sequestration in wetlands, together with methodological approaches in estimating SOC and hydrological impact assessment have also been presented. This review has provided insight into the study objectives. The next chapter presents the methods employed to achieve these objectives.

CHAPTER THREE
Materials and Methods

3.1 Introduction

This chapter presents the research methodology employed to achieve the study objectives. The chapter covers the research design, methods of data collection and analysis, and the mode of presentation of the study results. A summary of the methodology framework is presented in Figure 3.1.

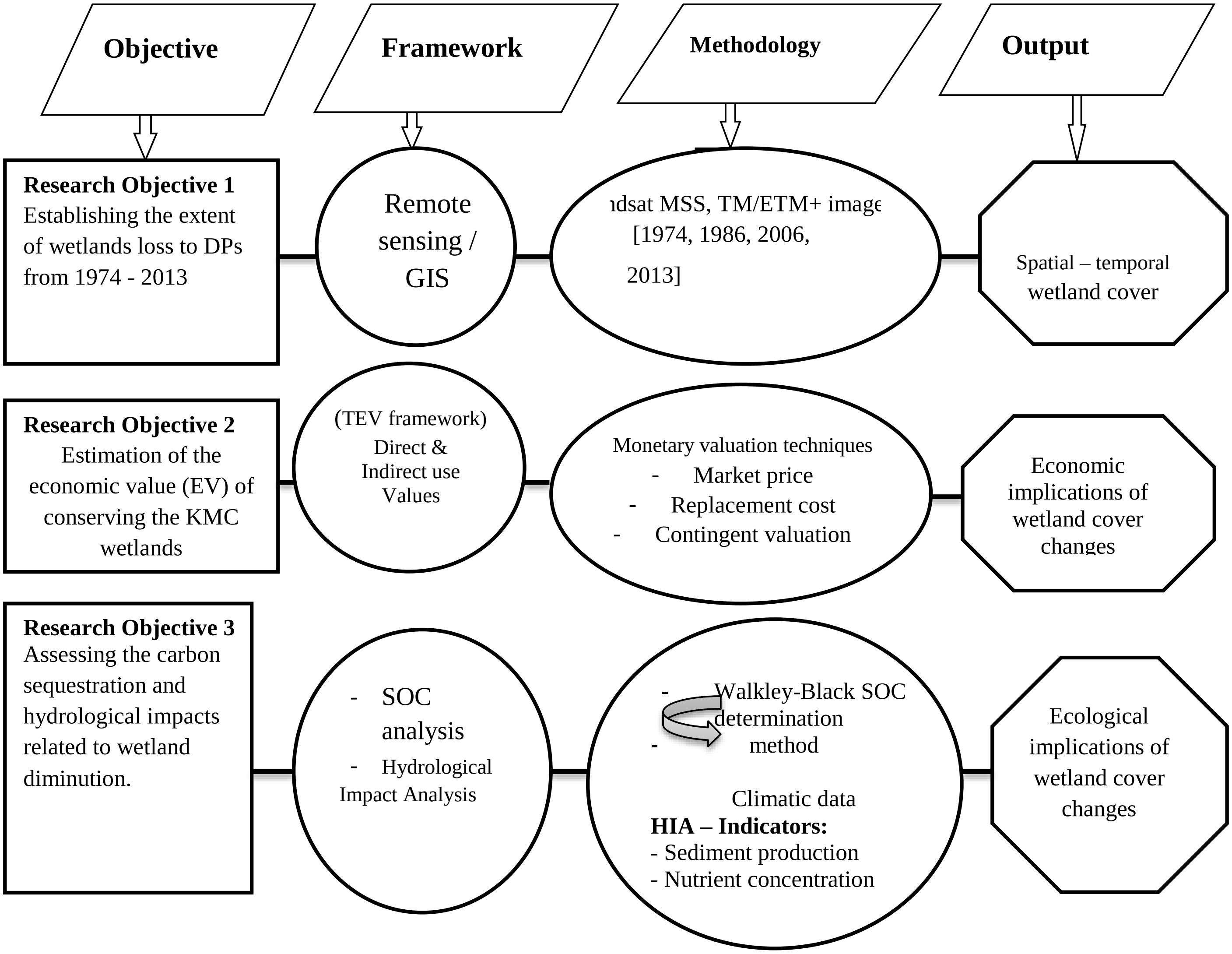


Figure 3.1**:** Structure of the research methodology employed in the current study

3.2 Research design

This study combined quantitative and qualitative research approaches by employing a cross-sectional survey design in which information relating to the economic valuation of wetlands and related surveys was collected from a cross-section of respondents who engage in resource utilization activities in the wetlands. The quantitative approach was used to analyse wetland economic values, the spatial and temporal wetland cover changes, soil organic carbon sequestration and hydrological impacts of wetland diminution. The qualitative approach was adopted in wetland economic valuation surveys, particularly in the inventorying of wetland goods and services and obtaining specific data required for the valuation process.

3.3 Methods of data collection and analysis

3.3.1 Assessment of the spatial and temporal wetland changes to DPs

This section presents the methods employed in the assessment of the spatial-temporal wetland changes and projection of future wetland change to DPs. In essence, this section covers Landsat satellite imagery acquisition, pixel harmonization procedures, image processing and classification assessments, change detection determination of drivers of wetland change. The section concludes with methodological explanation of how the prediction of future wetland change to DPs was assessed. A summary of these methods and approaches is presented in Figure 3.2.

3.3.1.1 Landsat satellite imagery

Satellite remote sensing of wetlands is a successful tool in identifying wetlands and separating them from other land use/cover types (Ozesmi & Bauer, 2002). The Landsat imagery can facilitate regular monitoring of land use/cover changes on the earth's surface. The freely available images enable the reconstruction of the history of the earth's surface as far as 1972, chronicling both anthropogenic and natural changes (Woodcock *et al*., 2008). The multispectral Landsat images were also selected for this study because of high satellite repetitive coverage and free image availability. Four sets of Landsat imagery datasets were downloaded from the Glovis web portal (http://glovis.usgs.gov/) for the years 1974, 1986, 2006 and 2013 with the cloud cover ranging from 1% to 10%, taken in the dry season. In this period, the atmospheric space has low cloud distribution, agricultural land is under preparation and allows spectral distinction of land use/cover activities. The year 1974 was used as the benchmark for the analysis because it was a time when the KMC wetlands had not yet experienced massive encroachment, as Kampala (the capital city) had not yet superseded Jinja (in Eastern Uganda) as a preferential location for industries (NEMA, 2005; Apunyo, 2008). Coupled with this was the absence of quality images of the study area for periods before 1972, when wetlands were intact and free from encroachment, owing to the existence of strong functional wetland regulatory frameworks. The image specifications of the downloaded images are shown in Table 3.1 below:

Table 3.1: Landsat Image Specifications

Year	**Landsat sensors**	**Spatial resolution**	**Cloud coverage**	**Path and Row**	**Band combinations**
29th January 1974	Landsat MSS	80m	1%	184060	2,3,4
28th December 1986	Landsat TM	30m	1%	171060	2,3,4
10th February 2006	Landsat 7 ETM+	30m	1%	171060	2,3,4
19th June 2013	Landsat 7 ETM+	30m	10%	171060	2,3,4

3.3.1.2 Pixel harmonization

The Landsat satellite images acquired from different sensors at different spatial resolutions and projections can be re-projected, co-registered, and orthorectified to the same projection, geographic extent, and spatial resolution using a common base image through a combined resampling strategy; which allows the performance of multi-temporal image analysis directly (Gao *et al*., 2009). For this reason, the spatial resolution of the degraded Landsat MSS imagery was upgraded to 30m using a resampling method. All the imagery pre-processings and analysis were performed in IDRISI software.

3.3.1.3 Pre-processing

Pre-processing of downloaded images plays an important role in ensuring that a higher classification accuracy is attained. The pixel-harmonized images were pan-sharpened (ETM+) and re-sampled to the 2013 imagery to harmonize the pixel resolution and later atmospherically corrected using the Dark Object Subtraction (DOS) method to represent the landscape as realistic as possible. The approach assumes the existence of dark objects throughout the image and a horizontally homogenous atmosphere, while in removing the random pixel errors and noise, the images were subjected to a calibration process with the help of a simple median filter (using 3 x3 windows). Correspondingly, the images were geometrically rectified for distortions to facilitate change detection assessment and computation of area of classified wetland use/cover activities on the ground with the help of ground control points. The image sets were geometrically corrected and referenced to the projection UTM zone 36N and datum WGS84 using an Authority Code of 32636. The transformation process posted a root mean square error of 0.3 pixel which falls within an acceptable range. The RMSE is a deviation between ground control points and ground point's location as predicted by the fitted-polynomial and their actual locations. In addition, the acquired images were filtered using spatial filtering method to weed out random errors and enhance the visibility of elements of land use/cover activities under interpretation.

The preliminary classified images were further refined by assigning classes to their location-specific names based on the developed wetland use/cover classification scheme (Table 3.2), using ground-truthed data collected in September 2013 within the locations, and picked using a calibrated Garmin Global Positioning Systems. The scheme was collated and updated with that developed by the National Forest Authority (National Biomass Study, 2003) – and also in reference to the developed national land use/cover change maps for Uganda. The purposively selected stakeholders (district officials) and knowledge of the research area guided the selection of sites that were randomly visited and mapped for wetland use/cover activities and their associated attributes such as soil, slope, development projects and type of crops grown. The 1974 image was validated using a topographic map (sheet number 50/y for year 1974) covering Kampala and Mukono districts, acquired from the Institute of Survey and Land Management in Entebbe. In addition, the later images (such as 2013) were collated using Google Earth (GeoEye- 1-0.5m) imagery because of inaccessibility to some of the intact wetland types like papyrus swamps, marsh and bogs.

Table 3.2 Description of wetland use/cover types

Wetland Use / Cover Types	Description
Forest swamps	Continuous stands of trees at least 10m in height with interlocking crowns – Not encroached.
Papyrus swamp, marsh, bog	More than 50% of the area dominated by dense papyrus cover, punctuated with grassland, reeds, sedges and bog mosses / heaths.
Palms and thickets	Scattered palms with bushes usually less than 10m in height, and a medium to dense canopy cover – Encroached.
Wetlands converted to agricultural	Wetlands converted and modified by agriculture (subsistence crop growing) as major land use. – encroached.
Wetlands converted to industrial	Wetland converted to industrial activities depicted with scattered industrial estates – both large and small-scale industries. – encroached
Wetlands converted to settlement	Wetlands converted and modified by settlement – slum and semi slum residential housing. – encroached.
Open water	Areas of permanent or semi-permanent water with little flow
Island	Exposed bare/barren land in a water body

Source: *Adopted from National Biomass Wetland Classification (2003)*

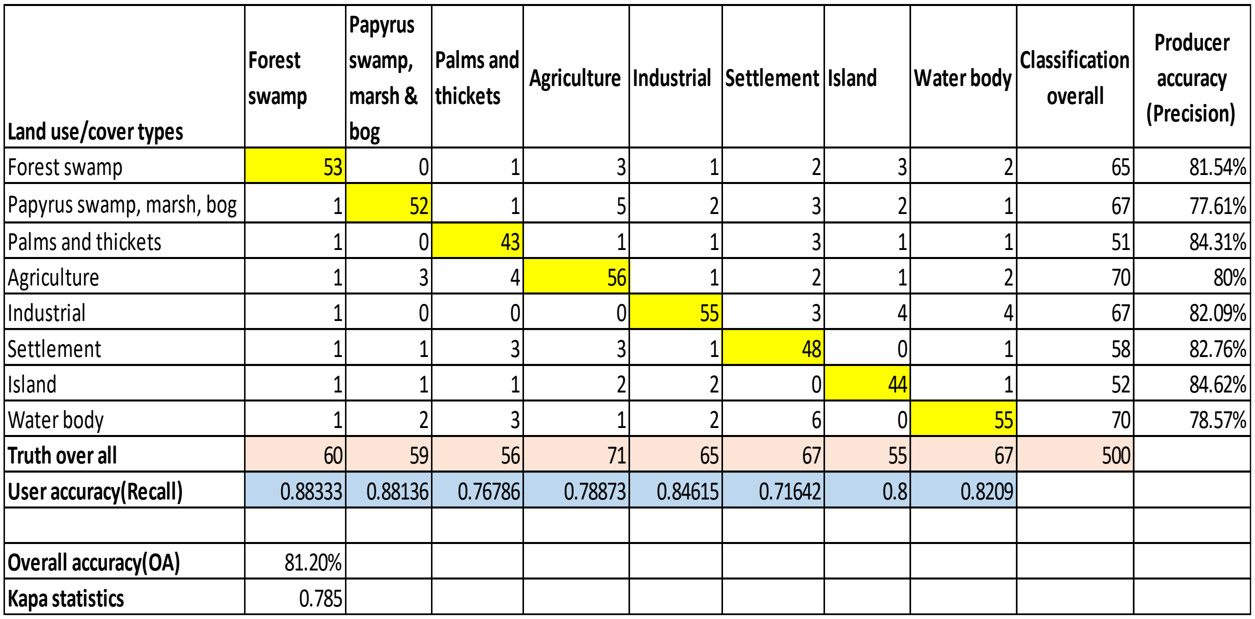
3.3.1.4 Image classification

Image band combinations gainfully adds value to image interpretation. The image composites (2, 3 and 4) were generated to facilitate the extraction of features and understand pixel spectral representations. The wetland use/cover type class separability for each year was computed using Jeffries-Matusita (J-M) method (Heumann, 2011). The metrics values ranged between 0 and 2.0, and accordingly, those greater than 1.9 indicated good separability of classes while for those less than 1.9, the wetland use/cover classes were further split and merged during post classification (See appendix N). Unsupervised image classification procedure was used, following the K-means clustering algorithm in IDRISI software platform, with the aim to statistically clump spectral features in each image into discrete classes. Unsupervised classification takes maximum advantage of spectral variability in an image. The Hill-climbing K-means clustering method with 8 clusters at an iteration of 5 deemed suitable for all the selected images utilised. The classified images were cleaned for pixel noise by performing a majority filtering method and clusters synchronised into 8 classes.

3.3.1.5 Image classification accuracy assessment

Image classification accuracy assessment is important in determining the adequacy of the classification approach. We envisaged errors to originate from interpretation and it's out of this investigation that the confusion matrix based accuracy assessment method was considered. The method is one of those most used in assessing the accuracy of classified images (Lu *et al*., 2004). The number of reference points is essential for estimating the accuracy of a classification and 100 points were used for the computation of Kappa and overall accuracy because it is usually considered to be the minimum number of reference points needed (Güler *et al*., 2007).

Table 3.2.1: Classification accuracy assessment for 1974 image



Land use/cover types	**Forest swamp**	**Papyrus swamp, marsh & bog**	**Palms and thickets**	**Agriculture**	**Industrial**	**Settlement**	**Island**	**Water body**	**Classification overall**	**Producer accuracy (Precision)**
Forest swamp	53	0	1	3	1	2	3	2	65	81.54%
Papyrus swamp, marsh, bog	1	52	1	5	2	3	2	1	67	77.61%
Palms and thickets	1	0	43	1	1	3	1	1	51	84.31%
Agriculture	1	3	4	56	1	2	1	2	70	80%
Industrial	1	0	0	0	55	3	4	4	67	82.09%
Settlement	1	1	3	3	1	48	0	1	58	82.76%
Island	1	1	1	2	2	0	44	1	52	84.62%
Water body	1	2	3	1	2	6	0	55	70	78.57%
Truth over all	60	59	56	71	65	67	55	67	500	
User accuracy(Recall)	0.88333	0.88136	0.76786	0.78873	0.84615	0.71642	0.8	0.8209		
Overall accuracy(OA)	81.20%									
Kapa statistics	0.785									

Key: Agriculture – wetlands converted to agriculture, Industry – wetlands converted to industry, Settlement – wetlands converted to settlements

Table 3.2.2: Classification accuracy assessment for 1986 image

Wetland type/cover	Forest swamp	Papyrus swamp, marsh & bog	Palms and thickets	Agriculture	Industrial	Settlement	Island	Water body	Classification overall	Producer accuracy (Precision)
Forest swamp	48	0	1	1	4	3	2	1	63	76.19%
Papyrus swamp, marsh, bog	1	45	1	1	2	3	2	0	55	81.82%
Palms and thickets	0	1	60	0	1	1	1	3	67	89.55%
Agriculture	1	1	1	49	1	6	2	2	63	78%
Industrial	0	2	0	1	57	2	1	0	63	90.48%
Settlement	1	1	2	0	1	40	0	1	46	86.96%
Island	1	1	2	5	2	1	45	2	59	76.27%
Water body	1	0	0	1	0	4	1	78	85	91.77%
Truth over all	53	51	70	58	68	60	54	87		
User accuracy(Recall)		88.24%	85.71%	84.48%	83.82%	66.67%	83.33%	89.66%		
Overall accuracy(OA)	84.23%									
Kapa statistics	0.819									

Key: Agriculture – wetlands converted to agriculture, Industry – wetlands converted to industry, Settlement – wetlands converted to settlements.

Table 3.2.3: Classification accuracy assessment for 2006 image

Land use/cover	Forest swamp	Papyrus swamp, marsh & bog	Palms and thickets	Agriculture	Industrial	Settlement	Island	Water body	Classification overall	Producer accuracy (Precision)
Forest swamp	53	0	0	3	1	0	3	10	70	75.71%
Papyrus swamp, marsh, bog	0	55	1	5	0	1	0	1	63	87.30%
Palms and thickets	1	0	51	0	0	2	3	1	58	87.93%
Agriculture	0	3	0	52	0	0	0	0	55	95%
Industrial	4	0	2	0	54	3	4	4	71	76.06%
Settlement	1	1	0	0	0	49	0	0	51	96.08%
Island	0	1	0	2	2	0	56	0	61	91.80%
Water body	4	1	3	0	2	6	0	55	71	77.47%
Truth over all	63	61	57	62	59	61	66	71	500	
User accuracy(Recall)	84.13%	90.16%	89.47%	83.87%	91.53%	80.33%	84.85%	77.47%		
Overall accuracy(OA)	85.00%									
Kapa statistics	0.829									

Key: Agriculture – wetlands converted to agriculture, Industry – wetlands converted to industry, Settlement – wetlands converted to settlements

Table 3.2.4: Classification accuracy assessment for 2013 image

Land use/cover	Forest swamp	Papyrus swamp, marsh & bog	Palms and thickets	Agriculture	Industrial	Settlement	Island	Water body	Classification overall	Producer accuracy (Precision)
Forest swamp	60	0	1	1	0	0	2	1	65	92.31%
Papyrus swamp, marsh, bog	1	50	1	1	1	0	0	0	54	92.59%
Palms and thickets	0	1	60	0	1	1	1	3	67	89.55%
Agriculture	1	1	1	60	1	0	0	2	66	91%
Industrial	0	0	0	1	47	0	1	0	49	95.92%
Settlement	1	0	0	0	1	60	0	1	63	95.24%
Island	1	1	0	0	0	1	50	0	53	94.34%
Water body	0	0	0	1	0	4	0	78	83	93.98%
Truth over all	64	53	63	64	51	66	54	85	500	
User accuracy(Recall)	0.9375	0.9434	0.95238	0.9375	0.92157	0.90909	0.92593	0.91765		
Overall accuracy(OA)	93.00%									
Kapa statistics	0.92									

Key: Agriculture – wetlands converted to agriculture, Industry – wetlands converted to industry, Settlement – wetlands converted to settlements

3.3.1.6 Change detection

A change detection is normally achieved by performing a post-classification. A pixel-based comparison procedure was adopted to detect changes between different periods at the pixel level, usually interpreted as changes “from – to” information. A cross tabulation method was used to determine the qualitative and quantitative magnitude of changes between different periods. The qualitative computations of overall wetland use/cover changes were reported in terms of gains and losses of land in each land cover/use category for each classified site.

3.3.1.7 Drivers of wetland changes

Changes within wetland classes can be understood through interviews. Key informants at District/ sub county levels, researchers and representatives from non-governmental organisations were purposively selected because of their expertise and experience in wetland management and interviewed on the most significant drivers of changes within wetland use/cover types.

3.3.1.8 Prediction of wetland changes

The IDRISI Selva-based Markov Chain model was employed to project future wetland losses to DPs in the KMC, at current degradation rates for the next 27 years. This model provides a platform for the modelling of the future state of a system based on the immediate preceding state. The next state depends only on the current state and not on the sequence of events which preceded it. It is, therefore, described as a set of states: $S = \left(S_{0,}\ S_{1,}\ S_{2\ldots\ldots}S_r\right)$

The process starts as one state and gradually moves to another, with each move referred to as a step, i.e. $\left(S_i\ to\ S_j\right)$. Each move is determined by a probability *p*, which in this case would be P_{ij}, and calculated as equation (3.1) (Bindal, 2013). Hence, state X_{i+1} in the system could be determined by a former stage X_i in the Markov chain, and their relationship expressed as a general formula (Eq. 3.2).

$$p = p_{ij}^{\ \ n}\begin{bmatrix} p_{11}\ \ p_{12\cdots}p_{1n} \\ p_{21}\ \ p_{22}\cdots p_{2n} \\ \cdots\ \ \cdots\ \ \cdots \\ p_{n1}\ p_{n2}\ \ p_{nn} \end{bmatrix} \qquad \text{Eq. 3.1}$$

Where *n* is the number of wetland types, p is the probabilities of change from type *i* to type *j*.

$$X_i\ +1 = PX_i \qquad \text{Eq. 3.2}$$

Where X_i denotes the state vector of the first stage.

The probabilities are referred to as transitional probabilities, and an initial probability distribution $\left(S_0\right)$ specifies the starting state. The probability matrix of the initial state $\left(S_0\right)$ is used to calculate the state of transition probabilities in the *n*th Markov state, using the formula in equation 3.3:

$$p_{ij}^{\ (n)} = \sum_{k=0}^{m-1} p_{ik}^{\ (n-1)} p_{kj}^{\ (n-1)} \qquad \text{Eq. 3.3}$$

Where *m* is the number of rows or columns of the transition probability matrix, and the *n*th transition probability matrix is equivalent to the *n*th power of the first transition probability matrix.

Based on the initial matrix $\left(S_0\right)$ and the transition probability of the *n*th stage *P(n),* the wetland distribution area in the KMC was projected by using a Markov simulation model *S(n),* which is expressed as equation (Eq. 3.4) (Bindal, 2013):

$$S\left(n\right)=S\left(n-1\right)\times P\left(1\right)=S\left(0\right)\times P\left(n\right) \qquad \text{Eq. 3.4}$$

Wetland proportion extents for 2006 to 2013 formed a major focus for calculating the initial state transition matrix.

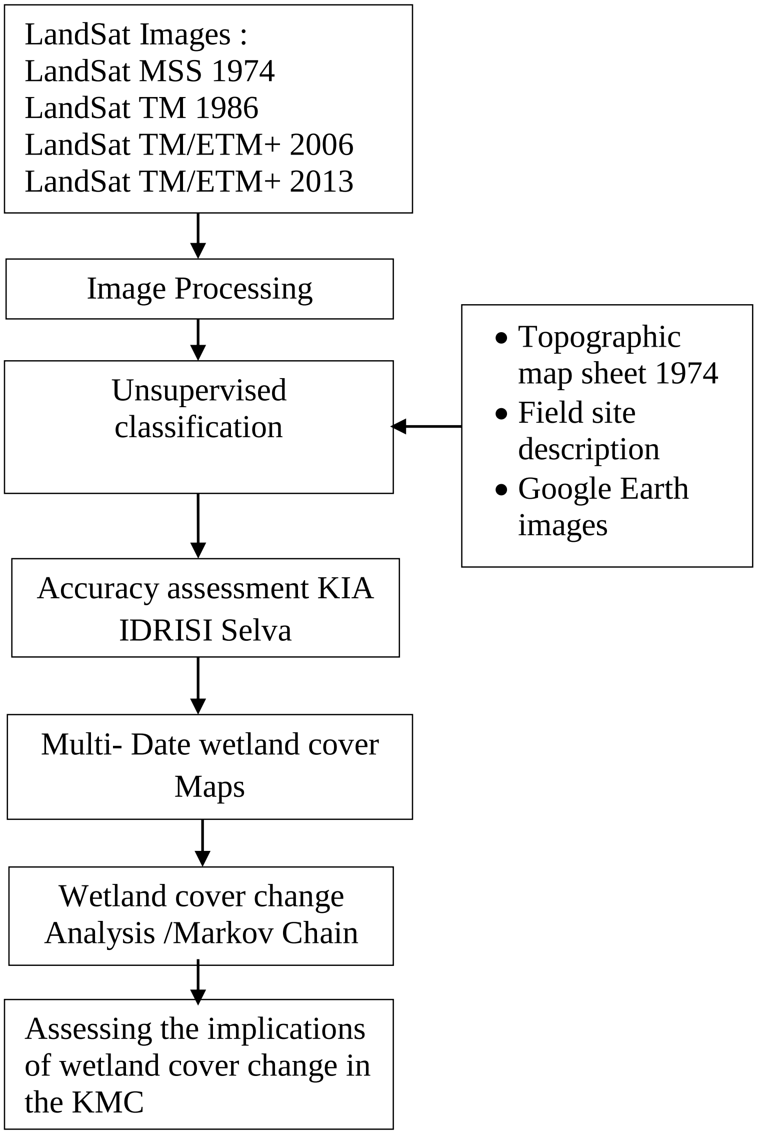


Figure 3.2: Scheme of methodology

3.3.2 Estimation of the economic value (EV) for conserving the KMC wetlands

Economic valuation is a tool that can be used to investigate public attitudes towards change in the state of wetlands by expressing the natural resources it contributes in monetary terms (Setlhogile *et al*., 2011). Purposive sampling was applied throughout the study because the KMC wetlands are not homogeneous in terms of wetland goods/resources and resource utilization activities. Three wetlands with significant resource utilization activities being encroached on by DPs were selected: Lwajjali, Nakiyanja and Namanve wetlands. Local leaders at the village level adjacent the selected wetlands were contacted to provide basic information about the numbers of people who were directly carrying out resource utilization activities in the wetlands. Through the local leadership networks, focus group discussions were organised with different groups of actors particularly; farmers, brick makers, sand extractors and thatch harvesters who provided detailed and specific estimates of the number of primary harvesters and traders of wetland goods (appendix M). These estimates provided a major input in the determination of sample sizes. The sample sizes were determined using Krejcie and Morgan (1970)'s table of sample size determination.

3.3.2.1 Valuation approach

Despite its versatility and applicability in related assessments (including Emerton *et al*., 1998; Karanja *et al*., 2001; MEA, 2001; IUCN, 2004; Schuyt, 2005; Kakuru *et al*., 2013), the Total Economic Valuation Framework by Emerton *et al*. (1998) (see Table 3.3) was not employed in totality during the economic valuation of the KMC wetlands but was only used during the wetland inventory as an analytical framework of categorizing wetland goods and services according to their use and non-use values. Emphasis was placed on use values (i.e. the direct and indirect benefits accruing from the use of wetland goods and services), because they are relatively straightforward to estimate (Schuyt, 2005), and in view of the justification for doing so presented in Chapter 2, Section 2.6.1.4. In essence, the study concentrated on four direct use values of wetland goods – crop production (mainly sweet potatoes and yams), thatch, clay, and water supply – in addition to two indirect use values, water purification and flood attenuation (see Appendix C). Three methods of quantifying the monetary values were used, namely, the market price method, the contingent valuation method and the replacement cost method. The study made use of heaps, bundles, tins and jerry-cans as units of volume or weight for the valuation of wetland goods, because they were the predominantly used units in the rural areas where wetland resource utilization activities thrived, while hectares were specified as the measurement for land areas. A detailed list of data requirements for economic valuation is provided in Appendix D. Various units of analysis were considered, depending on the type of good or service to be valued. These units consisted of groups of people involved directly or indirectly with the selected wetland resource (See Appendix C). The indicators of economic value considered for the selected goods and services included: Net Cash Income, Subsistence Consumption Value and Gross Value. These were calculated as indicated in Appendices E and I.

Table 3.3: Stages in wetland economic valuation and analysis

Step	Involves	Outcome
1.Identifying wetland economic benefits	Categorizing the benefits of a particular wetland according to the concept of total economic value	Full description of wetland economic benefits
2.Choosing which wetland goods and services to value	Prioritizing wetland benefits and selecting those to be valued	List of wetland economic benefits that will form the focus of the study
3.Choosing valuation techniques	Deciding on the economic methods and techniques that will be used to value selected wetland benefits	List of indicators of wetland economic value
4.Choosing indicators of economic value	Deciding on the way in which economic value will be expressed for the given wetland benefits	List of indicators of wetland economic value
5.Specifying data needs for valuation	Formulating a list of the data that must be collected to enable the economic valuation of wetland benefits	List of data requirements for wetland economic valuation
6.Collecting the data	Selecting and implementing methods to collect the information required to calculate economic value of wetland benefits	Data that can be used to calculate wetland economic benefits
7. Assessing the distribution of wetland benefits and costs	evaluating wetland benefits to stake holders (land holders, private sector, government)	Listing of which stakeholders gain or lose, and by how much, from wetland conservation or degradation.

Step	**Involves**	**Outcome**
8. Identifying economic measures for sustainable wetlands management	- Identification of groups responsible for wetland management - pinpointing groups and economic activities that benefit freely or at low cost from wetlands - Identification of opportunities for raising finance for wetland management - Which groups need economic incentives or disincentives to conserve the wetlands?	A listing of economic incentives and disincentives for wetland management

Adapted from Emerton *et al*. (1998)

The underlying assumptions behind the derived values were that: the selected goods and services existed across the KMC wetland; wetland goods are sold through a perfectly competitive market, which means that wetland actors had full information about associated goods and services; and that the derived monetary values represent a minimum estimate of the KMC total economic value since they exclude consideration of other benefits yielded by the KMC wetlands, such as their cultural and aesthetic value. The monetary values also deal only with existing (not potential) wetland resource activities.

A summary of the data for specified indicators of economic value, selected wetland goods and services, and the valuation techniques used is presented in Appendix D.

3.3.2.2 Data collection

Open-ended questionnaires were administered to respondents to elicit data about the production, harvesting and marketing of wetland resources (see Appendices B1 and B2). These were triangulated with in-depth interviews and Focus Group Discussions (FGDs, Appendix B5) with various key informants and members of the resource user groups. Open-ended questionnaires were used mainly in order to avoid the kind of bias that can result from suggesting responses to individuals, and also to ensure richness in the responses (Reja *et al*., 2003). The questionnaires were administered with the assistance of trained local native interviewers (enumerators) who translated the questions into the local vernacular (Luganda) in order to ensure that the right responses were obtained. Emerton *et al.*'s (1998) step-by-step valuation process as used in this study is summarized below (Equation 3.5):

$$R = f\,(x, y, z, p, q, r) \qquad \text{Eq. 3.5}$$

Where;

R = Total Economic Value of Wetland resources

x = Wetland economic benefits which is equivalent to $(x1 + x2 + x3 + x4)$, denoted as;

x_1 = Benefits with direct use values

x_2 = Benefits with indirect use values

x_3 = Benefits with optional use values

x_4 = Benefits with existence use value

y = Choice of wetland goods and services to value

z = Choice of valuation techniques

p = Choice of indicators of economic value

q = Specification of data needs

r = Data collection

3.3.3 Assessment of the carbon sequestration and hydrological impacts associated with wetland diminution

3.3.3.1 Field and laboratory SOC analysis

As was explained in Chapter 1, Section 1.2, it is important to undertake the analysis of C in order to enhance our understanding of the impacts of DPs on ecological sustainability and climate variability, so as to promote dedicated efforts to improve wetland integrity in development decision making.

Plots of 50m x 50m were used at 18 sites across the sampled wetlands, where 54 soil cores (three replicates) along delineated transects within the wetland cover types (Figure 3.3) were extracted from 0–10cm, 10–15cm and 15–30cm soil depth in the KMC study area. In total, 27, 18 and 9 samples were extracted from Namanve, Lwajjari and Nakiyanja wetlands (Figure 1.1), respectively.

Purposive sampling was employed during the extraction of soil samples in which the classified wetland cover types formed the basis of the extraction. The spatial sampling frequency was determined by the spatial distribution of DPs, and the availability and accessibility of classified wetland cover types. The study examined 54 samples in order to get a spatially representative sample of SOC at different depths across the wetland cover types. The soil composite samples were kept in plastic bags (Figure 3.4) at 5^{o}C to limit microbial degradation, oxidation and volatilization activities. The study adopted the manual wet chemistry/oxidation method of Walkley-Black (1934) because of its simplicity, rapidity, and precision (compared to the dry combustion method with its attendant high cost of equipment [Nelson & Sommers, 1975; Kimble *et al*., 2002; Schumacher, 2002]), and its wide application in related studies.

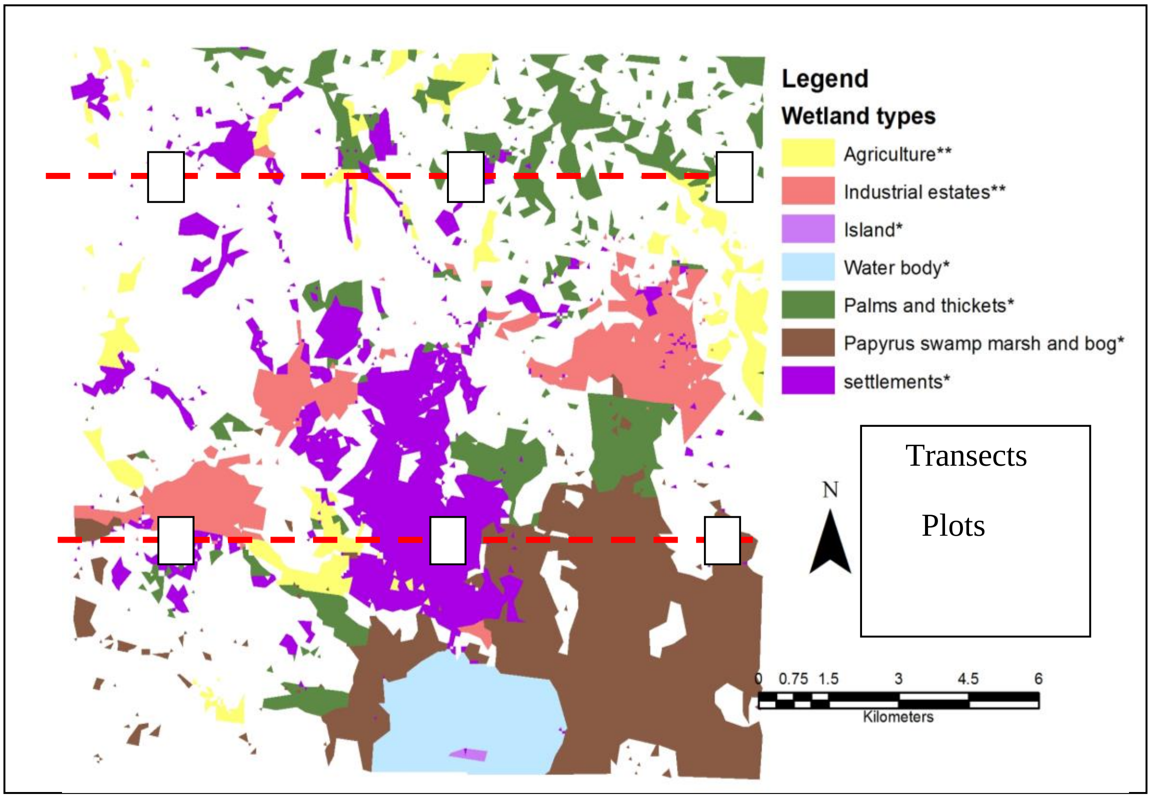


Figure 3.3: Location of sites and transects from which SOC samples were extracted in the KMC

For all the samples, 0.1g to 0.5g of ground (60 mesh) soil was put in a block digester tube and oven dried at 150^{0} C for 30 minutes. The dried samples were heated with potassium dichromate solution ($K_2Cr_2O_7$) in sulphuric acid (H_2SO_4). The digest was transferred to a 100-ml conical flask where 0.3 ml of ortho-phenanthroline ferrous complex (Ferroin) was added. Utilizing the titrimetric method, the amount of potassium dichromate used for SOC oxidation (as in Equation 3.6) was estimated. The excess dichromate (Cr_2O_7) was titrated against ferrous ammonia sulphate solution, Fe $(NH_4)2(SO_4)26H_2O$, with the endpoint being a colour change from green to reddish brown. The Cr_2O_7 reduced during the reaction with the soil was considered a measure of organic C present in the sample.

$$3C + 2KCr_2O_7 + 8H_2S0_4 = 2Cr_2(SO_4)3 + 3\ CO_2 + 2KSO_4 + 8H_2O \quad \text{Eq. 3.6}$$

Figure 3.4: Collection and labeling of soil samples in preparation for laboratory C analysis

3.3.3.2 Hypothesis

A null hypothesis that: “the magnitude of wetland carbon stocks does not depend upon wetland cover type” was developed to test the relationship between SOC stocks and wetland cover types. Spatial autocorrelation (Moran’s Index - I) analysis in Arc GIS 10.1 was employed to test the stated hypothesis.

3.3.3.3 Spatial-temporal SOC storage changes and implications for local climate variability

The sampled wetland types in the KMC and the link to their SOC stocks provided a baseline for estimating SOC storage changes associated with wetland diminution during the analysis period 1974 – 2013. The temporal SOC sequestration for the period 1974 to 2013 was estimated by extrapolating the calculated unit soil organic carbon stocks (SOCs) for the classified wetland cover types to the spatial coverage of similar wetland cover types in the preceding observation period (see Equation 3.7).

The gross SOC loss was estimated by calculating the unit SOC in the initial year of benchmark (1974) based on the then wetland cover, as in equation 3.8. The Net SOC loss to DPs was estimated as the difference between the gross SOC and the present/current SOC in the wetlands converted for DPs (settlement and industry) (see Equation 3.9). The assumption underlying this approach was that SOC varies with wetland cover type spatial extent in the KMC. This method was used owing to its versatility and application in related assessments (including Penman *et al*., 2003; Yu, 2011; Edmondson *et al*. 2012; Edmondson *et al*. 2014). The implications of SOC storage changes for climate variability were analysed by seeking a relationship between the KMC wetland SOC stock changes and climatic data for Kampala (see Appendix F) during the same observation period, 1974 to 2013.

The relationship between SOC and local climatic data was sought by conducting a correlation between SOC and temperature data, upon which a linear regression was performed. This is because SOC loss (after wetland degradation) contributes to the total atmospheric carbon load which enhances the greenhouse effect and consequently raises atmospheric temperatures, triggering carbon-driven local climate variability, especially with regard to local temperatures (Mitra *et al*.

2005). The climatic data were obtained from the Kampala weather station at Makerere University, managed by Uganda National Meteorological Authority (UNMA).

$$SOC = TSOC/s\ (g) \times A\ (h) \qquad \text{Eq. 3.7}$$

$$Gross\ SOC\ loss = SOCn \times AL\ (h) \qquad \text{Eq. 3.8}$$

$$Net\ SOC\ loss = SOCn \times AL\ (h) - SOCf \qquad \text{Eq. 3.9}$$

Where;

$SOCS$ - Soil organic carbon sequestration

SOC/s (g) – Total soil organic carbon content per sampled wetland type (g)

A – Area of the different wetland cover types (h)

$SOCn$ – Estimated SOC in the initial / benchmark year

$AL\ (h)$ – Area lost to DPs between the initial year and current year, in hectares (h)

$SOCf$ – Estimated SOC in the present / final year.

3.3.4 Assessment of the hydrological impacts of wetland diminution

3.3.4.1 Hydrological impact assessment parameters

The hydrological impact analysis (HIA) of wetland diminution caused by DPs was based on testing hydrologic wetland chemical nutrient concentration, total suspended sediments (TSS) and related hydrologic flow data for the different wetland cover types in the KMC. The chemical nutrients that formed the basis of the study were total nitrogen (TN), total phosphorous (TP) and total dissolved solids (TDS). Flow data analysis was based on four components: water level, speed, stream width, and bed load. Fifty-four water samples for nutrient concentration and stream flow analysis with a sampling interval of 50m were collected on a monthly basis. The sample collection took place over a period of three months after the rainy season (May, June, July of 2013) in the different wetland cover types (forest swamps, palms and thickets, papyrus swamps, marshes and bogs, and wetlands converted to industry, agriculture, and settlement). This once off data collection was done in order to gain an understanding of the present status of hydrological implications caused by disturbances arising from the establishment of development projects in the KMC wetlands for many years 1986 – 2013. Hence, the samples were collected from the encroached / disturbed wetlands. The sampling procedure was set and strictly followed for quality control.

A narrow open-mouthed bottle was used to collect the water samples, which were poured into ½ litre plastic bottles and labelled according to the wetland cover type of extraction. The labelled samples were packed in an insulated container and transported to the laboratory for analysis after fifteen hours of collection. Chemical analysis (TN, TP, and TDS) and TSS analysis were anchored in the Standard Methods for the examination of water and waste water. A spectrophotometer (Hach DR 4000) was used to measure concentrations of chemical variables. Total phosphorous and total nitrogen were determined using the alkaline per sulphate digestion method. This method was used because of its high sensitivity, accuracy and being less toxic than the alternative Kjeldahi digestion method (Patton and Kryskalla, 2003). TDS and TSS were determined as described in the procedures 2540-C and 2540-D of the APHA (1995) Standard Methods. Stream flow components (stream velocity and depth) were measured using a handheld flow probe - model FP211 (Figure 3.5).

Figure 3.5: Water velocity and stream depth measurement in an open wetland stream at a marsh/ bog site, KMC

3.5 Methodological limitations

Some limitations were encountered during the execution of the study as described below;

- The economic analysis concentrated on use values particularly the direct and indirect values and excluded the Non-Use values (including option, existence and other non-use values attached to aesthetics, biodiversity, bequest and cultural values) owing to the fact that the study was interested in painting a picture on the direct monetary values accruing to the use communities. This, therefore, obscured some important detail that could have arisen.
- The study used selected wetland ‘use values’ to assess the economic importance of the provisioning services for the KMC wetlands which would promote the notion that converting wetlands to those similar uses would increase their value, which is not the case.
- The economic valuation was undertaken at a time when Government was evicting wetland encroachers within Kampala and Mukono Districts. This made wetland communities hesitant to openly reveal the exact number of wetland actors for fear of being reprimanded. Even with thorough explanation that this was purely an academic study and engaging with the local leaders, it was noticeable that some were obscuring some detail, especially in regard to material extraction from the wetlands under study.
- Similarly, it was also difficult to access some development projects especially the privately-owned types during the hydrological sample collection because Research Assistants were mistaken to be part of the then ongoing eviction team from government.
- The inaccessibility of some wetland types particularly the papyrus swamps, marsh and bog made it difficult to collect information since these types were intact and waterlogged. In this case, Google Earth images (GeoEye- 1- 0.5m) were used to validate some of the observed phenomena on the 2013 satellite images.

3.6 Summary

This chapter has presented the research methodology employed to achieve the study’s objectives, which were to assess the spatial and temporal wetland loss to DPs, estimate the EV of conserving the KMC wetlands, and assess the carbon sequestration and hydrological impacts relating to wetland diminution, as well as the limitations of the methods. The next chapter presents the results of the assessment of the spatial and temporal wetland loss to DPs.

CHAPTER FOUR

A spatial and temporal assessment of wetland loss to development projects: the case of the Kampala-Mukono corridor wetlands in Uganda

Abstract

Human-induced activities are responsible for extensive wetland loss in Uganda. Monitoring the spatial and temporal changes in wetlands is critical for the development of robust strategies for the management and rehabilitation of these ecologically sensitive ecosystems. This study aimed at assessing the spatial and temporal loss of wetlands to development projects (DPs) in the Kampala–Mukono Corridor (KMC). Utilizing a series of satellite images from 1974 - 2013, historical and field data sets, significant changes in the spatial extent and land cover types were identified. The images were pre-processed using the Dark Object Subtraction method and Majority Filter method. Unsupervised classification was employed to delineate wetlands and DPs, and validated by use of topographic maps, apriori knowledge, and Google Earth images of respective imagery sets. Projections of future wetland losses to DPs were done using the IDRISI Selva-based Markov Chain model. The KMC wetlands have shrunk by almost a half (47%) of their coverage since 1974. Wetland loss to DPs during the observational period accounted for 56% of the total loss, with settlements being responsible for the majority of the loss. Projections indicate that 26% of the current KMC wetlands will be lost to more DPs by 2040. The consequences of the loss manifest in the deteriorating ability to moderate local climate, flooding, water quality, biodiversity changes; a drop-in wetland migratory birds, decreasing leisure activities, particularly bird watching and hunting, and a minimum economic loss of over US$ 19.3 million between 1974 and 2013. The vulnerability of wetlands to DPs in urban areas and in the vicinity of major transport arteries, calls for proactive measures to protect these fragile ecosystems.

Key words: Spatiotemporal changes, DPs, Kampala-Mukono Corridor, Wetlands, Uganda

4.1 Introduction

Wetlands occupy about 7% of the earth’s land surface (Mitsch, 1986; MEA, 2005). These ecosystems are considered integral to a range of ecological processes and functions (Daniels & Cumming, 2008). In Uganda, they represent one of the vital ecological and economic natural resources (UNDP, 2009), producing goods and services that have economic value and therefore directly or indirectly affect human welfare (Schuyt, 2005; Brander *et al*., 2006; Xu *et al*., 2011). Wetlands are a direct source of fresh water supplies, food products, fuel and fish (Hruby *et al*., 1995; Costanza *et al*., 1997). They also contribute up to 40% of annual global ecosystem services

(Costanza *et al*., 1997) including water quality enhancement, flood attenuation, nutrient retention, groundwater recharge, climatic regulation (Barbier, 1993; Acharya, 2000; Oglethorpe & Miliadou, 2000), and carbon storage (Mitra *et al*., 2005). On the basis of this, wetlands are protected and monitored by various agencies, and recognized by international treaties, particularly the Ramsar Convention on Wetlands (Töyrä & Pietroniro, 2005).

Despite their importance, wetlands are not managed as environmental capital worthy of protection and investment (UNDP, 2009). They are instead being degraded for other uses; particularly settlements, plantations and other development initiatives (Joshi *et al*., 2002), a trend that is likely to result in irreversible environmental consequences detrimental to human welfare. By the year 2000, an estimated 2,376km^2 of wetland area had been reclaimed for agricultural and industrial activities in Uganda (NEMA, 2001; Apunyo, 2008). In the Kampala–Mukono Corridor (KMC), numerous wetlands have been converted for alternative land use, particularly for manufacturing and residential housing. Development projects of this kind have encroached on wetlands like Nakivubo, Namanve, and Kinawataka in the Kampala District.

According to Joshi *et al*. (2002), Schuyt (2005), and Owino and Ryan (2007), such encroachments are a function of both inadequate knowledge about wetland values and an (increasing) annual population growth rate of 3.03% in Uganda (UBOS, 2014), exacerbated by high poverty levels (UNDP, 2009; Turyahabwe *et al*., 2013a; 2013b). In the KMC, this has been compounded by the collapse of the Jinja Industrial base during the early 1970s and the increasing Development Index in Kampala since the mid-1980s, which has driven an increase in population and potential markets. The rapid expansion of industrial establishments has given rise to infringement upon wetlands in Kampala and its peripheries (Wegener, 2001; Kataata, 2003). Such ecosystem degradation undermines its functioning and resilience, and thus threatens the capacity of wetlands to continue the supply of the flow of ecosystem services to present and future generations (de Groot *et al*., 2012).

Monitoring wetland change at the level and scale of landscape plays a fundamental role in wetland conservation (Munyati, 2000; Romsho, 2004; Xu *et al*., 2011). Using remote sensing methods, wetland change can be detected using spatial and temporal information, which permits exploration of patterns in and drivers of that change (Xu *et al*., 2011). Although wetland systems in Uganda have been mapped, there is little or no information on how they are changing over time in response to rapid economic development (Huising, 2002). The study assesses the spatial and temporal changes of the KMC wetlands during the four decades from 1974 to 2013. The specific objectives of this study were:

1) To assess the spatial and temporal wetland changes in the KMC from 1974 to 2013.
2) To identify the major drivers responsible for wetland changes from 1974–2013 in the KMC.
3) To predict future wetland losses to DPs in the KMC.

4.2 Results

4.2.1 Spatial extent of the KMC wetlands between 1974 and 2013

The spatial and temporal changes in the KMC are presented in Table 4.1. The KMC wetlands have lost as much as 47% of their 1974 extent, excluding the open water body. The major contributors to wetland degradation are considered to be anthropogenic activities, particularly industrialization, settlement and agriculture. The greatest loss occurred between 2006 and 2013, while 1974–1986 witnessed the lowest loss of wetlands.

Table 4.1: Area of wetlands between 1974 and 2013

Year	Area (Hectares)	%	% Change
1974	10,140	100	-
1986	8,677	86	-14
2006	7,190	71	-17.4
2013	5,410	53.3	-24.9

4.2.2 Wetland changes within the KMC (1974 - 2013)

The proportionate spatial extent of the KMC wetland during the four-decade observational period (1974–2013) is presented in Table 4.2 and Figure 4.1. From Table 4.2, in 1974, forest swamps dominated the wetland area, covering an extent of 6,430 ha, followed by papyrus swamp, marsh and bogs, with 3,710 ha. Palms and thickets and wetlands converted to industrial, agriculture and settlement use classes are missing during this period, which puts the actual wetlands cover at 10,140 ha in 1974.

Table 4.2: Area covered by different wetland types (1974–2013) in KMC

Class Name	**Area 1974 (ha)**	**%**	**Area 1986 (ha)**	**%**	**Area 2006 (ha)**	**%**	**Area 2013 (ha)**	**%**	**Change from 1974 to 2013 (ha)**
Forest swamps	6,430	59	327	3	-		-		- 6,430
Papyrus swamp, marsh, bogs	3,710	34	3,440	28	3,130	27	3,360	26	- 350
Palms and thickets	-		4,910	40	4,060	34	2,050	16	- 2,860
Wetlands converted to agriculture	-		1,040	8.4	638	5.4	1,010	8	+ 1,010
Wetlands converted to industrial	-		460	4	593	5.1	2,370	18	+ 2,370
Wetlands converted to Settlement	-		1,165	9	2,330	20	3,280	25	+ 3,280
Island	16	0.1	15	0.1	15	0.1	17	0.1	- 2
Water body	834	8	841	8	839	7	802	6.2	- 32
Total (ha)	**10,990**		**12,198**		**11,605**		**12,889**		**6,660**

By 1986, palms and thickets constituted the bulk of wetland type in the KMC (4,910 ha), having taken over part of the former forest swamps (Figure 4.1 and Table 4.2). A slight reduction in the area covered by papyrus swamp, marsh and bog from 3,710 ha in 1974 to 3,440 ha in 1986 is noted. Converted wetland cover types to industrial, settlement and agricultural use classes have emerged within the KMC wetlands, occupying 2,665 ha of the total wetland area, among which (in 1986) wetlands converted to agriculture and settlement registered the greatest share of 1,165 and 1,040, respectively. The emerging wetland classes were anthropogenic and had occupied the former forest swamps by 1986. Indeed, forest swamps shrunk by 95% between 1974 and 1986. Palms and thickets emerged to occupy over 40% of the study area.

By the year 2006, forest swamps had disappeared, while palms and thickets, as well as papyrus swamp, marsh and bogs, diminished to 4,060 ha and 3,130 ha, respectively (Table 4.2). Wetlands converted to industrial and settlement increased, with those converted to settlement constituting the largest area (2,330 ha).

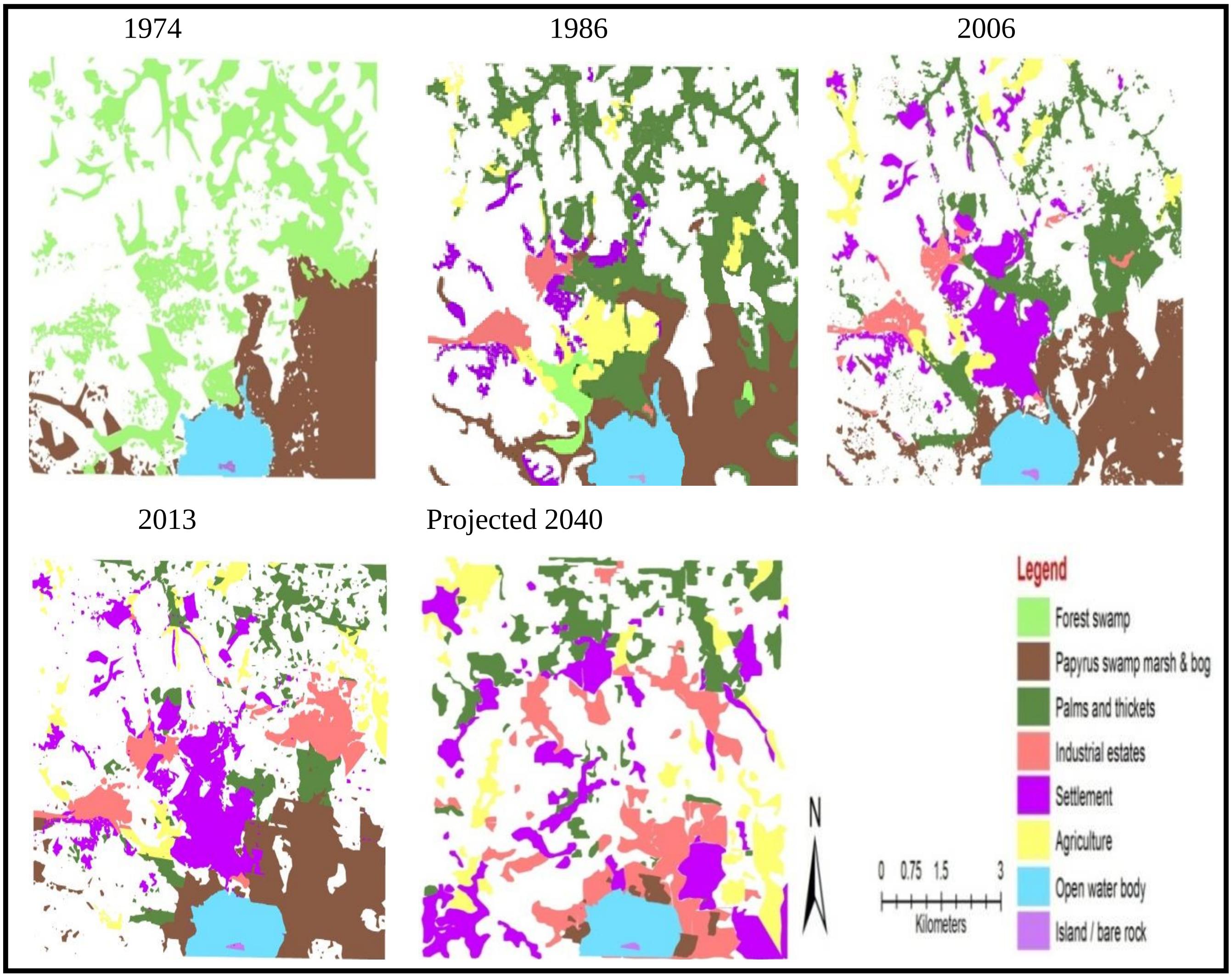


Figure 4.1: KMC wetland cover maps for 1974 - 2013 and projected wetland cover for 2040

However, despite the increments in industrial use and settlement (DPs), wetlands converted to agriculture decreased from 1,040 ha to 638 ha, which is by 39%. By 2013, forest swamps had disappeared, while papyrus swamps, marsh and bog gained slightly (by 7.3%) on their 2006 coverage. There was a sharp decrease in the area covered by palms and thickets to almost a half (49%) of its 2006 coverage. On the other hand, wetlands converted for industry, agriculture and settlement registered a striking increase of their 2006 spatial extents, to 6,660 ha.

A progressive loss of the KMC wetlands to DPs is discernible, particularly for industry and settlement. Observations of change from 1986 to 2013 indicate a progressive rise of these DPs, from 1,625 ha to 2,923 ha and finally to 5,650 ha, in 1986, 2006, and 2013 respectively (Table 4.2 and Figure 4.2). Settlements are responsible for degrading the bulk of the KMC wetlands, from 1,165 ha to 3,280 ha in a period of only 27 years (1986–2013), while conversion to industrial use accounts for 2,370 ha.

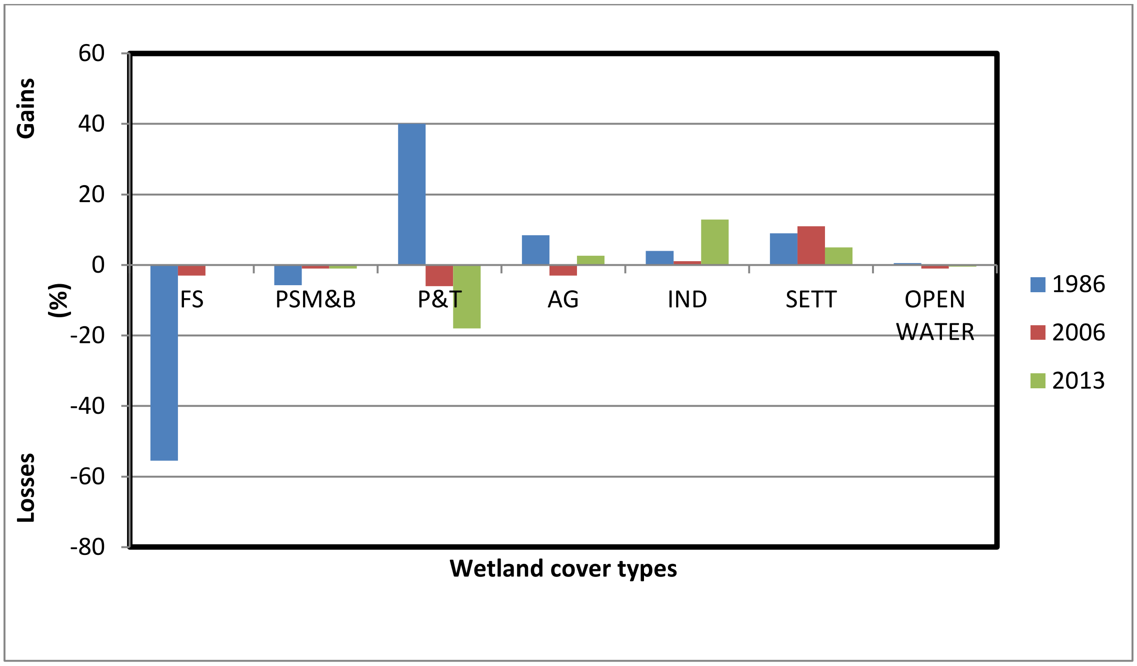


Figure 4.2: Analysis of gains and losses for different wetland types and cover changes 1974 - 2013 in the selected wetlands of KMC

Key: AG – Wetlands converted to agriculture, IND – Wetlands converted to industry, FS – Forest Swamp, ISL – Island, P&T – Palms and thickets, PSM&B – Papyrus swamp marsh and bog, SETT – Wetlands converted to settlement.

Results from the cross tabulation and analysis of gains/losses (Table 4.3 and Figure 4.2, respectively) indicate that DPs gained most land from forest swamps, with settlement taking the greatest toll during the period 1974 to 2013. Papyrus swamps, marsh and bogs had been converted to settlement and agriculture by 1986, while palms and thickets gained from forest swamps in 1986 and continuously lost to DPs, mainly settlements and industry.

Table 4.3: Cross-tabulation of wetland change from 1974 to 2013

	PSM&B	AG	FS	ISL	SETT	OPW
IND	0.5	18.7	22.0	0.0	7.9	0.0
SETT	2.4	25.0	35.0	0.0	42.7	0.6
AG	0.3	12.7	12.0	0.0	9.6	0.0
P&T	9.3	15.8	25.0	0.0	23.0	0.0
PSM&B	87.0	27.0	6.0	0.0	17.0	7.0
OPW	0.7	1.0	0.0	32.6	0.0	92.0
ISL	0.0	0.0	0.0	67.3	0.0	0.3

Key: AG – Wetlands converted to agriculture, IND – Wetlands converted to industrial estates, FS-Forest Swamp, ISL – Island, P&T – Palms and thickets, PSM&B – Papyrus swamp marsh and bog, SETT – Wetlands converted to settlement OPW – Open water body.

4.2.3 Major drivers responsible for wetland changes from 1974–2013 in the KMC

Respondents from Focus Group Discussions and key informants reported a combination of drivers to wetland changes from 1974 to 2013, which have been classified into economic, social, and institutional drivers. The major economic drivers included the closure and relocation of industries from the former Jinja industrial hub to Kampala (32% Table 4.4). Other drivers included: the pursuance of the economic transformation policy focusing on industrial growth by government, the proximity of the KMC to emerging industrial incentives e.g. market, the low cost of land in the KMC wetlands and the general commodification of land in Kampala. The major social drivers of wetland change were high poverty rates and economic stress with a response of 48%, followed by population increase in Kampala, rural urban migration and general information failures about wetland benefits among decision makers. The Institutional drivers involved weaknesses in historic development planning around Kampala with the highest frequency of response percentage (Table 4.4), inadequate law enforcement to conserve the KMC wetlands, political interference, land tenure systems, and informal land acquisition policies. The class-specific drivers are presented in Table 4.4 bellow.

Table 4.4: Drivers of wetland change from 1974 to 2013 in the KMC

	Dimensions	Significant drivers	Percentage
1.	Economic drivers	Closure and relocation of industries from Jinja to Kampala in 1980s.	32
		Pursuance of the economic transformation policy focusing on industrial growth.	28
		The proximity of KMC to industrial incentives e.g. markets.	18
		Low cost of land in the KMC	14
		General commodification/monetization of land	08
		Total	**100**
2.	Social drivers	High poverty rates / economic stress	48
		Population increase	24
		Rural-urban migration	07
		Information failures about wetland benefits	21
		Total	**100**
3.	Institutional drivers	Inadequate low enforcement to protect wetlands	21
		Political interference	31
		Inadequate development planning for Kampala	38
		Land tenure	02
		Informal land acquisition policies	08
		Total	**100**

4.2.4 Projected wetland cover change in the KMC by 2040

Wetland cover maps for 2006 and 2013 were used to create a transitional probability matrix (n = 1) in order to project future wetland cover changes by 2040. The projected wetland cover change (Figures 4.2 and 4.3) indicates that only 3,095.3 ha of wetland area (57.2%) will survive by 2040. Palms and thickets will constitute the bulk of the coverage (69%), while papyrus swamps, marsh and bog will cover 32%. This therefore implies a gross wetland loss of approximately 2,314.7 ha.

Of this loss, 61% (1,412.2 ha) will accrue to DPs, with industry degrading most of it (73%), and settlements accounting for 27%.

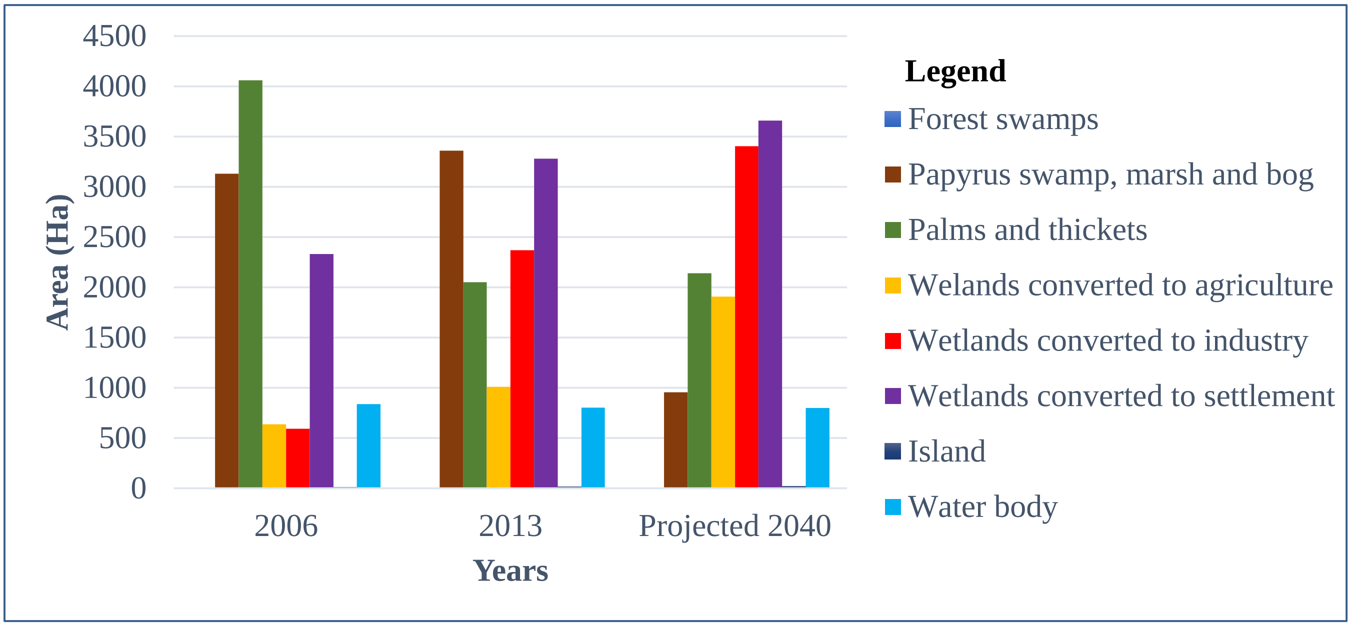


Figure 4.3: Spatial temporal KMC wetland extents 2006–2013 and projected wetland change by 2040.

4.3 Discussion

4.3.1 Wetland area changes between 1974 and 2013

Despite the existence of the National Wetland Policy, with a fully facilitated statutory body/ agency responsible for Environmental Governance (Emerton & Muramira, 1999; Byaruhanga & Ssozi, 2012), wetland loss in the KMC has amounted to almost a half (47%), which is equivalent to 4,765.8 ha over the last four decades, with 56% of the loss accruing to DPs (industrial and settlement). Extending these percentage wetland losses to the entire KMC, which had a total wetland area of 40,700 ha (Kamanyire, 2002; NBS, 2003), the present study reveals that a total of 19,129 ha have been lost from 1974 to 2013, with 10,712 ha accruing to DPs. This confirms earlier observations in related studies, which reported that by 2000, over 2,376 KM^2 of wetlands had been reclaimed for DPs, for settlement, industry, agriculture and related activities (NEMA, 2001; Apunyo, 2008; Gumm, 2011).

The drastic loss of approximately 95% of forest swamps (Figure 4.2) and their eventual transformation to palms and thickets by 1986 could be as a result of deforestation for settlements in the forest reserves during the 1970s and 1980s (Obua *et al*., 2010), leaving behind scars of degradation currently existing as palms and thickets. The findings from this study further indicate that settlements registered the highest gains (from forest swamps) in the period 1974 to 1986 (Figure 4.2). This is supported by other studies such as that of Tejuoso (2006), where increments in wetland converted for settlement in Mukono and neighbouring areas were noted to stem from their proximity to the urban area of Kampala, the nation's capital. The gains for settlement could also be attributed to the ease with which thickets can be converted to settlements, owing to the fact that they are not permanently water-logged as compared to papyrus swamps. This partly explains why papyrus swamps, marsh and bogs only lost 17% and 4% respectively of their coverage to DPs from 1974 to 2013.

The total area occupied by the different wetland cover types was noted to vary during the period between 1974 and 2013. This is because some components of the KMC wetlands are seasonal in nature (WRI, 2009; NEMA, 2010), with much of their coverage determined by rainfall distribution patterns. These wetland components, together with the earlier converted portions, could not be detected on the multi-temporal satellite images. Based on the projected wetland losses, the present study reveals that 42% of the extent of the KMC wetlands in 2013 will be lost by the year 2040, with 61% of this loss attributable to DPs. Extrapolating this value to the entire wetland extent of 40,700 ha (Kamanyire, 2002; NBS, 2003), suggests that the KMC will lose approximately 17,094 ha by 2040, with 10,427 ha of this loss arising from DPs.

The emerging (converted) wetland cover classes by 1986 and related wetland changes experienced to the period 2013 also demonstrate a local version of the competition for land that has lately been globally recognized. The emergency of wetland converted types to settlements and associated agricultural use by 1986 indicates competition for land between development and conservation, which according to Haberl *et al*. (2014) is attributable to ecosystem amenities or advantages that attract footloose (non-permanent or transient) households and firms away from their traditional urban areas (Deller *et al*., 2001; McGranahan, 2008). These transient land users transferred from Kampala to the ecologically sensitive wetland ecosystems in neighbouring Mukono, whose preference was dictated by cheap and fertile soils that could support agriculture and livelihoods for the new urban immigrants (see Figures 4.1 and 4.4.) As indicated by Eakin *et al*. (2014), this increased “urbanity” creates a greater demand for rural and distal populations to provide land-based resources, which explains the contemporary tele-couplings between the two urban and peri-urban areas of Kampala and Mukono. The consequence of this interaction is a competition between rural and urban land uses in which the latter finally outbids peri-urban and rural land uses, pushing them away to virgin and perhaps conserved ecosystems, thereby resulting in degradation (Seto & Kaufmann, 2003; Seto *et al*., 2012). The reduction in wetlands converted to agriculture (a rural land use) between 1986 and 2006, and the subsequent rise in those converted to settlements by 2006, is a demonstration of urban/rural land use competition in which settlements have taken over areas formerly taken over by agriculture (see Figure 4.1 by 1986 and 2006), pushing agricultural use elsewhere.

According to Seto *et al*. (2012), changes in the demands of the city prompt a restructuring of the urban hinterland, triggering an indirect competition. The continuous rise in settlements, which according to the findings of this study occupied 2,330 ha and 3,280 ha in 2006 and 2013, respectively, triggered changes in the volume and pattern of resource demand. This has led to the restructuring of the urban hinterland and the creation of industrial parks in the suburbs of Kampala, thereby contributing to more land use competition in the KMC wetlands. This phenomenon is mirrored in the large gains in industrial land use from 593 ha to 2,370 ha from 2006 to 2013.

4.3.2 Most significant drivers of the KMC wetland change 1974–2013

The drivers of wetland change from the 1974 to 2013 are a combination of factors and the major ones have been noted to include: economic dynamics and the preference of Kampala as an industrial zone, weakness in the previous spatial planning of Kampala, the general lack of information flow to various institutions involved in the establishment of DPs and general poverty / economic stress. However, Hurtt *et al*. (2011) and, Seto and Reenberg (2014) have identified different but related factors driving long-term natural resource conversion in similar urban environments, including global population growth, shifting consumption patterns and growing economic activity. The degradation of the KMC wetlands from 1974 to the mid-1980s is primarily a consequence of economic dynamics triggered by chronic political instability and erratic mismanagement of Uganda's economy (Ndikumana, 2001). Consequently, as already reported by this study (Table 3.2), many industries of the 1950s and 1960s in the former Jinja industrial hub (eastern Uganda) closed, leading to the relocation of industrial incentives/imperatives to Kampala (NEMA, 2005). Coupled with the public nature of wetland resources in the 1980s (Ntambirweki, 1998), these footloose industries chose to locate in the previously unplanned industrial zones, some of which were in the KMC wetlands.

Figure 4.4: A factory site and subsistence agriculture in Namanve wetland site

Before 1986, wetlands in Uganda were considered wastelands and there was, therefore, no policy to guide wetland drainage (Ntambirweki, 1998; Apunyo, 2008). This study already highlights this as one of the major institutional shortfalls permitting large scale degradation (Table 3.2). Kataata, (2003) and Umar, (2010) have also endorsed to this by indicating that the first environmental policy was formulated in 1995, when most development and large-scale investments in the wetlands had been started or already completed, and when EIA practice was unheard of. Consequently, many wetlands in the KMC were swallowed up in the previous spatial plans that allocated wetlands for industrial use. They were seen as strategic points for infrastructural and industrial development owing to their low acquisition costs (Apunyo, 2008). For this reason, wetlands in Kasokoso, Kinawataka and Namanve in Kampala were included in the residential and industrial spatial planning for Uganda by 1972 (Kataata, 2003; Lwasa, 2004), which partly explains the wetland losses from 1974 to 1986.

Continuous wetland loss after 1986 is explained by the pursuance of economic transformation policies (Table 3.2), which aimed at diversifying economic production through a National Industrial Policy of 1991 and later 2008 (MTTI, 2008). In this regard, the GoU established the Uganda Investment Authority (UIA) in 1991 to attract and promote investments and according to Nyakaana & Sengendo, (2004), Kampala became a focus of this policy implementation because of its proximity to industrial incentives, especially the market forces of consumption (see: Table 3.2). Driven by the general conception among policy-makers and local decision-makers that wetland conservation yields limited, invisible and only long-term economic benefits compared with the costs of their degradation, the KMC consequently suffered a rapid loss of wetlands to DPs after 1986 (Wasswa *et al*., 2013). The new competing urban land uses – particularly industry and settlement (Figures 4.4 and 4.5, respectively) – are therefore backed by policy makers (UIA, district land boards and the city council), who end up issuing titles to land in conserved wetland areas in order to promote “economic growth.” This explains the observed wetland loss of 82% by 2006. As indicated by Haberl *et al*. (2014) and Seto and Reenberg (2014), urban natural resource conservation with respect to the wetlands must now be considered a new form of urban land use which competes with others – rather than a passive “victim” of land use competition. But this new form of land use in the KMC urban setting will only be accepted if its values are enumerated and highlighted to decision-makers.

Similarly, economic transformation policies through industrialization after 1986 are responsible for the changing population dynamics and rural-urban migration reported as major social drivers of wetland diminution in the KMC (Table 4.4), which, as also reported by NEMA (1996); Huising, (2002) and Kataata, (2003) partly explains the proliferation of informal settlements (Figure 4.5) at the expense of wetland ecological sustainability. The present study reveals an escalation of this from 2,330 ha in 2006 to 3,280 ha by 2013.

Figure 4.5: Proliferation of informal settlements in Kasokoso - Namanve wetland site

These settlements are further driving the establishment of new industries with concomitant informal settlements, leading to the commodification and informalization of land acquisition policies (Lwasa; 2004; Lwasa *et al*., 2005). What results from this is the conversion of strategic environmental components, particularly wetlands, not only because they are seen as the cheapest areas for industrial development (UNEP, 2009; Aryamanya, 2011), but also because of inadequate law enforcement and inconsistent policy innovations (Rwakakamba, 2009). Already 5,560 ha of wetlands have been lost to DPs, resulting in the city's expanding into neighbouring rural Mukono, which is transforming the once wild area into an industrial corridor and it is primarily the wetlands along transport arteries that have been converted.

4.3.3 Implications of the KMC wetland loss

The diminution of the KMC wetlands has direct implications for wetland ecosystems. The conversion of forest swamps to industrial, agricultural and settlement uses destroys the habitat of a wide range of wetland fauna including warthogs, sitatunga antelopes (*Tragelaphus spekii)*, geese and red-tailed monkeys (*Cercopithecus ascanius*) (Musoke, 2001). The depletion of these wetland types has resulted in a drop in numbers among forest fauna, most of which have migrated to neighbouring rural areas of Mukono District; for example, the famous crop raids by monkeys, reported in areas like Kasawo, Kyampisi and Namuganga sub-counties (Baranga *et al*., 2012).

Papyrus (*Cyperus papyrus*) is known for creating a distinctive habitat for wild life species (see: Bennum & Njoroge, 1999; Birdlife International, 2004; Byaruhanga & Ssozi, 2012). The observed losses in papyrus swamps, marsh and bog are likely or may already have affected the breeding patterns of migratory birds, thereby affecting ecotourism activities, notably bird watching. As noted by Langdale-Brown *et al*. (1964) and Pomeroy (2004), the shoebill (*Balaenicepsrex)* and the grey-crowned crested crane (*Balearica regulorum*) have already been displaced by the shrinking macrophytes. These effects will be aggravated by the total loss of the existing scars of wetland degradation (palms and thickets). As Haberl *et al*. (2014) and Seto and Reenberg (2014) suggest, conservation of these fragile palms and thickets will not only enhance the rewilding of wetlands but also revive related outdoor tourism.

Finally, these changes will not only distort wetland biodiversity but also decrease the economic value of the wetlands. With over 5,650 ha of wetlands lost to DPs in the KMC by 2013, the findings by Wasswa *et al*. (2013) put the minimum economic value lost at US$ 19,311,700, which translates to US$ 36,613,616 for the entire KMC. This is expected to increase in respect to the projected wetland loss by 2040, resulting in serious negative effects on the subsistence livelihoods of communities in wetland peripheries, and sending many folks to deeper rifts of poverty. Already 49% of Mukono District's population is living below the poverty line, with some parts like Nakifuma reporting 56% (MDDP, 2010).

Ecosystem degradation undermines its functionality and resilience to provide a flow of production and environmental benefits to the present and future generations (De Groot *et al*., 2012). The consequences of this will primarily manifest in decreasing carbon sequestration potential, and deteriorating nutrient cycling and water holding capacity (Liddicoat *et al*., 2010). As a result, the decreasing wetland SOC sequestration potential will negatively impact local climatic modification, while the lost hydrological wetland services will be mirrored in compromised hydrological wetland services, creating adverse effects on ecosystem biodiversity. In this regard, the current high prevalence of infectious diseases (notably, typhoid, cholera, bacillary dysentery) in the peripheries of Kampala is due to the decreasing infiltration capacity of adjacent wetlands (Lwasa, 2004; Byaruhanga & Ssozi, 2012).

4.3.4 Mitigating wetland diminution for DPs in the KMC

The rate at which wetlands have been lost in the KMC over the four decades 1974 - 2013, and the projected future losses, highlight the need to decide on appropriate responses to abate wetland diminution. The responses suggested for mitigating continued wetland loss in the KMC are anchored in the Ramsar Resolutions and Recommendations Framework, which considers a threefold approach to decision making: avoidance, mitigation, and compensation. Utilizing the Wetland Risk Assessment Framework (1999) in decision making means that degradation would have a higher likelihood of similar but irreversible scenarios in future. As a rule of thumb, avoidance, redirecting or significantly modifying wetland activity plans would be the default position taken by policy makers in Uganda.

However, given the scale of DPs already in the region, such a position may not be practical. Consequently, the adoption of mitigation measures aimed at minimizing *in situ* wetland impacts while achieving the objectives of DPs is more feasible. In this regard, the present study recommends the revision of earlier spatial development plans with a view to cancelling proposed development activities in wetland zones. Coupled with this is the need to bridge the information gap about wetland values that exists between environmental agencies and development decision makers (land use planners, investment authorities and the private sector). This can be done through sensitizing these agents to the Total Economic Value of wetlands, in order to engender a positive shift in perceptions of these ecosystems (Wasswa *et al*., 2013).

The development and enforcement of regulatory mechanisms aimed at reducing the scale of DPs in the wetlands is also critical. These will involve streamlining land acquisition policies in wetland areas by checking the overlapping mandates of national agencies like UIA, District land boards and the city council in issuing land titles in wetland areas. Additionally, regulating the scale of DPs also involves ensuring the strict adherence of developers to EIA standards, through strengthening follow-ups on proposed mitigation measures and developing enforcement strategies (Kataata, 2003; Umar, 2010).

Additionally, Emerton (2000) and Anderson (2002) recommend the adoption of economic measures like taxes, charges, fees and fines in natural resource conservation, so as to shift the responsibility for biodiversity conservation to wetland actors. Similar measures have been recommended by other studies (see Emerton *et al*., 1998; Karanja *et al*., 2001; Schuyt, 2005 and Wasswa *et al*., 2013) to induce behavioural change towards sustainable wetland utilization. However, these measures often do not reflect the full economic costs of wetland degradation. There is therefore a need to revise such surcharges and penalties to levels equivalent to the estimated costs of wetland degradation in order to induce behavioral change among actors.

4.4 Conclusion

The KMC wetlands have progressively diminished by more than a half over four decades from 1974 to 2013. DPs account for the greatest percentage of this wetland loss, with the proliferation of settlements taking the greatest toll. Forest swamps dominated wetland cover in 1974 but had disappeared by 2006. Papyrus swamps, marsh and bogs decreased slightly between 1986 and 2006, but slightly regained by 2013. Palms and thickets had emerged by 1986, colonizing former forest swamps, though these in turn lost over a half of their coverage to DPs and agriculture. Future wetland projections indicate a continuous loss to DPs of up to 61% in the next 27 years.

The drivers of wetland diminution comprise a combination of factors, including economic dynamics and the preference for Kampala as an industrial zone, resulting in serious socio-economic and ecologically irreversible impacts on wetlands. It is recommended that mitigation measures should be adopted to minimise these impacts. These range from sustainable utilization of wetland resources, revision of earlier development plans in the KMC, regulatory mechanisms for DPs in wetland areas, and bridging the information gaps between stakeholders. All these should be used in conjunction with other restrictive economic incentives.

4.5 Summary

This chapter has assessed the spatial and temporal loss of wetlands to DPs in the KMC between 1974 and 2013. A projection of future wetland loss to DPs has also been presented. The implications of wetland loss manifest in socio-economic and ecological impacts. The next chapter presents the economic implications of wetland conversion for local people’s livelihoods.

CHAPTER FIVE

Economic implications of wetland conversion for local people’s livelihoods: The case of the Kampala–Mukono Corridor wetlands in Uganda[1]

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[1] This chapter is based on a published paper:
Wasswa, H., Mugagga, F., Kakembo, V. 2013. Economic implications of wetland conversion to local people’s livelihoods: The case of the Kampala Mukono Corridor (KMC) wetlands in Uganda. *Academia Journal of Environmental Sciences*, 1 (4), 066 – 077.

Abstract

Uganda's wetlands constitute an important stock of natural capital, producing goods and services that have economic value. Despite the need to conserve them, their loss to unsustainable resource utilization has continued because they are considered to have little or no economic value. This study aimed at highlighting the economic importance of three wetlands within the Kampala-Mukono Corridor (KMC) and the economic implications of their degradation for local people's livelihoods.

Emerton *et al*.'s (1998) Total Economic Valuation Approach (TEV) was used to quantify selected use values of wetland benefits, drawing on the market price, replacement cost and contingent valuation techniques.

The results revealed that the KMC wetlands yield a flow of economic benefits at a minimum approximated value of US$ 3,418 / ha / per year. Degradation of these wetlands would imply serious economic costs to the government and local communities, through high expenditure to duplicate wetland services, foregone incomes, livelihood support and alternative employment. The study recommends several strategic interventions, including the use of economic incentives and disincentives, intensification of economic valuation of threatened wetland ecosystems, promotion of efficient harvesting technologies, ensuring the independence of environmental monitoring and regulatory institutions, and community participation in planning and the enforcement of regulations.

Key words: Conservation, Goods and Services, Total Economic Value, Kampala-Mukono Corridor, Wetlands, Uganda.

5.1 Introduction

Uganda is endowed with wetlands covering approximately 13% of its land surface (NEMA, 2006; UNDP, 2009), and representing one of its most vital ecological and economic resources (Amaniga Ruhanga & Iyango, 2010; BakamaNume, 2010). The wetlands are associated with important functions that provide goods and services with economic value and satisfy human wants, directly and indirectly (Schuyt, 2005; Brander *et al*., 2006). Directly, wetlands are sources of water supply and other products such as fish and plant resources, clay, papyrus, and sand. They are also centres for recreation. Indirectly, they perform environmental functions vital in the maintenance and protection of human systems, through services like the preservation of water quality, flood attenuation, nutrient retention, groundwater recharge and climatic regulation (Barbier, 1993; Acharya, 2000; Oglethorpe & Miliadou, 2000). Because of their socio-economic importance, they have attracted human populations which survive by exploiting wetland resources, often driven by economic and financial motives (Schuyt, 2005). This has resulted in the degradation and modification of these valuable stocks of natural capital.

The situation has arisen from the fact that wetlands are perceived to have little or no economic value (Schuyt, 2005), coupled with the fact that no formal markets exist for their services to humanity (Newcome *et al*., 2005). This prevents wetland conservation from competing with other uses that seem to yield more tangible and immediate economic benefits. As a result, inadequate resources are fed into wetland management, which breeds environmental degradation through inappropriate commercial exploitation (Oglethorpe & Miliadou, 2000). The KMC presents an area where conservation benefits have been hampered by the human desire for economic gains. Decision-makers, particularly at the local level, opt for the conversion of wetland resources to other uses like agriculture, clay extraction and brick making. This trend is likely to result in grave and irreversible environmental consequences detrimental to human welfare.

The present study therefore aims to carry out an economic valuation, with a view to quantifying the actual and potential economic benefits accruing from conserving wetlands in the KMC. This ought to facilitate optimal and informed decisions about wetland management for a sustainable future. The specific objectives of this study were:

1. To estimate the direct and indirect wetland economic benefits accruing from the KMC wetlands.
2. To establish the significance of wetland values to people's welfare and the environmental costs of converting them for DPs.

5.2 Study area

The study was conducted within the Kampala-Mukono Corridor (KMC) in Uganda. Located between 0^{o}23' 56.22"N 32^{o}42' 51.22"E, 0^{o}23'48.66"N 32^{o}35'20.79"E, 0^{o}16'04.07"N 32^{o}42'49.38"E and $0^{o}16'16.05''$N $32^{o}35'03.16''$E, this area lies along the Northern shores of Lake Victoria, in the central and eastern parts of the country, traversing the two Districts of Kampala and Mukono (see Figure 1.1). A specific area comprising Lwajjali, Nakiyanja and Namanve wetlands, representing zones with diverse resource utilization activities, was selected for the study. The area is located in the broad uniform valley slopes, which descend into extensive papyrus wetlands, punctuated by flat topped hills that rise to an average height of about 1300 m a s l (NEMA, 1996).

The geology of the area is dominated by Precambrian–Paleozoic sedimentary cover sequence, punctuated with segments of crystalline Precambrian basement. It is the warping associated with these geological periods that is responsible for the formation of alluvium and lacustrine deposits that were colonized by numerous wetlands, including lacustrine and riverine swamps/flood plains (NEMA, 2002).

The area receives bimodal rainfall with the wettest periods being March to May and September to November, while very dry periods are experienced in December to February, and June to August. The mean annual rainfall often exceeds 2100 mm /831 inches, with sunny intervals most of the year, characterized by temperatures that rarely rise above 29° Celsius (NEMA, 2002).

The vegetation in the KMC follows the existing rainfall and relief patterns. The National Biomass Study (NBS) categorized the Kampala area’s vegetation into woodland trees, shrubs, bush thickets, scrub, built up vegetation, and wetlands (NEMA, 2002). In the Mukono District, vegetation cover mainly comprises a forest/savannah mosaic characterized by patches of dense forest, scattered trees and shrubs, grasslands and wetland vegetation (NEMA, 2002). Collectively, KMC is estimated to have a total of 40,700 ha of wetland area, i.e. 15 Km^2 in the Kampala District (NBS, 2003) and 392Km^2 in the Mukono District (NEMA, 1997). The major threats to these wetlands include reclamation for industrial expansion, for commercial and residential expansion, agricultural development, brick making, sand extraction and papyrus harvesting.

The study area is largely urban and peri-urban, with Kampala being more developed than Mukono in terms of infrastructure, urbanization, industry, commerce and trade. However, Mukono District is already showing indicators of economic growth and development in the form of agricultural and agro-based industries, improved infrastructure and growing urbanization (NEMA, 2002). This has translated into greater environmental stresses, including habitat destruction, pollution, deforestation, and wetland degradation. There is therefore an urgent need to place environmental resource utilization on an ecologically sound footing.

5.3 Results and Discussion

5.3.1 Wetland benefits from the KMC

From the inventory of wetland goods and services made during the reconnaissance survey (Table 5.1), various wetland benefits supporting people's livelihoods were identified and categorized according to their direct and indirect use, option value, and non-use/existence value. This categorization was based on the Total Economic Valuation (TEV) approach. The direct production services – including the harvesting of raw materials, particularly clay, and the physical products used for the production, consumption and sale of different goods like crops, clay bricks, thatch and water – were perceived as valuable to the people in wetland peripheries. This is because they provide benefits that directly satisfy human wants, such as the direct use of wetland products for income generation and human welfare. Besides, they are intimately known to the people since they involve human–environment interaction through a range of resource utilization activities, like brick making, sand mining, fish farming, thatch extraction and agriculture, that provide much-needed employment for the local people (Apunyo, 2008; Amaniga and Lyango, 2010).

Table 5.1: An inventory of benefits accruing from the KMC wetlands

Direct uses	Indirect uses	Option values	Existence values
Fish, wood fuel, building poles, sand, clay, thatch, water, wild fruits, herbs and rich soils for agriculture, pastures for grazing.	Water quality control, water flow regulation, water storage, water purification, flood control, storm protection and nutrient retention.	Tourism, pharmaceutical applications, leisure, unknown future developments of wild species and genes.	Heritage values, cultural, religious and aesthetic values.

(Information is based on field observations and secondary data from NEMA (2002).

However, the indirect ecological functions also play a role in supporting and maintaining natural and human systems, through regulation services that include flood control, water purification, water storage, storm protection, microclimatic regulation and ecosystem services such as nutrient cycling, nitrogen fixation, carbon sequestration and soil formation.

According to Barbier *et al*. (1997), these services offer support and protection to economic activities with indirect measurable value. For example, through nutrient cycling, the KMC wetlands support subsistence agricultural activities that sustain livelihoods, especially for the poverty-stricken rural and urban populations. Because these services do not directly involve human interaction, their importance to society goes largely unnoticed. Alternatively, they are perceived as ‘free’ public services, which makes it difficult for them to be accounted for in the open market (de Groot *et al*., 2006). All this contributes to the undervaluation of the KMC wetland’s TEV, which fuels inadequate resource management. As noted by Loomis *et al*. (2000) and Oglethorpe and Miliadou (2000), this situation instigates poverty-stricken local communities, driven by financial motives, to exploit wetland resources to their own advantage, causing environmental degradation and affecting human welfare.

The option use values vary from tourism, pharmaceutical uses, leisure, to unknown future developments of wild species and genes. The existence of these resources presupposes that their current exploitation may have irreversible implications (Barbier *et al*., 1997). Because local communities in and outside the wetlands are not certain of the future demand for or availability of these resources, particularly wild species and genes, they attach a high value to option uses of the KMC wetlands, some of which may not currently be known.

The existence values include heritage, cultural, religious, aesthetic and bequest values. This category of value is keenly recognized among communities that live and spend much of their time in the wetlands (Loomis *et al*., 2000; Petrics & Rusco, 2006). It is the direct users involved in the harvesting of papyrus, thatch and reeds, direct exploiters who extract mineral resources like clay, sand and other wetland resources, water abstractors and agricultural producers, who particularly value this use option. Because of their strong attachment to the wetlands, they advocate for the conservation of the wetland resources so as to see their way of life passed on to future generations.

5.3.2 The economic value of the KMC wetlands

Table 5.2 presents the economic value of the sampled wetlands in the KMC, estimated at US$ 1,543,738 per year, which is equivalent to US$ 3,418 / ha / year**.** The benefits from clay and flood control make up the bulk of this value, contributing 48% and 35% respectively. Water purification contributes 11% of this value, while water supply, crop cultivation and thatch contributed the least economic value (3.8%, 0.26% and 0.19%, respectively). According to Emerton *et al*. (1998), these figures represent a minimum estimate of KMC wetland's Economic Value. This is because they exclude other benefits yielded by the wetlands, most importantly, option values and the non-use values attached to aesthetics, biodiversity, bequest and cultural values. Additionally, they deal with selected existing direct production services related to significant utilization activities, which represent a small portion of the potential utilization opportunities.

In the present study, the value of wetland goods surpassed that of wetland services. The wetland goods considered included crops (yams and sweet potatoes), thatch, clay and water. Only two wetland ecosystem services (water purification and flood control) were considered. This clearly confirms what (Schuyt, 2005) observed with the valuation of similar African wetlands such as the Hadejia-Nguru wetlands in Nigeria by Acharya and Barbier (2000); the Nakivubo wetland in Uganda by Emerton *et al*. (1998), and the Zambezi Basin wetlands in Zambia by Seyam *et al*. (2001), that it is still relatively difficult and time-consuming to value wetland ecosystem services. Hence, even when their importance may be intuitively known by both the local and the national planning units, it is more probable that these non-use services will continue to be ignored in wetland management decisions, which underestimate the gross value attached to wetlands; most importantly, the ecological services resulting in continuous conversion of the KMC wetlands. There remains a need for capacity building in wetland valuation studies of this kind in Uganda and, particularly, for those regions where demographic growth amidst poverty and the current economic stress threaten the existence of wetlands.

Table 5.2: Summary of the estimated economic value of the KMC wetland benefits

Wetland goods and services ***A. WETLANDS GOODS (With direct use value)***	**Total Value in USD per year***(Buying at UGX 2,500)*
1. YAMS	
1.1 Estimated Annual subsistence consumption value accruing to the yam producers in the wetlands	1,983
1.2 Estimated value added through the sale of yams accruing to yam traders	13
Estimated total economic value of yams in the selected wetlands of the Kampala-Mukono corridor per year	**1,996**
2. SWEET POTATOS	
2.1 Estimated Annual subsistence consumption value accruing to the yam producers in the wetlands	2,088
2.2 Estimated value added through the sale of sweet potatoes accruing to sweet potato traders	38
Estimated total economic value of yams in the selected wetlands of the Kampala-Mukono corridor per year	**2,126**
3. ***THATCH***	
Estimated Net Annual value accruing to the thatch harvesters in the selected wetlands	**3,007**
4. CLAY	
4.1Estimated Annual Net value accruing to the clay extractors in the selected wetlands	184,959
4.2 Estimated Annual Net value accruing to the clay brick makers in the selected wetlands	552,287
4.3 Estimated Annual Net value accruing to the clay pot makers in the selected wetlands	7,853
4.4 Estimated Annual Net value accruing to the clay charcoal stove makers in the selected wetlands	1,299
Total economic value of clay in the selected wetlands	**746,398**
5. WATER	
Estimated annual net subsistence consumption value of water in the selected wetlands	**590,028**
SUBTOTAL **Minimum economic value of wetland direct use benefits**	**812,528.5**

B. WETLAND SERVICES (With indirect use value)	
FLOOD CONTROL	
6. 6.1 Estimated annual economic value of protecting upstream gardens accruing to the 52 farmers / households in the selected wetlands	805
6.2 Estimated annual economic value of protecting 1,132 motorized road linear distances with 50m in the selected wetlands from floods	28,379
6.3 Estimated economic value of protecting dwellings from floods	269,236
Total Wetlands Economic Value of Flood Control	**553,832**
Water purification	
Estimated Total annual replacement cost of water purification and treatment for 8,437.3 users of unsafe water in the KMC	**177,378**
SUBTOTAL Minimum economic value of wetland indirect use benefits	**731,209.1**
Minimum Economic Value of selected wetland goods and services in the KMC	**1,543,738**
Estimated Total wetland area in the study area (based on field GIS measurements): 451.7 hectares	**N/A**
Estimated Minimum Economic Value KMC wetlands (US$ / ha / year)	**3,417.6**

The unit value of US$ 3,418 / ha per year is relatively high compared with similar African case studies, which find a value of between US$ 45 and $ 90 / ha / year (de Groot *et al*., 2006). This should not discredit these results, since this area is on the peri-urban fringe of Kampala city with diverse resource utilization activities that command higher returns. Besides, it is quite plausible that the value of wetlands is enhanced by proximity to cities (Stuip *et al*., 2002). Considering the unit estimate of US$ 3,418 / ha /year, the economic value accruing to the entire KMC with 40,700 ha or 15 km^2 for Kampala District (NBS, 2003) and 392 km^2 for Mukono district (Kamanyire, 2002), would amount to approximately US$ 139,097,020. It has been shown that over 56% of wetlands were lost to DPs in the KMC by 2013 (see chapter 4), bringing the minimum economic value lost to US$ 19,311,700 in the sampled wetlands. Considering the unit economic value per hectare, it is revealed that US$ 65,382,922 have been lost from 1974–2013, with US$ 36,613,616 accruing to DPs. This economic value reflects the potential losses to the people if wetlands are totally degraded. In tandem with Emerton *et al*. (1998), Karanja *et al*. (2001) and Schuyt, (2005), it is argued that these losses should be integrated into wetland management decisions, and weighted against the benefits of wetland conservation.

According to Balmford *et al*. (2002), the Total Economic Value of intact wetlands far exceeds that of converted wetlands. Consequently, this value would certainly be higher if the KMC wetlands were still intact. But since they have been converted, their value is significantly lowered, a situation that has over time created long-term national capital debts, in part to fund expenditure on costly programmes for wetland restoration, management and sensitization. In the face of this, immediate conservation and sustainable utilization of these natural stocks of capital is critical to the survival of present and future generations.

5.3.3 Distribution analysis of wetland benefits among stake holders

The distribution analysis arising from this study (Table 5.3) indicates that a great deal of wetland economic benefits (over US$ 1.3 million) accrues to local communities, particularly at the subsistence level. Although this may not seem feasible to the District Planning Units, it ought to be taken as a substantial amount (Emerton *et al*., 1998; Karanja *et al*., 2001), whose loss through unsustainable wetland utilization would make communities adjacent the KMC wetlands substantially poorer.

Table 5.3: Distribution of wetland economic benefits in the KMC

Beneficiary groups	**Nature of benefits**	**Value of benefits US$ /yr**
1.Local level communities (Direct extensive users)	**1. Subsistence and livelihood**	
	(a.) Goods	
	- Crops - Water supply	- 4,070 - 59,001
	(b). Services Flood control - Attention to: Household dwellings - Attenuation to gardens - Attenuation to roads - Water purification	 - 269,236.5 - 805 - 283,790 - 177,378

Table 5.3 continued:

Beneficiary groups	Nature of benefits	Value of benefits US$ /yr
	2.Estimated incomes accruing to local level communities:	
	- Net annual revenue from sale of crops. - Net revenue from brick making/yr. - Net revenue from pot making/yr. - Net revenue from the sale of Charcoal stoves. - Income earnings from thatch harvesting.	- 52 per year - 552,287 per year - 7,853 per year - 1,299 per year - 3,007 per year
Economic Value accruing at the local level beneficiary group		***1,358,779***
2.Local government level	Expenditure saved on the provision of goods and services	- On the minimum calculated at US$139 million for the entire KMC

Note: The sum of components is not equal to total wetland value since the distribution analysis is made between two stakeholders (local communities and local government) who benefit from the same wetlands.

With an estimated population of 2.45 million – Mukono District having 795,393 persons (Muyomba-Tamale *et al*., 2009) and Kampala 1.66 million (UBOS, 2010) – and in view of the fact that a great deal of the economic value estimated in this study accrues at the local level, wiping out the current wetlands (estimated at a minimum value of over US$139 million) would mean that the Local Government Administrations in these two Districts would have to meet the costs of providing for the socio-economic needs of the population that have thus far been provided for by the wetlands freely or at a lower cost. Subsistence livelihood products, incomes and employment benefits would be forgone in favour of unsustainable wetland utilization activities or DPs which only offer short-term solutions to important social and economic problems (Gumm, 2011).

The Local Government Administrations in Kampala and Mukono Districts should embark on developing a land use plan that will ensure that the KMC wetlands are not degraded at the expense of poverty-driven unsustainable utilization activities or DPs that encroach on their lands as they search for strategic locations to enjoy economies of scale. According to Forman (2001), Randolph (2004) and Perlman and Milder (2005), such land use planning should be tailored in line with ecological principles that embrace collaborative environmental management, ecosystem and watershed management and environmental design.

The District Administrations in the two Districts making up the KMC mainly benefit from the wetlands through taxes charged against wetland resource utilization, from the production to the marketing stage. In addition, these wetlands are saving or subsidizing public expenditures through providing goods and services which the government would otherwise have had to provide. At the minimum this amounts to US$139 million. Owing to the fact that the KMC wetlands provide substantial benefits to local communities and the public sector, these stakeholders should be sensitized of the huge benefits that they acquire from the KMC wetlands, particularly the indirect use and non-use values that do not involve human-environment interaction. Local communities should themselves be led to understand that the sustainable attainment of the same benefits will only be guaranteed if wetlands are conserved rather than converted for unsustainable utilization activities.

5.3.4 Economic measures for sustainable wetland management

The location of the KMC wetlands adjacent to a densely populated and rapidly developing capital city (Kampala) makes wetland resources vulnerable to encroachment, modification and conversion. One way of ensuring that the remaining wetlands are managed sustainably would be through carrying out regional awareness campaigns regarding the KMC wetlands' economic value, demonstrating their contribution to the local and national economy. Such sensitization will empower local communities with knowledge and awareness, particularly about the ecological roles of wetlands, so as to influence a positive shift of attitudes toward these ecosystems (Apunyo, 2008). Other scholars, such as Crafter *et al*. (1992), Mathooko *et al*. (2009) and Macharia *et al*. (2010), have noted that such awareness and educational campaigns made profound impacts that changed the attitudes and perceptions of local communities in two highland wetlands of Central Kenya. Communities organized themselves, revived a dormant community group, and later created an ecotourism venture which has helped to address many wetland threats.

A further observation in the present study is that the KMC wetlands are principally threatened by human-induced activities and government-driven reclamation activities. The former applies to extractive resource utilization activities like agriculture, clay mining, thatch extraction and water utilization, which are driven by poverty, demographic factors and economic anxiety, while the latter takes the form of large industrial expansion allocations and infrastructural development. The first category of stakeholders includes those who live within the wetlands, whose actions are dictated by economic stress and tradition. In order to survive, these people have to carry out unsustainable wetland utilization activities that contribute to ongoing wetland loss.

The second category comprises those who perceive the economic benefits of wetland conversion to be higher than the economic benefits of wetland conservation. This perception is a function of information failures about the potential economic benefits of wetland conservation. As recommended by Schuyt (2005), the first category of actors in the wetlands should be approached by dealing with the principal causes of unsustainable utilization, while the second category of actors may be addressed through economic valuation studies of the present kind.

As wetlands become degraded, livelihoods and communities' welfare become progressively weakened (Farmer, 2012); yet local communities in the wetlands are unlikely to conserve them in the course of their utilization activities. Economic incentives offer a valuable tool for both nature conservation and sustainable livelihood development (Emerton, 2000; Anderson, 2002). Incentive-based regulations should be adopted by developing countries, owing to their greater cost effectiveness than the traditional command and control approach, which relies solely on the enforcement of regulations. Such approaches should include the use of direct economic incentives, including property rights that enable the formation of conditions under which communities will benefit from the wetlands and thus have a stake in their conservation; performance bonds; or subsidies for environmentally-friendly activities. Owing to the fact that the KMC wetlands are degrading under 'the tragedy of the commons scenario' due to individualised ownership and high resource use, the present study recommends that sustainable management and wise use of wetlands in the KMC requires a revision / conceptualisation and subsequent regulation of historic property rights in the area. Five property rights regimes exist in Uganda but those with in Kampala and neighbouring big towns include: Mailo, free hold, lease hold (categorised as premier modes of private land ownership under English law) and public land tenure (Green, 2006). However, since most of the natural resources in the KMC occur within individualised property right regimes particularly leasehold, Mailo and free hold, resource owners do not appreciate off-site societal benefits provided by wetlands, which is creating limited motivation for wise use and sustainable management of the KMC wetlands. It is noted that public land regime has proved to be an efficient framework for the conservation of Uganda's natural resources by way of utilising the traditional model of creating protected areas as a mechanism for natural resource conservation (Infield and Namara, 2001). Hence, in order to protect the off-site societal benefits from the destructions arising from selfish individualised interests of resource owners and regulate wetland use to ensure sustainability wetland benefits, the present study recommends that all wetlands in the KMC be declared 'public goods' and following the public trust doctrine, these wetlands be conserved in public interest for public benefits and not transferred to private individuals for private use.

Where incentives fail to change people's behaviour in promoting sustainable wetland utilization, disincentives should be used (Karanja *et al.*, 2001; Farmer, 2012). These may include taxes, charges, fees, or fines for unacceptable levels of degradation; and tradable permits (Emerton, 2000; Anderson, 2002) for local land holders who prefer to give up their lands in the wetlands to unsustainable wetland utilization activities. However, these should be refundable against proper sustainable wetland utilization.

Ironically, some progress has been made in this direction by environmental monitoring and regulatory agencies like the National Environmental Management Association (NEMA), where charges are levied at the local level for unsustainable wetland use. However, these do not reflect the full economic costs of wetland degradation, and therefore may not amount to a sufficiently stringent penalty to induce a positive change in people's behaviour towards sustainable wetland utilization. These charges should be raised to levels equivalent to the total estimated costs of wetland degradation as highlighted in this study. They should be revised so that they clearly appear as private or public expenditure that significantly affects private profits, with the potential to actually change people's behaviour in respect of wetland utilization. Furthermore, the District Planning Units should consider strengthening community livelihood enhancement measures in order to reduce reliance on wetland resources. This may be done through the promotion of efficient harvesting technologies that will not only increase the value of raw wetland resources, but also

provide the much-needed employment and alternative incomes to the population engaged in wetland exploitation (Crafter *et al*., 1992; Mathoko *et al*., 2009; and Macharia *et al*., 2010).
Tradable permits should be developed in the context of liability regimes that focus on the concept of 'wetland banking' in order to ensure no further net wetland loss to DPs. This mechanism would make developers liable for the damage they cause to wetlands and also compensate for it by creating wetlands elsewhere. According to Shabman 2004, compensating companies have to buy wetland credits from private companies that have already set up wetland banks in other areas. If applied in this context, tradable permits will not only introduce collective responsibility for stake holders to comply in their conservation, but will also enable developers to view this form of tradable permits as aimed at balancing wetland conservation and economic development. Bräuer *et al*., (2006) notes that this system has generally been regarded as successful in the US where wetlands were destroyed at alarming rates without compensation. However, the main challenge of using wetland banks to guide tradable permits in wetland conservation lies in defining equivalence of habitats elsewhere. This challenge can be overcome by carrying out wetland inventories for the replacement wetlands in order to assess whether they would provide similar ecological and social benefits that are fore gone in favor of DPs. Nevertheless, as indicated by Wissel and Wätzold (2010), the success of this form of tradable permits in wetland conservation is premised on a functional institutional framework, expert knowledge, monitoring and enforcement mechanisms.

The future of African wetlands lies in a stronger political will to protect them, based on sound wetland policies (Schuyt, 2005). In Uganda, this will has created fairly comprehensive wetland legislation. However, its effective functionality is hampered by inadequate funding and political interference (Apunyo, 2008). These institutions charged with responsibility for wetland protection should be left to make independent decisions and execute their work without government or political interference.

Owing to the fact that the KMC wetlands are threatened by human-induced activities and government-driven reclamation initiatives for industrial and infrastructural development, their sustainable management requires stepping up strategies that emphasize community involvement in the planning and implementation of appropriate approaches. Ironically, this was the situation during the colonial period (before 1962), when wetlands belonged to the central government, and traditional institutions through monarchical systems played a big role in their protection, based on traditional beliefs and spiritual attachments (Apunyo, 2008).

However, the reduction of traditional institutional powers over time is leading communities to drop their attachments to such ecological resources. Community-based participation is being revamped through the formation of Community-Based Wetland Management Plans (CBWMP), though these often face immense funding challenges. Such community involvement in wetland conservation should be active in the planning and enforcement of conservation regulations. As noted above, this strategy registered formidable results in the central Kenya highland wetlands (Crafter *et al*., 1992; Mathoko *et al*., 2009; Macharia *et al*., 2010). Yet, Emerton *et al*. (1998) argue, strict protection of these fragile ecosystems is rarely effective since it entails enforcement costs, and governments are already facing public sector deficits, with many sectors competing with wetlands for scarce resources. Hence, there is need to establish innovative funding mechanisms for wetland conservation and management. These may come from charges, fines, bonds and deposits levied against unsustainable wetland utilization.

5.4 Conclusion

Communities around the KMC wetlands directly benefit from wetland goods and services through the utilization of wetland resources. They also benefit from indirect wetland uses particularly regulation, supporting services and the option values which are worth millions of dollars. At the minimum, the economic benefits of the KMC wetlands are estimated at US$ 3,418 / ha / year. The benefits from clay extraction and flood control make up the greatest bulk of this value, followed by water purification, while the benefits from crop cultivation and thatch contribute the least economic value. It is also revealed that a great deal of wetland economic benefits (over US$ 1.3 million) accrue to local communities, particularly at the subsistence level. Protection of these wetlands could, therefore, be achieved through carrying out awareness campaigns about the economic value of the KMC wetlands; the development of land use plans that integrate economic values, particularly in wetlands and riparian areas; the use of economic incentives including a revision / conceptualisation and subsequent regulation of historic property rights in the KMC, and disincentives such as fines, bonds, fees, tradable permits and taxes against unsustainable wetland utilization practices; ensuring the independence of environmental institutions in decision making and the development of innovative funding mechanisms for wetland conservation and management.

5.5 Summary

The present chapter has estimated the EV of conserving the KMC wetlands. It also presents the economic implications of KMC wetland conversion for local people’s livelihoods. A distribution of the wetland benefits and recommendations for sustainable wetland management are also presented. However, the conversion of wetlands for DPs not only has socio-economic implications for local people’s livelihoods, but also poses threats to the ecological wetland benefits. The subsequent chapter presents an assessment of the carbon sequestration and hydrological impacts associated with wetland conversion for DPs in the KMC.

CHAPTER SIX

Assessment of carbon sequestration and hydrological impacts associated with wetland diminution in the Kampala–Mukono Corridor (KMC) wetlands in Uganda

Abstract

Wetland conversion may have ecological implications, particularly for carbon sequestration and hydrological services. The present study assessed the carbon sequestration and hydrological impacts associated with wetland diminution by DPs in the Kampala Mukono Corridor (KMC). The soil organic carbon (SOC) was determined using the Walkley-Black (1934) method. The SOC changes between 1974 and 2013 and implications for local climate variability formed the basis for the spatial temporal SOC analysis, while the hydrological impact analysis focused on nutrient concentration, sediment transport and flow parameters. The Total Soil Organic Carbon (TSOC) densities ranged from 5.94 – 27.4g m^{-2} in the 0 – 50cm soil depth range across the KMC wetlands. Forest swamps, palms and thickets and wetlands converted to agricultural use exhibited the highest carbon sinks, accounting for 25% of the KMC wetlands by 2013. The lowest TSOC range was observed among converted wetland cover types that occupied 47% of the study area. Land use change through the conversion of forest swamps for DPs is identified as one major factor responsible for the diminishing SOC pool in KMC. A strong relationship between wetland cover types and nutrient concentration – Total Phosphorous (TP) and Total Nitrogen (TN) – was revealed in the hydrological impact analysis ($R^2 = 0.912$ & $R^2 = 0.941$, respectively). Converted wetland cover types registered the highest nutrient concentration, with industrial use taking the largest toll (51.4 and 42.9 µg/L), respectively. Total Dissolved Sediments (TDS) concentrations were generally low in all cover types, with the highest concentrations occurring in forest swamps, wetlands converted to agriculture and papyrus swamps, marsh and bog. Runoff from adjacent fertilized croplands, industrial effluent discharge, the general conversion of the KMC wetlands and subsequent adsorption by sediments are major causes of high nutrient pollution, which consequently compromises water quality. High Total Suspended Sediment (TSS) values were observed in converted cover types – industrial, settlement, and agriculture (1.17, 0.83 and 0.82, respectively) – while the lowest values occurred in papyrus and forest swamps (0.38 and 0.46 mg/L, respectively). Results point to upstream wetland conversion for DPs and related alterations of wetland hydrological regimes as the principle causes of growing TSS and bed load, creating adverse effects on wetland hydrological processes, particularly filtration, water storage/recharge and flood attenuation benefits. Restoration measures and wetland conversion regulatory mechanisms need to be undertaken to reduce the scale of DPs and restore wetland hydro-ecological and social benefits.

Key words: *Carbon sequestration, hydrological implications, nutrient concentration, sedimentation, KMC.*

6.1 Introduction

Increasing atmospheric carbon emissions and changing hydrological regimes are major environmental concerns in many urban areas where wetlands face degradation. Dubbed "nature's kidneys" (Su *et al*., 2009), wetlands possess numerous beneficial attributes whose conservation results in the provision of a wide range of environmental services to humanity (Mitsch, 1986). Most important of these environmental services are climatic modification through carbon sequestration and hydrological benefits such as water purification, waste filtration, flood control, water storage, groundwater recharge and discharge and sediment stabilization (Acharya, 2000; Zedler & Kercher, 2005). For instance, about 20% – 30% of the global soil C pool is stored in wetlands (Roulet, 2000; Bridgham *et al*., 2006), while approximately 68% of nitrogen and 43% of phosphorous pollutants can be removed from drainage water by wetlands (Woltermade, 2000), that only occupy 5% – 8% of the earth's land surface (Mitsch, 1986).

Despite these enormous bio-geochemical attributes, hydrologic and carbon sequestration wetland benefits are poorly understood (Mitra *et al*., 2005). Additionally, the available literature pertaining to wetland diminution seems to inadequately tackle the ecological implications of hydrological and carbon sequestration (Saunders *et al*., 2007; Maltby & Barker, 2009). Consequently, wetlands are given little weight in decision making – a situation which leads to their conversion and degradation for economic gains (Joshi *et al*., 2002; Schuyt, 2005; Huising, 2002). In Uganda, about 2,376km^2 of wetland area had been lost to anthropogenic activities by the year 2000 (NEMA, 2001; Apunyo, 2008).

In the light of present development dynamics, characterized by the desire to pursue economic transformation policies, growing populations, increasing urban land markets and the preference for Kampala as an industrial hub, the KMC wetlands continue to face considerable pressure, with many on the brink of total degradation. The heavy burden of wetland DPs and rapid land use change are likely to distort the geochemical processes as well as the hydrological equilibrium of the wetlands. Resulting from this is a rapid loss of C from organic soils, enhancing carbon-driven climate change (Mitra *et al*., 2005) and significant alterations in wetland hydrological functions and services (Acreman & Miller, 2006). Devising ways to reverse this trend is an urgent need for the KMC and other urbanizing zones globally, where wetlands seem to offer the only strategic land for developers to tap into urban economies of scale. The present study assesses the implications of wetland diminution for carbon sequestration and hydrologic benefits and impacts. An attempt is made to extrapolate carbon sequestration impacts back to 1974. The specific objectives of this study are:

1. To estimate SOC storage changes relating to wetland cover changes in the KMC from 1974 to 2013 and their implications for climate variability.
2. To assess the hydrological impacts relating to wetland cover changes in the KMC

6.2 Results

6.2.1 SOC storage changes and implications for climate variability in the KMC wetlands

This section presents results pertaining to SOC distribution in different wetland cover types of the KMC, the extrapolation in time and the implications for climate variability.

6.2.1.1 SOC density in the KMC wetlands cover types

The distribution of soil organic carbon density (SOCD) in the KMC wetland cover types is presented in Figure 6.1. The results indicate that the SOC densities in the 0–50cm soil layer across the study area ranged from 5.94–27.4 g m^{-2}, with the highest mean C storage occurring in the first layer of soil depth, 0–15cm (see Appendix I). Over 47% of the total study area revealed a lower TSOC range of 5.948–6.66 g m^{-2}, which occurred in continuously distributed wetland cover types converted to industrial estates and settlements. Wetland areas covered with papyrus swamp, marsh and bog, accounting for about 28% of the total study area, had a relatively high SOC density storage of 20.206 g m^{-2}. The highest TSOC sinks were registered in forest swamps, wetlands converted to agriculture and the palms & thickets wetland cover type (Figure 6.1), that only accounted for 25.2% of the total study area by 2013. Whereas the lowest values of TSOC were seen in wetlands converted to industrial use, the highest TSOC sinks were evident in the wetlands converted to agricultural use. Based on the spatial autocorrelation of wetland types and TSOC stocks, the Moran index I was 0.149804, implying a positive spatial correlation of SOC stocks and wetland cover types. The Z- score was 19.364263 indicating a less than 1% likelihood that the clustered pattern in the spatial SOC stocks in the study area could be the result of random chance. The analysis further revealed a significant relationship between wetland cover types and SOC sequestration (p–value: 0.000000) (see Table 6.1 and Table 6.2), with the most significant relationships observed among agricultural and industrialized converted wetlands, while the least occurred in the palms and thickets wetland class (Figures 6.1).

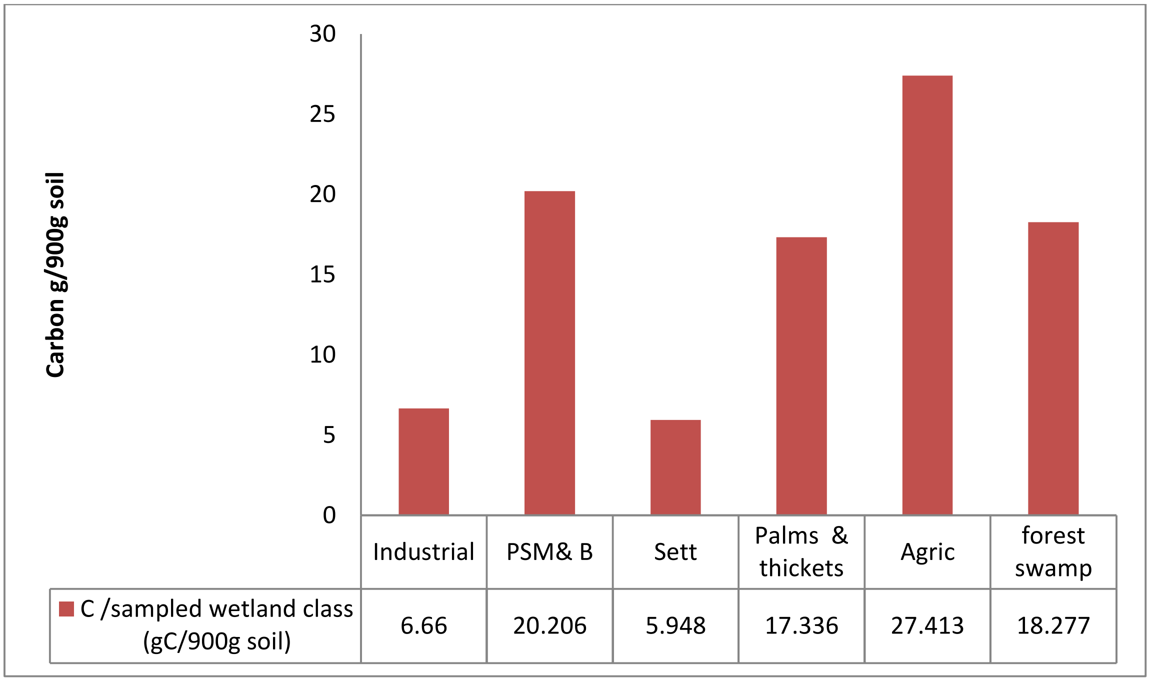


Figure 6.1: TSOC (g / 900g soil) as sampled for different wetland cover types in 2013

Key: Agric – Wetlands converted to agriculture, PSM&B – Papyrus swamp marsh and bog, Sett – Wetlands converted to settlement, Industrial – Wetlands converted to industrial use.

Table 6.1: Analysis of variance of soil carbon in the samples

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	8	46.573	5.822	5.538	< 0.0001
Error	54	56.762	1.051		
Corrected Total	62	103.335			

Table 6.2 Results of the spatial autocorrelation analysis of SOC stocks and wetland cover types

OBJECTID	VARNAME	VARIABLE	DEFINITION
1	Bandwidth	11135.81	
2	Residual Squares	901.2436	
3	Effective Number	6.782116	
4	Sigma	1.961603	
5	AIC	1014.28	
6	R2	0.67765	
7	R2 Adjusted	0.669692	
8	Dependent Field	0	classes
9	Explanatory Field	1	SOC

Spatial Autocorrelation Report

Moran's Index: 0.149804
z-score: 19.364263
p-value: 0.000000

6.2.1.2 SOC storage changes associated with wetland cover changes in the KMC from 1974 to 2013

The 0–50cm organic spatial carbon storage for different wetland cover types during a 39-year observation period was estimated as presented in Table 6.3. The results showed that the SOC storage in 1974, 1986, 2006, and 2013 were 96.1 t, 99.3 t, 84.2 t, and 88.99 t respectively, with the highest carbon storage registered in 1974 and 1986. The biggest SOC bank in the KMC wetland cover types were the forest swamps and palms and thickets, with over 58 t and 42.5 t in 1974 and 1986 respectively. The lowest carbon sinks were seen in wetlands converted to industrial estates and settlement uses. Decreases in C stocks over the observation period mainly occurred in forest swamps and palms and thickets. Between 1974 and 1986, 95% of the C stock in forest swamps was lost, while 42% was gained in palms and thickets. Other relatively smaller gains are observed in settlement and industrial converted wetland classes up to 2013. There were smaller C storage changes registered for papyrus swamps, marsh and bogs, and wetlands converted to agriculture.

Table 6.3: SOC storage changes in the KMC wetland cover types between 1974 and 2013

Class name	Wetland Area (ha) by 1974	TTC(t) per wetland class 1974	Wetland Area (ha) by 1986	TTC(t) per wetland class 1986	Wetland Area (ha) by 2006	TTC(t) per wetland class 2006	Wetland Area (ha) by 2013	TTC(t) per wetland class area by 2013
IND	0	0	460	1.5	593	1.9	2,370	7.89
PSM&B	3,710	37.4	3440	34.7	3130	31.6	3,360	33.9
SETT	0	0	1165	3.5	2330	6.9	3,280	9.7
P&T	0	0	4910	42.5	4060	35.1	2,050	17.7
AG	0	0	1040	14.2	638	8.7	1,010	13.8
FS	6,430	58.7	327	2.9	0	0	0.0	0.0
Total	**10,140**	**96.1**	**11,342**	**99.3**	**10,751**	**84.2**	**12,070**	**82.99**

Key: AG – Wetlands converted to agriculture, IND – Wetlands converted to industrial estates, FS-Forest Swamp, P&T – Palms and thickets, PSM&B – Papyrus swamp, marsh and bog, SETT – Wetlands converted to settlement.

6.2.1.3 Implications of SOC storage changes for local climate variability

As highlighted in Chapter 4 (Table 4.1), there was a progressive loss of the KMC wetlands to DPs of 1,625 ha, 2,923 ha, and 5,650 ha in 1986, 2006 and 2013, respectively. Based on the fact that wetland losses to DPs from 1986 to 2013 were majorly from former forest swamps (with 18.277g C/900g soil, see Figure 6.1), which is 0.00929 t/ha (see appendix I), the present study puts the gross SOC loss accruing to DPs in the KMC wetlands at 14.8 t, 26.7 t, and 51.6 t, in 1986, 2006 and 2013 respectively. However, C stocks are not entirely lost. The present study reveals an existing percentage of 5 t, 8.8 t, and 17.59 t carbon stocks among wetlands converted to industrial and settlement uses (see Table 6.3). Consequently, deducting the gross SOC loss implies that the KMC wetlands have recorded a net loss of 9.8 t, 17.9 t and 34 t of SOC as a result of their conversion to DPs in 1986, 2006 and 2013, respectively. The SOC losses to DPs during the observation period were compared with climatic data for Kampala so as to make inferences regarding local climate variability. The results indicated a strong relationship between C losses and temperature (see Appendix G and Figures 6.2a and 6.2b).

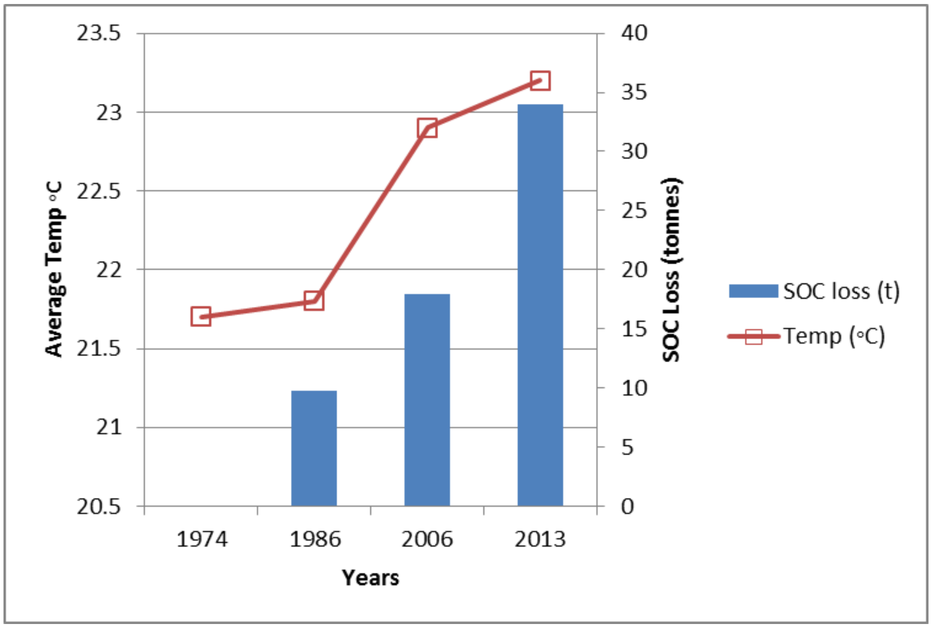


Figure 6.2a: The implication of the KMC wetland SOC loss for localized temperatures 1974–2013

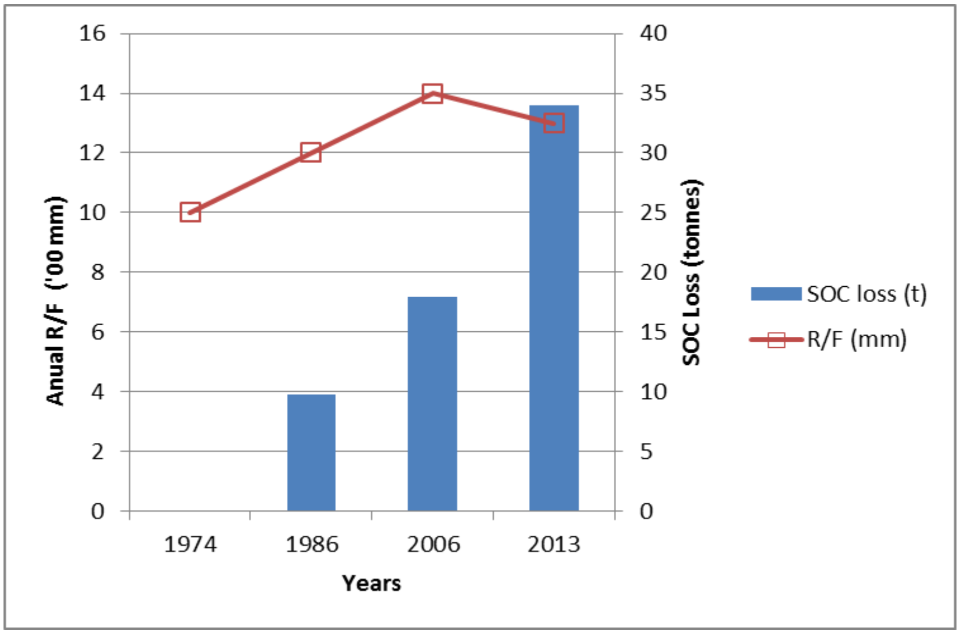


Figure 6.2b: The implication of the KMC wetland SOC loss for annual rainfall 1976–2013

6.2.1.4 Relationship between SOC loss and atmospheric temperature

The relationship between SOC loss and atmospheric temperature as exhibited in Appendix G was strong (R^2 = 0.8432), confirming a positive correlation between SOC and temperature. By implication, carbon loss strongly influenced local climate variability through increasing atmospheric temperatures.

6.2.1.5 Trends in carbon sequestration and carbon loss between 1974 and 2013

According to the study results (Figure 6.2a and 6.2b), carbon sequestration decreased as more carbon was lost from the KMC wetlands between 1986 and 2013 (Figure 6.4). The lowest carbon sequestration was registered in the period 2006 to 2013. This is the same period in which the highest carbon loss was registered. The highest carbon stocks were observed between 1974 and 1986.

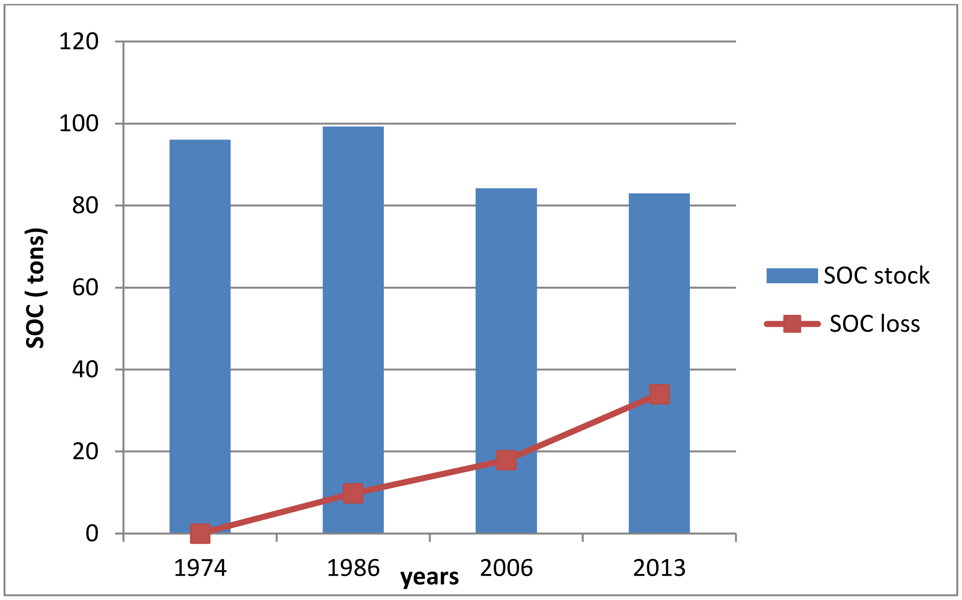


Figure 6.4: Trends in carbon sequestration and carbon loss between 1974 and 2013

6.2.2 Hydrological impacts resulting from wetland cover changes in the KMC

Results from the hydrological impact analysis of wetland diminution to make way for DPs are presented in Table 6.4. The major parameters include chemical nutrient concentration, total suspended sediments (TSS) and related hydrologic flow data for the different wetland cover types in the KMC (Appendix J).

Table 6.4: Chemical nutrient concentrations and flow data for the KMC wetland cover types

Wetland class	TP (µg/L)	TN (µg/L)	TDS (ppm)	TSS (mg/L)	AV Depth (Cm)	Av Width (ft.)	Av speed (m/s)	Bed Load kg.
P&T	4.9	46.5	84.6	0.84	41.3	6.8	0.6	3466.4
PSM&B	2.6	27.1	93	0.38	58	9.8	0.3	1236.3
FS	3.9	32.1	104	0.46	32.3	5.7	0.2	3600.3
AG	3.6	25.3	96.3	0.82	25	9.6	0.4	2940.6
IND	51.4	42.9	79	1.17	11	5.2	0.5	980.4
SETT	4.9	45	65.3	0.83	15	5.6	0.6	1342.6

Key: P&T – Palms and thickets, PSM&B – Papyrus swamp marsh and bog, FS- Forest Swamp, AG – Wetlands converted to agriculture, IND – Wetlands converted to industrial estates, SETT – Wetlands converted to settlement, TN- Total Nitrogen, TP- Total phosphorous, TDS- Total Dissolved Sediments, TSS- Total Suspended sediments, AV- average

As shown in Table 6.4, the highest mean chemical nutrient concentrations occurred among the wetlands converted to industrial, settlements and palms & thickets wetland cover classes, with the industrial wetland use type having the highest value. The lowest nutrient concentrations were registered in the papyrus, wetlands converted to agriculture and the forest swamps cover types. Industrial land use registered the highest mean phosphorous concentrations (51.4µg/L), in contrast with its generally low concentrations across the wetland cover types. The highest nitrogen concentrations were observed in the palms and thickets.

The highest mean TSS were in the wetlands converted to industrial use (1.17 mg/L) whilst the papyrus swamps, marsh and bog and forest swamps had the lowest mean concentrations with 0.38 and 0.46 mg/L, respectively. Moderate values of TSS with a range of 0.82–0.84 mg/L were observed in palms and thickets and in the wetlands converted to settlements and agricultural use. Peak channel bed loads occurred within forest swamps, palms & thickets and agriculture with 3600.3, 3466.4 and 2940.6 kgs respectively; whereas the lowest channel bed loads were recorded in papyrus swamps and wetlands converted to industrial, settlement, ranging from 980–1342 kgs. It is also noted that high TDS values were registered in all wetland cover types, with peak values observed in forest swamps (104 ppm).

The lowest mean water depth and wetland stream widths were recorded amongst wetlands converted to industrial and settlement use i.e. 11, 15 cm and 5.2, 5.6 cm. respectively. On the other hand, the highest mean water column and wetland stream widths across the KMC wetland cover types were registered among the papyrus swamps, marsh & bogs, and the palms and thickets, with 58, 41.3 cm and 9.8, 6.8 cm. respectively. Mean flow velocities through the KMC wetland cover types were 0.2, 0.3, 0.5 and 0.6 m/s for forest swamps, papyrus swamps, converted wetlands to industrial, and settlement use and palms and thickets, respectively. The results in Table 6.5 indicate a significant relationship between wetland cover types and nutrient concentrations, with a p-value of <0.002 - 0.008. The strongest relationship was exhibited with TP and TDS concentrations ($R^2 = 0.912$ & $R^2 = 0.941$ respectively), while the least occurred with TN ($R^2 = 0.684$). There was no significant relationship between the wetland cover types and flow data (p-value range of >0.204 – 0.935).

Table 6.5: Relationships and significance levels between wetland cover types and nutrient concentration

Variable labels	p-values	R^2 values
TDS (ppm)	0.002	0.941
TSS (mg/L)	0.003	0.567
TP (µg/L)	0.004	0.912
TN (µg/L)	0.008	0.684

Key: TN- Total Nitrogen, TP- Total phosphorous, TDS- Total Dissolved Sediments, TSS- Total Suspended Sediments

6.3 Discussion

6.3.1 TSOC storage changes

The results from the spatial autocorrelation analysis of SOC stocks and wetland cover types indicated a positive and significant relationship (Moran's index 0.149804, p – value: 0.000000, R^2 0.67765) (see Table 6.2). This led to the rejection of the null hypothesis (section 3.3.3.2) and acceptance of the alternative hypothesis that: "the magnitude of wetland carbon stocks depends upon wetland cover type”. This observation has been supported by other studies like those of Penman *et al*. (2003), Yu (2011) and Edmonson *et al*. (2014).

It is noted that the highest SOC storage across the KMC occurred in the first 0-15cm soil profile, particularly in agricultural and forest swamps. This is attributable to the interplay of several factors, including climate, soil texture, vegetation and land use change (Amundson, 2001; Kongsager *et al*., 2012). Similar results are reported by Yu *et al*. (2014) in a study undertaken along the coastal wetlands of the Yellow River Delta estuary, where higher SOC stocks were observed at the 0-10 cm compared to the 40-50 cm depth, while Craft (2007) also found that SOC stocks at 0-30cm were two times greater in the marshes of the fresh water-dominated Altamaha River. High C storage is observed in agricultural soils because they generally have a high percentage of organic matter in the form of fresh plant materials and root exudates (Liguori *et al*., 2009), for which SOC has a share of approximately 58% (Batjes, 1996). Coupled with this is the fact that agriculture occurs in wetland anaerobic soils known to slow down decomposition rates, leading to a high build-up of SOC (Kamanyire, 2000). This is exacerbated by the existence of clay and sandy wetland soils supporting agriculture in the KMC which, as pointed out by Krull *et al*. (2001), slow down decomposition rates by way of limiting exposure of absorbed C to oxygen diffusion. This explains why wetlands converted to agricultural use exhibit high C sequestration levels compared to forest swamps and forest plantations, where the percentage of organic matter that is a key determinant of SOC is limited by lower levels of fresh plant materials, root exudates and seasonality in anaerobic conditions.

Similarly, the high carbon sinks in papyrus and forest swamp wetland cover types, result from the existence of clay and sandy soils (Kamanyire, 2000), shallow and intensive root depth, and semi-permanent anaerobic wetland conditions. This view is supported by the work of Bernal and Mitsch (2013), who reported that SOC stocks in fresh water wetlands were strongly influenced by high temperatures and seasonal water availability.

Tropical forest plantations are known to have high sequestration of C potential (Kongsager *et al*., 2012). However, land use change tends to undermine this, resulting in high C emissions and reduced carbon fixation capabilities (Rees *et al*., 2005). The drainage of the KMC wetlands like the forest swamps, for DPs (settlements and industrial estates) involves the diversion of streams and soil fills. According to Bridgham *et al*. (2006), these conversion activities affect wetland anaerobic conditions and soil structures, and therefore increase decomposition rates leading to large net losses of SOC. In this regard, the conversion of several wetland patches (forest swamps) for DPs has drastically reduced the SOC storage levels from 18.277g m^{-2} in 1974, to 5.94g and 6.66g (for wetlands converted to settlement and industry, respectively) by 2013. This conclusion validates the general view shared by Smith (2008) and Vaccari *et.al*. (2012) that tropical soils have lost 40-90 Pg C through disturbances mainly from anthropogenic land use change. Mitigating land use change would therefore be an effective option to reduce soil C loss in the KMC wetlands.

6.3.2 Wetland diminution for DPs and related implications for SOC sequestration changes from 1974 to 2013

A general decrease of 13.11t was determined in the KMC total SOC storage from 1974 to 2013. This value represents a minimum estimate of the potential SOC storage in KMC wetlands because it excludes seasonal components of the KMC wetlands and other converted wetland portions which could not be detected in the earlier multi-temporal Landsat TM/ETM+ images. The highest carbon pool was registered in 1974 due to the existence of large expanses of intact forest swamps (Table 6.3). These contributed more than 60% of SOC in 1974, occupying about 63% of the study area. These wetland types sequester large quantities of C owing to the high amount of above ground litter inputs to the soil, in association with higher moisture content through shading, resulting in reduced decomposition and evapotranspiration. Novara *et al*. (2015) has also observed that forest soils are characterized by high C stocks due to vegetative C inputs after processes of abandonment, with a higher quality and quantity of litter inputs which contribute to higher SOC stability.

However, this big SOC pool (forest swamps) drastically reduced between 1974 and 2013, with a large portion being converting to palms and thickets after deforestation (Table 6.3). The rest were cleared for DPs that accounted for only 21% of the SOC, and yet occupied 46% of the study area by 2013. Indeed, DPs are responsible for the conversion of 1,625 ha, 2,923 ha and 5,650 ha of the KMC wetlands during the periods to 1986, 2006, and 2013, respectively (see Table 6.3). The restoration of converted wetland areas would imply a large net carbon pool of 14.8 t 26.7 t and 51.6 t. However, their present conversion to DPs has drastically lowered these values to 5 t, 8.8 t and 17.59 t by 1986, 2006 and 2013, respectively.

The relatively higher C accumulation in papyrus swamps over time is attributed to the fact that they are located in valley depressions where occasional flooding reduces decomposition rates, leading to the accumulation of more SOM (Sjogersten *et al*., 2014). The high regeneration rate of papyrus biomass means more organic matter inputs below ground (Jones & Humphries, 2002). This explains the generally small variation in related SOC values from 1974 to 2013. However, there are already indications that, at current degradation rates, the KMC will lose over 2,404 ha of papyrus swamps by 2040, contributing a net SOC loss of 24.2 t to the atmosphere.

The sharp drop in SOC stocks (5 t, 8.8 t and 17.59 t by 1986, 2006 and 2013 respectively), stem from the decreasing soil water content and increased soil permeability, themselves resulting from the diversion of wetland streams and related murram soil fills. The shrinking carbon stocks partly reflect the ecological trade-offs with negative consequences for the communities in the KMC. As noted by Liddicoat *et al*. (2010), these effects manifest in the deteriorating production and environmental benefits performed by wetlands. These effects will unfold through decreased soil biological health, decreasing infiltration and water holding capacity. Resulting from this is reduced nutrient cycling, decreased reliability of production services, weakened ability to recharge and discharge groundwater, as well as distorted wetland biodiversity, which anchors an array of resource utilization activities (Adhikari *et al*., 2009; Liddicoat *et al*., 2010).

6.3.3 Wetland conversion related implications for local climate variability 1974 --2013

The increasing wetland conversion for DPs contributes to more ecological trade-offs by promoting SOC loss to the atmosphere, resulting in changing local climatic conditions in the KMC (R^2 = 0.8432) (Appendix G). The results illustrate that these ecological impacts are closely associated with local climate variability, manifested through increased temperatures and erratic rainfall, which are accompanied by higher incidences of floods and droughts (Barraclough *et al*., 2015). The growing atmospheric carbon load leads to high local temperatures, which step up evaporation rates, resulting in high precipitation. This has been modelled by Olesen *et al*. (2004), who showed that an increase of 66 – 234 kg CO_2 emission increased temperatures by 4^0C. This local carbon-driven climate variability affects carbon sequestration potentials, which in turn affect the functionality of the wetland ecosystem (Krull *et al*., 2001). In this regard, the increasing temperatures lead to the waterlogging of wetland soils, which according to Foster *et al*. (2012) increases oxygen diffusion into sediment profiles, distorting the wetland anaerobic state.

Additionally, with increased soil respiration, the vulnerability to soil erosion and runoff due to erratic rainfall increases (Breuer, 2012). Consequently, these conditions increase biomass decomposition rates and also modify the structural stability of the soil, compromising the carbon storage potential in wetland sediments (Lal, 2004). The aggregate of these effects compromises wetland ecological and physical functions, particularly the supportive and regulation services, lowering the wetland's economic benefits.

The challenges created by decreasing C sequestration and the reverse effects from climatic variability on wetland functionality call for the "removal" of C from the atmosphere. As observed by Albrecht and Kandji (2003), this Greenhouse Carbon effect could best be addressed through the storage of C in the biosphere terrestrial system. However, given the scale of development projects and the desire for economic growth accruing from them, coupled with the fact that the KMC wetlands provide critical lifeline agricultural subsistence needs for the poor urban dwellers, it's prudent to focus on development approaches that would strike a balance between economic and ecological benefits. Based on this, the sustainable development of the KMC wetlands would focus on agricultural and agro - forestry activities, because they have demonstrated to store large amounts of C as opposed to industry and settlement (Figure 6.1). However, such destructive resource utilisation activities, though already supported by the Ramsar Resolution VIII.34 (2002) on agriculture and the Clean Development Mechanism (CDM) of the Kyoto Protocol FAO, (2010) respectively, would only promote wetland conversion. In light of this paradox, this study recommends that restoration / rehabilitation campaigns be adopted, although this strategy may meet resistance from already established project owners in the wetlands. Given the historical and on-going wetland loss, the present study identifies the need to restore forest swamps since they have registered the greatest conversions to Dps (Figure 4.1 and Table 4.2) and also because they have demonstrated to store large amounts of carbon (Figure 6.1). Hence, this restoration/ rehabilitation strategy should target about 5,650 ha across the KMC, particularly in gazetted wetland zones given away to developers, but where actual development has not fully taken off. These measures must be complemented by an emphasis on proactive strategies that address the primary causes of wetland conversion for DPs (as addressed in Chapter Four).

6.3.4 Hydrological implications of wetland conversion

The significant relationship between wetland cover types and nutrient concentrations is attributed to the fact that the KMC wetlands occur in a land use setting that worsens their hydrological regimes. As observed by LaGrange *et al*. (2011), this phenomenon can lead to a cascading of negative effects on wetland hydrological functions reflecting the ecological trade-offs of wetland conversion for DPs.

The high mean chemical nutrient concentrations (TP and TN) among converted wetlands for industrial and settlement use, and palms/thickets cover classes is attributed to anthropogenic sources of nutrient pollutants, particularly runoff from adjacent fertilized croplands (Figure 6.5) and effluent discharge from industrial zones of the KMC wetlands. These results are consistent with Kansiime *et al*.'s (2007) study carried out in the Kampala wetlands, which also reported high nutrient concentrations (N and P) in Nakivubo and Kirinya districts, arising from expanding urban, agricultural, industrial and infrastructural developments. Despite the fact that wetlands act as natural filters, helping to improve the quality of runoff by trapping pollutants, this hydrological value has been compromised by their conversion for DPs. It has reduced vegetation productivity and subsequent nutrient uptake by wetland vegetation, leading to excessive accumulations of N and P pollutants. Large quantities of N and P nutrients promote the growth of algal blooms and other undesirable aquatic plants (Sharpley *et al.* 2001), which are already manifesting in the KMC degraded wetland cover types (Figure 6.6). These invasive hydrophytes in turn reduce oxygen levels in water (Anderson *et al*., 2002), leading to the loss of aquatic species or changes in their composition, and a reduced suitability of water for domestic and recreational activities. According to Paerl *et al*. (2001), high nutrient concentration is linked to the growth of nuisance phytoplankton blooms with harmful toxins which may result in fish kills and harmful effects on human health.

The highest TDS values occur in downstream cover types, particularly forest swamps, palms and thickets and agriculture (104, 84.6 and 96.3 ppm, respectively). As noted by Weber-Scannell and Duffy (2007) and Leisenring *et al*. (2011), these high TDS concentrations are attributed to upstream industrial effluent, changes to the water balance (by limiting inflow, through ditching and channelization in a bid to convert wetlands for DPs), residential/urban runoff, or the leaching of mineral salts, nutrients, and humic substances from the soil. This is corroborated by a recent study by Vengosh *et al*. (2014), who attribute increments in surface water salinity in the Marcellus shale region of the United States (from 25 to ~ 250g TDS/L) to illegal direct waste discharges. These results confirm the presence of a wide range of harmful chemical contaminants in converted wetland cover types in the KMC. Using the WHO (1996) standards, the current TDS levels demonstrate acceptable water quality standards for consumption (below 1000ppm / mg/L). However, given the predicted scale of wetland conversion (see Chapter 4, Figures 4.2 and 4.3 in this study), these figures are likely to reach critical levels and pose a health hazard to communities. Phyllis and Lawrence (2007) warn that elevated TDS concentrations can cause toxicity through increases in salinity, which has been shown to cause shifts in biotic communities, limit biodiversity, exclude less-tolerant species and cause acute or chronic effects at specific life stages.

The high TSS among wetlands converted to settlements, industrial use and palms and thickets is attributed to the high flow velocities (Table 6.4). As observed in related studies (Maltby, 2009; Sottolinchio *et al*., 2000), the higher the mean flow velocity, the greater the ability of water to transport particles of increasing size. The alteration of natural wetland hydrological regimes through the construction of ditches and channels (Figure 6.5), in the conversion of wetlands for DPs, has increased wetland outflow velocities and reduced the residence time in the KMC (Table 6.4). This makes it difficult for these wetland classes to settle channel sediments. The high velocities are further enhanced by decreasing hydrologic roughness resulting from the degenerating macrophytic wetland vegetation in the converted wetland cover types (Tabacchi *et al*., 2000; Haygarth & Jarvis, 2002). Similar observations have been reported in related studies (see Hunt *et al*., 2006; Hatt *et al*., 2008; Manganka, 2013), where a low velocity for streams flowing across wetlands are found to facilitate high settling and sedimentation of solid particles, while reduced retention arising from increased velocity decreases the opportunity for solid particles to settle. Resulting from this is increased wetland loading along with decreased retention and residence times, leading to compromised wetland hydrologic functionality and benefits to the community. The results in Table 6.4 confirm the direct effects of increased TSS amidst high average speeds in degraded cover types, manifesting in increased bed load in downstream forest swamps, and palms and thickets (3600 and 3466 Kgs, respectively).

Figure 6.5: A Fertilized cropland site in the KMC wetlands. (Lwajjali wetland site)

Figure. 6.6: Algae blooms due to excessive N and P nutrient pollutants in the Lwajjali wetland site of the KMC

Similarly, wetlands converted to agricultural use exhibit relatively higher sediment loads (2941kgs). This is mainly due to the fact that continuous sedimentation makes wetlands vulnerable to more agricultural conversion (Tang *et al*. 2015). Consequently, continuous sedimentation in the former forest swamps has resulted in the engulfment of these cover types by agriculture (Figure 6.5) and the invasion of other highland species (Daniel *et al*., 2015).

Conversely, the relatively low TSS values among papyrus swamps, marshes and bogs and forest swamps are attributed to the fact that these wetland types remain intact, as their vegetation continues to offer substantial resistance to channel waters. Similar conclusions have been reached by Tabacchi *et al*. (2000), Haygarth and Jarvis (2002), and Mburu *et al.* (2008), where moderate TSS removal of at least 50% is reported for papyrus tropical wetlands. This has reduced the average speed of wetland channel water, allowing for the filtration and settling of suspended sediments in the wetlands. Indeed, forest swamps, papyrus swamps and wetlands converted to agriculture use exhibit the lowest mean average flow velocities, due the existence of wetland vegetation that is relatively intact compared to the degraded types.

Suspended sediments are detrimental to water quality and also carry adsorbed particles, particularly nitrogen and phosphorous (Kolok, 2010). In this regard, the results in Table 6.4 demonstrate that the high nutrient concentration within the industrial, settlement wetland uses and palms/thickets wetland cover types is partly a function of elevated TSS in the wetland channel waters. The findings are consistent with those of Zhang *et al*. (2004) and Sadeghi and Yaghmaei (2015), who maintain that over 90% of nutrients like total phosphorus transported into estuarine waters comes from river-borne suspended particulate matter. This affects the potential of the wetlands to sustain bio-geochemical processes in the long term (LaGrange *et al*., 2011). This scenario calls for the government to free the KMC wetland waters from suspended particulate matter through the establishment of costly filtration/flocculation facilities. Indeed, these have already been established, notably the one sited at Lwajjali (Figure 6.7), whose annual cost of treating water for over 8,437 beneficiaries in the KMC is estimated to be over 177,000 US dollars (Wasswa *et al*., 2013).

Donovan (2000) observes that the turbidity caused by an increase in suspended particles attenuates light penetration, decreasing photosynthesis and oxygen production by the submerged aquatic plants. This partly explains the existence of patchy, dwarfed wetland vegetation among the wetlands converted to industrial use where the highest TSS and related turbidity was registered. The high TSS associated with degraded wetlands is also responsible for crippling the water storage and flood attenuation benefits of wetlands. The continuous accumulation of sediments in the degraded wetlands notably those converted to industrial, settlement and agriculture has reduced water storage volumes, as manifested in the reduction of wetland water depths to 11, 15 and 25cm, respectively (Table 6.4).

The loss of water storage will not only affect recharge and discharge wetland benefits but will also result in reduced residence time and subsequent loss of ponded water in the wetlands. The end result will be a drop in the water table, leading to the drying up of water springs and shallow wells, as already reported in Mukono (Turyahabwe *et al*., 2013b), and a tremendous loss of wetland plant diversity (LaGrange *et al*., 2011). High sedimentation and related effects in converted wetland cover types have also been reported in other studies (see Costanza & Greer, 1995; Azous & Homer, 2000; Burton *et al*., 2004), where the highest sediment loads were found to be associated with wetlands converted for agriculture and urban expansion.

Figure 6.7: Filtration / flocculation facility in Lwajjali wetland – KMC.

The high average speed of channel water in the degraded wetland cover types suggests a greater likelihood of reduced residence time (Table 6.4). This situation will not only make the KMC wetlands vulnerable to more conversion, but will also significantly affect ecosystem food chains, leading to a critical loss of wetland fauna. A great number of wetland invertebrates will be lost as their egg-banks are buried by continuous sedimentation, leading to a diminution in amphibian and avian diversity (Gleason, 2001; Tsai *et al*., 2007). Indeed, the shoebill (*Balaenicepsrex*) and the grey crowned crested crane (*Balearica regulorum*) have already been displaced from the KMC (Pomeroy, 2004).

As stated in Chapter 4 (Section 4.3.4) of this study, it is recommended that the restoration of upstream wetlands be undertaken in the KMC so as to increase hydrologic roughness to reduce sedimentation rates, particularly in the downstream converted cover types. This must be coupled with the adoption of strong regulatory mechanisms aimed at reducing the scale of DPs in the KMC wetlands. This will also counteract hydrological alteration through excessive ditching and channelling, to restore wetland hydrological balance and functionality.

6.4 Conclusion

Extrapolated estimates have shown a general decrease in SOC sequestration from 1974 to 2013 across the KMC wetlands, with the lowest C pool registered in 2013. The highest C sinks occurred in wetlands converted to agriculture, forest swamps and palms and thickets wetland cover classes, while the lowest TSOC range was seen among other converted wetland cover types (wetlands converted for industrial and settlement uses). The degenerating SOC is largely attributed to land use change through the conversion of forest swamps for DPs. The dwindling SOC banks are partly responsible for microclimatic variability and related effects on carbon sequestration potentials, which in turn affect wetland functionality and economic benefits in the KMC. The conversion of the KMC wetlands has also affected wetland hydrological functions, particularly filtration, flood attenuation, and recharge and discharge benefits, adversely affecting ecosystem biodiversity. It is thus recommended that restoration/rehabilitation campaigns mainly targeting forest swamps be undertaken, as a way of promoting the sustainable management of the KMC wetland benefits.

6.5 Summary

This chapter has assessed the carbon sequestration and hydrological impacts of wetland diminution for DPs in the KMC. It is observed that converted wetland cover types exhibit lower SOC stocks, with adverse effects on local climate variability and hydrological functions. The next chapter provides a synthesis of the results-based chapters: 4, 5 and 6.

CHAPTER SEVEN

Synthesis of findings, conclusions and recommendations

7.1 Introduction

This chapter integrates the various strands of the present study, as presented in the foregoing chapters. A synthesis is made of the spatial-temporal wetland loss to DPs (1974–2013), economic implications of wetland loss for local people's livelihoods, carbon sequestration and hydrological impacts of wetland conversion for DPs, in order to vividly indicate the economic and ecological trade-offs of wetland conversion for Dps. The chapter concludes by developing and presenting a conceptual model which functionally integrates the components of the study. This is followed by a presentation of general conclusions, recommendations and directions for future research.

7.2 Spatial-temporal wetland loss

Monitoring wetland change on the scale of landscape plays a fundamental role in the exploration of patterns and drivers of that change (Xu *et al*., 2011). Analysis of spatial-temporal wetland change indicates that the KMC wetlands have shrunk by almost half of their coverage since 1974. This observation is similar to that made by Aryamanya (2011), who reported a loss of 50% in the Kampala wetlands from 1995 to 2006. As noted by other studies (WRI, 2009), it implies that the rate of wetland degradation in Kampala and neighbouring areas is higher than the national average of 30%, owing to their proximity to the Central Business District (CBD) with social amenities like roads, workplaces, places of worship and social networks. This is confirmed by more recent studies like that of Isunju *et al.* (2016), which puts the estimated degradation of the Nakivubo wetland in Kampala at 62%. As indicated in Chapter 4, more than half of this loss accrued to DPs (industrial and settlement), with settlements accounting for the greatest toll. Similar results were obtained by related studies (see Aryamanya, 2011; Emerton *et al*., 1998; Gumm, 2011). Increments in settlement are said to result from the heavy population density and an increase of immigrants to the area, owing to its proximity to Kampala and to ecosystem amenities that attract footloose households and firms away from their former traditional or urban areas (Deller *et al*., 2001; McGranahan, 2008; Seto *et al*., 2012). According to Seto *et al*. (2003) and Seto *et al*. (2012), the poor immigrants resort to agriculture in the wetlands for their livelihood, which partly explains the observed concomitant increments in agricultural land use up to 2013. The increasing rural settlement in the KMC wetlands triggers indirect land competition between rural and urban areas, induced by changing patterns of demand in favour of industrial resources. The latter resources finally dominate peri-urban and rural land uses, pushing residents away to new virgin and perhaps conserved ecosystems and thereby promoting more degradation (Seto *et al*., 2003; Seto *et al*., 2012).

With a wetland area of 40,700 ha in the KMC (Kamanyire, 2002; NBS, 2003), the present study reveals that almost half of the KMC wetlands have been lost from 1974 to 2013, with the greatest losses accruing to DPs (see 4.3.1). It is projected that close to a half of the 2013 KMC wetlands area will be lost, with the greatest percentage of this accruing to DPs, by the year 2040 (section 4.2.4).

The drivers of wetland loss in Kampala wetlands have been described as no different from those in other parts of the world, given that they depict general global challenges of population growth, increased demand for finite environmental resources and the need for space to accommodate urban and industrial growth (Isunju, 2016). The uniqueness of the KMC wetlands is however that their conversion is primarily driven by the preference for Kampala as an industrial and residential hub, weaknesses in earlier land use planning legislation, and information failures by decision makers. In line with Musoke (2001), Pomeroy (2004) and Baranga *et al*. (2012), and as discussed in sections 7.3 and 7.4, it was found that rapid land use change in the KMC wetlands results in alteration of the hydrological equilibrium, distorts the physio-chemical wetland functions, and leads to significant ecological and economic impacts. As Haberl *et al*. (2014) and Seto *et al.* (2014) have shown, all these changes are either irreversible or require large investments to be reversed.

These impacts have already manifested in the wetlands' deteriorating ability to regulate local climate, flooding, water quality, biodiversity changes, a drop-in wetland migratory birds, decreasing leisure activities (bird watching and hunting), and a slashed wetland economic value (see Wasswa *et al*., 2013). The vulnerability of wetlands to DPs in urban areas and in the vicinity of major transport arteries calls for pro-active measures to protect these fragile ecosystems. This finding is confirmed by another study that found that proximity to previously built-up areas and public infrastructure are key predictors for urban expansion and encroachment on wetlands (Vermeiren *et al*., 2012). The spatial-temporal losses have inevitable implications for economic value of wetlands, notably livelihood consumption benefits. The subsequent section presents a synthesis of the economic implications of wetland conversion to DPs.

7.3 Economic trade-offs of wetland conversion for DPs

The present study revealed that the KMC wetlands yield a substantial flow of economic benefits per hectare/per year (see Chapter 5). This value would be higher if the KMC wetlands were still intact (Balmford *et al*., 2002). Similar valuation studies carried out in Africa have revealed a much lower unit value of US$ 45–90 / ha / year (De Groot *et al*., 2006). But the unit value as presented by this study is valid because the KMC wetlands have diverse resource utilization activities which command higher returns owing to its proximity to Kampala. Indeed, it has been concluded in earlier studies (see Stuip *et al*., 2002) that the value of wetlands is enhanced by proximity to cities.

Distribution analysis of the economic benefits further revealed that a great deal of these accrues to the local subsistence level in the form of livelihood products, incomes and employment benefits (Chapter 5). These findings confirm those of previous studies which revealed that over 80% of the people living adjacent to wetland areas in Uganda directly use wetland resources for their household needs (Turyahabwe *et al*., 2013a). This conclusion is further validated by Isunju (2016)'s study on wetlands around Kampala, and the national inventory of benefits from wetlands in Uganda that also indicates that more than half of the communities around these wetlands benefit from subsistence use values like free water. Degradation of the KMC wetlands will therefore deprive local communities of these invisible but important livelihood consumption benefits.

Considering the unit estimate in Table 5.2, the minimum economic value accruing to the entire KMC with 40,700 ha of wetland area (NBS, 2003; Kamanyire, 2002), comes to approximately US$ 139,097,020. This value reflects the economic trade-off if the KMC wetlands are totally converted for DPs. It appears that over 56% of wetlands were lost to DPs in the KMC by 2013, bringing the minimum economic value lost to US$ 19,311,700 in the sampled wetlands. Considering the unit economic value per hectare, the present study reveals that US$ 65,382,922 have been lost from 1974 to 2013, with US$ 36,613,616 accruing to DPs. At current degradation rates, this study therefore projects that the entire KMC will lose over 61% (14,151 ha) of the total projected wetland loss (23,199 ha) to DPs by 2040, which is equivalent to US$ 48,368,118. The declining wetland economic value implies more related economic trade-offs. These economic trade-offs will be reflected in the cost of local government having to provide foregone social-economic benefits from the KMC wetlands, particularly, subsistence livelihood products, incomes (Table 5.3), and employment benefits. As observed by Gumm, (2011), the trade-off of wetland conversion only offers investment in unsustainable resource utilization activities and DPs which provide only short-term solutions to important social and economic problems. Additionally, these wetlands are subsidizing public expenditure through providing goods and services at subsistence level, which the government will have to provide if they are totally lost. At the minimum this economic trade-off (contribution at the substance level) translates to US$139 million / year for the entire KMC.

The establishment of DPs in the KMC wetlands does not necessarily make economic sense and cannot be done on the basis of immediate/short-term economic benefits or profits that benefit a few individual developers. There is a need also to consider the social benefits particularly; the economic losses (highlighted by this study) and the attendant ecological trade-offs associated with wetland conversion to Dps. This view also lends support to Emerton *et al.*'s (1998) recommendation that there is a need to integrate wetland values into development decisions for the Kampala wetlands, in order to paint a more complete picture of the economic and ecological desirability and long-term viability of converting these wetlands. Against this background, section 7.4 presents a synthesis of the ecological trade-offs of wetland conversion to DPs.

7.4 The ecological trade-offs of wetland conversion for DPs

The ecological trade-offs presented in this study focused on carbon sequestration and the hydrological consequences of wetland conversion for DPs.

7.4.1 The carbon sequestration trade-offs of wetland conversion for DPs

Based on carbon sequestration analysis, the present study reveals that forest swamps, palms thickets and agricultural cover types exhibited the highest carbon sinks, accounting for 25% of the KMC wetlands by 2013. The lowest TSOC range was observed among converted wetland cover types (wetlands converted for industrial and settlement) that occupied 47% of the study area. These results indicate a significant relationship between wetland types and TSOC stocks, which implied that “the magnitude of wetland carbon stocks depends upon wetland cover type.” This hypothesis is corroborated by other studies which have found that SOC stocks vary with land cover and land use change, with significant changes occurring through disturbance and cultivation (see Penman *et al*., 2003; Yu, 2011; and Edmonson *et al*., 2013).

Based on the SOC estimates at the KMC study sites, the present study indicates substantial SOC losses associated with conversion for DPs in the KMC wetlands (Chapter 6) in 1986, 2006 and 2013. As noted by Edmonson *et al*. (2013) and Smith (2008), land use change through the conversion of forest swamps for DPs is a major factor responsible for the diminishing SOC pool in KMC. In essence, the drainage of the KMC wetlands for DPs involves diversion of streams and soil fills which affect wetland anaerobic conditions and soil structures, and increases decomposition rates leading to large net losses of SOC.

The shrinking wetland SOC stocks in the KMC imply serious ecological trade-offs of foregoing a vital service of local climate modification which results in local climate variability, manifesting through erratic rainfall due to changes in evapotranspiration, induced by wetland conversion, as well as local temperature variations (Figure 6.2a and 6.2b). According to Lwasa *et al*. (2013), local temperature variations unfold partly in the form of the 'heat island effect' experienced around Kampala. The effect of wetlands on local climate has also been substantiated by Tong *et al*. (2014) and Liu *et al.* (2015) in which the latter indicated that the increase (or decrease) of wetland area could reduce (or increase) the increment of maximum temperature and the decrement of precipitation respectively. In a related study, the former also endorsed that changes in selected wetlands of Northern China managed to pose local climate variability by turning local climate from warm-dry to warm-wet which saw an increase in average temperature and precipitation by 0.91 °C and 101.99 mm, respectively. This carbon-driven microclimatic variability affects carbon sequestration potentials, which in turn affect wetland functionality (Krull *et al*., 2001) and also compromise economic benefits.

As demonstrated by Liddicoat *et al*. (2010), these ecological trade-offs manifest through deteriorating production and environmental wetland benefits. They will unfold through decreased soil biological health, decreasing infiltration and water holding capacity, and increasing frequency of flash flooding events. Associated effects have already been observed in Kampala; for instance, Mhonda (2013) indicates that Kampala is frequently affected by flooding events which are resulting at least in part from reduced infiltration levels of storm water from the upstream wetlands like Lubigi and Nakivubo where conversions have taken place. Consequently, this is likely to result in reduced nutrient cycling, a decrease in the reliability of production services, weakening ability to recharge and discharge groundwater, and distorted wetland biodiversity that anchors an array of resource livelihood activities (Adhikari *et al*., 2009; Liddicoat *et al*., 2010). This argument is validated by the District Wetland Inventory Report on the Mukono wetlands, which showed that numerous soil fills during the establishment of industries and settlements have resulted in adverse hydrological consequences (flooding and damaged water purifying capacities) for those living downstream, as well as distorting wetland biodiversity through the destruction of habitats for a wide range of faunae, such as antelopes (*Tragelaphus spekei)*, geese, and red-tailed monkeys (*Cercopithecus ascanius)* (Musoke, 2001). The ecological trade-offs of wetland conversion for DPs manifest not only in compromised carbon sequestration potentials and related effects but also in hydrological impacts. The next section is a synthesis of the hydrological trade-offs of wetland conversion for DPs.

7.4.2 The hydrological trade-offs of wetland conversion for DPs

The conversion of the KMC wetlands for Dps implies a compromise on the hydrological services performed by the wetlands, resulting in environmental impacts that will compromise social welfare. In this regard, the major hydrological services foregone for wetland conversion include water filtration, flood control, water recharge and discharge during dry periods (Table 5.1). The present study already reveals higher nutrient concentrations (TP and TN), TDS and TSS values which as supported by Weber-Scannell & Duffy, (2007) and Leisenring *et al*., (2011) are a linked to upstream developments through limiting inflow, by ditching and channelization during wetland conversion for DPs. Similar results were reported by Kansiime *et al.* (2007) in respect of the disturbed urban wetlands of Nakivubo and Kirinya in Uganda, where higher values of nutrients were recorded – particularly of ammonium nitrogen, Ortho-phosphates and electro conductivity (31.68mg/l; 2.83mg/l; 335µS/cm and 10mg/l; 1.87mg/l; 502 µg/L), respectively.

TSS concentrations in converted cover types (Table 6.4) due to increased outflow velocities that stem from upstream wetland conversion for DPs and over-exploitation of wetland resources point to more ecological trade-offs in wetland conversion for DPs related to water retention service. According to Vepraskas & Craft, (2016), these will manifest in reduced wetland filtration, storage and flood attenuation capabilities, resulting in a decrease in water retention and residence time in the KMC wetlands. The decreasing water retention/residence time in the wetlands will inevitably result in loss of ponded water and a subsequent drop in the water table, making the wetlands prone to more conversions (Turyahabwe *et al*., 2013a) which confirms the projected continuous wetland loss to Dps (Figure 4.3).

Additionally, these hydrologic alterations trigger the cascading of negative ecological effects on wetland biodiversity which are already manifesting in changing ecosystem food chains and a critical loss of wetland fauna, reflected in a significant reduction in wetland amphibian and avian diversity (LaGrange *et al*., 2011). The shoebill (*Balaenicepsrex)* and the grey crowned crested crane (*Balearica regulorum)* are already reported to have been displaced on account of the shrinking macrophytes in the Kampala area (Langdale-Brown *et al*., 1964; Pomeroy, 2004).

In view of the economic and ecological trade-offs of wetland conversion for Dps, there is urgent need for the conservation of the KMC wetlands in order to ensure a sustainable flow of societal ecological and economic benefits as highlighted in Table 5.1. However, this position means trading off some destructive resource utilization activities since they are perceived to promote wetland conversion. In essence, agriculture, brick making and papyrus harvesting are the main trade-offs of wetland conservation and therefore sacrificing them for conservation will also affect welfare of communities dependant on these resources for their livelihood needs. A middle ground in favour of sustainable wetland utilization could therefore be taken in which resource utilisation may be controlled through the use of economic disincentives like tradable permits as suggested in section 5.3.4.

In summary, the conversion of the KMC wetlands as triggered by economic, social and institutional factors (Table 4.4), constitutes economic and ecological trade-offs that compromise social and environmental benefits for private / individualised short-term benefits. The economic trade-offs include livelihood wetland products, subsistence incomes and subsidized government expenditures in providing social services while the ecological trade-offs involve sacrificing the hydrological and carbon sequestration wetland services for Dps. All these will manifest through adverse environmental effects on wetland functionality particularly; compromised water quality, water storage and flood attenuation benefits, economic value and social welfare. There is therefore urgent need to conserve the KMC wetlands in order to ensure a sustainable flow of societal ecological and economic benefits. A conceptual model illustrating these trade-offs is presented in Figure 7.1.

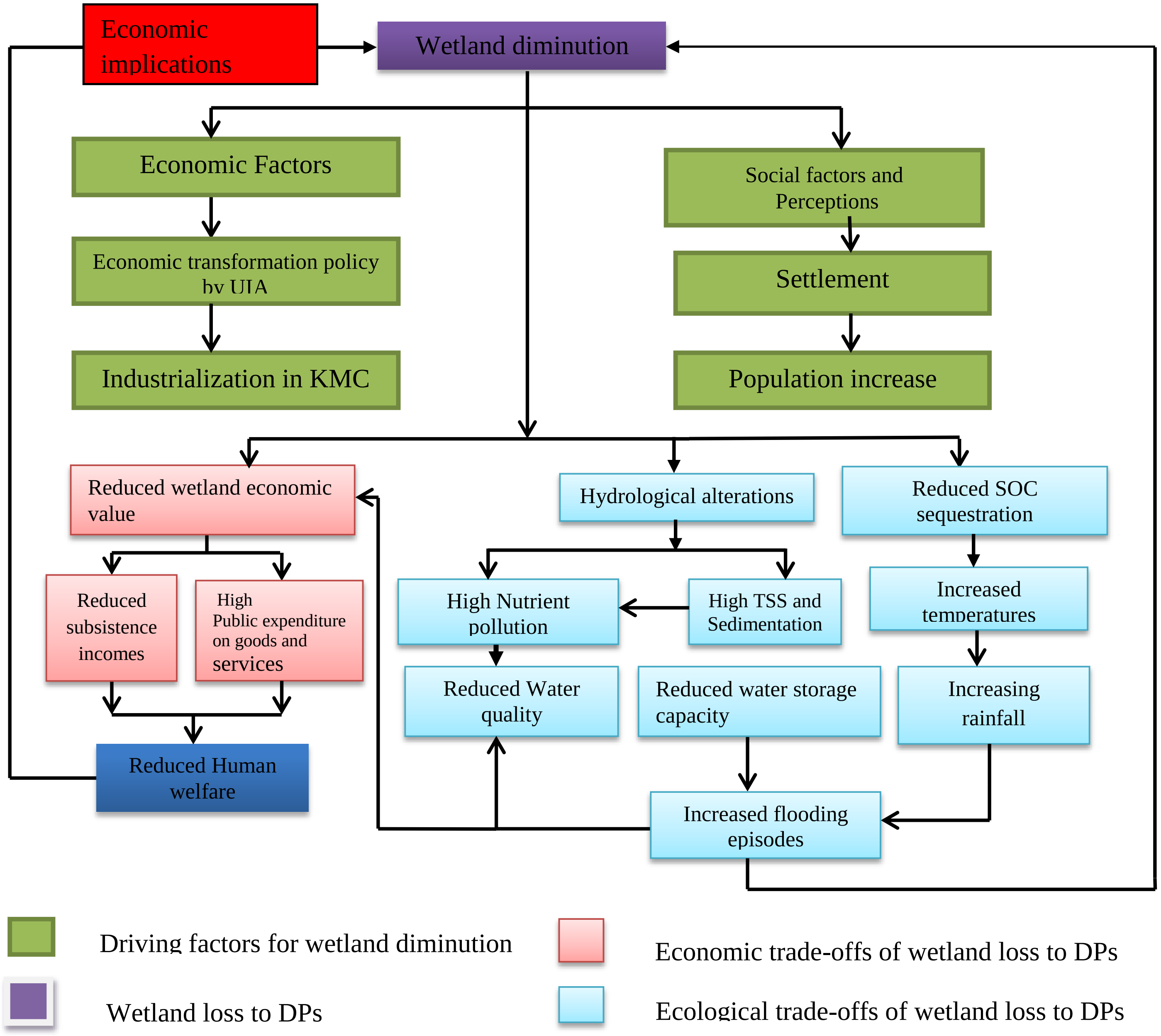


Figure 7.1: A conceptual model illustrating the economic and ecological trade-offs of wetland conversion for DPs.

As the Schematic shows, wetland diminution is primarily driven by economic transformation policies pursued in the vicinity of Kampala through industrialization coupled with social factors, like increasing settlements leading to dense population. Wetland loss has resulted in far-reaching economic and ecological changes. The economic implications manifest in decreasing wetland economic value, reduced subsistence incomes and increased public expenditure on wetland goods and services, which all impact human welfare. The ecological implications are reflected in altered hydrological services and reduced SOC sequestration, creating effects on hydrological benefits and local climate variability respectively. The hydrological impacts have manifested in increased nutrient and TSS pollution, which have reduced water quality, water storage and increased flooding episodes in the KMC, while the climatic impacts resulting from reduced SOC sequestration include an increase in temperatures and rainfall episodes. These impacts have all negatively affected human welfare, which is ostensibly the cause of on-going wetland diminution.

7.5 Recommendations

According to the findings of the present study, there is an urgent need to reduce the scale of wetland diminution in respect of DPs in the KMC. This requires the adoption of mitigation measures so as to minimize the *in situ* environmental and social-economic effects of wetland loss. In this regard, there is a need to revise earlier development plans in the KMC so as to suspend proposed development initiatives in wetland zones.

In the same vein, information gaps among stakeholders (land use planners, investment authorities and the private sector) should be bridged by sensitizing them to the economic and ecological benefits of wetlands and the possibility of sustainable wetland management.

There is also a need to develop and enforce regulatory mechanisms aimed at downscaling wetland conversions for DPs. This should be done through streamlining land acquisition policies in wetland areas by checking the overlapping mandates of national agencies like the Uganda Investment Authority (UIA), District land boards and the Kampala Capital City Authority (KCCA) in issuing land titles in wetland areas. Coupled with this is the need to ensure the strict adherence of developers to Environmental Impact Assessment (EIA) standards, often regarded as an ordeal by investors who consider it expensive and unnecessary.

It is also recommended that restoration and rehabilitation programs be undertaken so as to reduce the carbon sequestration and hydrological impacts of wetland diminution. The present study identifies the need to restore forest swamps across the KMC since they have been the main targets of conversion from DPs and also because they have demonstrated to store substantial amounts of carbon. This strategy should target gazetted wetland zones given away to developers, but where actual development has not fully taken place. Although such strategies may be resisted by already established project developers in the wetlands, such resistances can be counteracted though massive sensitizations about the goal of the management strategy and the benefits accruing from it.

Incentive-based approaches including the revision of historic property rights to regulate wetland use and performance bonds, or subsidies for environmentally friendly investments should be integrated into wetland conservation owing to their cost-effectiveness, to enable the creation of conditions under which communities will benefit from the wetlands, and therefore have a stake in their conservation. Economic disincentives should also be adopted where economic incentives fail to instil positive shifts in attitude towards wetland conservation. These should include taxes, charges, fees and fines for unacceptable levels of degradation, and the tradable permits mechanism that focusses on the concept of ‘wetland banks’ for local land holders who prefer to give up their land in wetlands to unsustainable wetland utilization activities and investments. It should however be noted that the success of these disincentives rests upon their revision to reflect the full level of wetland degradation costs, local community’s involvement in the planning and implementation of these approaches, functional institutional framework, expert knowledge, monitoring and enforcement mechanisms.

There is also a need to improve the effective functionality of national environmental institutions by establishing independent environmental agencies (like environmental courts) to make sure these institutions execute independent decisions, free from political interference. Implementation of the above recommendations will incur management and enforcement costs (in the context of public sector deficits, with many sectors competing with wetlands for the scarce resources). Hence there is need to establish innovative funding mechanisms for wetland conservation and management. These may come from charges, fines, bonds and deposits levied against unsustainable wetland utilization.

7.6 Directions for further research

The following research directions are suggested:

- A comprehensive economic valuation study that focuses on the Total Economic Value (Use and Non-use values) in the KMC.
- A regional assessment of wetland carbon sequestration potentials for climate change
- A comprehensive analysis of hydrological implications of wetland diminution for socio-economic development in Uganda
- A feasibility study of wetland restoration options and their implications for local people's livelihoods in the KMC.

7.7 Conclusion

The study has revealed that the KMC wetlands have progressively been reduced by almost a half of their coverage in 1974 because of anthropogenic activities, mainly DPs. The greatest wetland loss was registered between 2006 and 2013, with the land accruing to settlements and industry. The former forest swamp wetlands that dominated the region in 1974 were partly converted to DPs by 1986, while the rest degenerated into palms and thickets after deforestation for agriculture and settlement in the period after 1986. Slight losses of Papyrus swamps, marshes and bogs have been experienced since 1974. Based on 2006–2013 degradation rates, it is projected that the KMC will lose more wetlands to DPs by 2040, with the greatest loss incurred among papyrus swamps as a result of industrial development, while palms and thickets will experience the least loss.

The KMC wetlands provide an array of wetland benefits, including direct, indirect, option and existence values. These wetlands yield a minimum economic value of US$ 3,418 / ha / year, comprising the unit economic trade-off of their conversion for DPs. The bulk of this accrues from clay extraction, flood control and water purification, with lesser values for crop cultivation and thatch. It has also been revealed that the major share of estimated wetland economic value was enjoyed by local communities, at the subsistence level. Degrading the KMC wetlands implies a total loss of economic value estimated at over US$ 139 million.

A spatial autocorrelation revealed a strong relationship between wetland cover types and SOC stocks. The highest SOC across the wetland cover types was stored in the first layer of soil depth. The highest C stocks occurred in unconverted wetlands consisting of forest swamps, palms and thickets and papyrus swamps, while the lowest SOC stocks were registered in converted wetland cover types. A general decrease in SOC stocks across the KMC wetlands from 1974 to 2013 was also noted. However, earlier periods were characterized by relatively higher C stocks due to the existence of more unconverted wetland areas. The dwindling SOC banks constitute part of the serious ecological trade-offs of wetland conversion for DPs, that manifest themselves through local climate influences and related impacts on carbon sequestration potentials, which in turn affect wetland functionality, productivity and the related economic benefits.

A strong relationship between wetland cover types and nutrient concentration was also observed. The highest mean nutrient concentration and TSS occurred in the converted wetland cover types, while the lowest were identified in the intact forest swamps and papyrus swamps. High TDS values occurred in downstream wetland cover types (forest swamps, palms and thickets and wetlands converted to agriculture) compared to upstream converted wetland cover types. The increased nutrient concentrations (TDS and TSS) in converted wetland types represent another set of ecological trade-offs of wetland conversion for DPs, expressed in reduced wetland filtration, storage, recharge/discharge, flood attenuation capabilities, and in adverse impacts on ecosystem biodiversity.

REFERENCES

Acharya, G. 2000. Approaches to valuing the hidden hydrological services of wetland ecosystems. *Ecological Economics*, 35:63-74.

Acharya, G. & Barbier, E.B. 2000. Valuing groundwater recharge through agricultural production in the Hadejia-Nguru wetlands in northern Nigeria. *Agricultural Economics*, 22: 247-259.

Acreman, M.C. & Miller, F. 2006, January. Hydrological impact assessment of wetlands. In *Proceedings of the ISGWAS Conference on Groundwater Sustainability, Spain*: January 2006, 225-255.

Adekola, O., Morardet, S., de Groot, R. & Grelot, F. 2012. Contribution of provisioning services of the Ga-Mampa wetland, South Africa, to local livelihoods. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 8:248-264.

Adger, N.W. & Luttrell, C. 2000. Property rights and the utilization of wetlands. *Ecological Economics*, 35:75-89.

Adhikari S., Bajracharaya, R.M. & Sitaula, B.K. 2009. A review of carbon dynamics and sequestration in wetlands. *Wetlands Ecology*, 2:42-46.

Ajibola, M.O. 2014. Factors influencing the choice of wetland valuation methods in the Niger delta, Nigeria. *British Journal of Economics, Management and Trade*, 4:213-227.

Albrecht, A. & Kandji, S.T. 2003. Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystems & Environment*, 99:15-27.

Alsdorf, D.E., Smith, L.C. & Melack, J.M. 2001. Amazon floodplain water level changes measured with interferometric SIR-C radar. *IEEE Transactions on Geoscience and Remote Sensing*, 39:423-431.

Alvarez, S. & Larkin, S.L. 2010. Valuing ecological restoration and recreational benefits in a mountain protected area: the case of Los Nevados National Park, Colombia. *Journal of Sustainable Development*, 3:3.

Amaniga Ruhanga, I. & Iyango, L. 2010. A socio-economic baseline survey of communities adjacent to Lake Bisina / Opeta and Lake Mburo / Nakivali wetland systems. Providing baseline information for the implementation of the COBWEB Project in Western and Eastern/North-Eastern Uganda. Nature Uganda, Kampala, Uganda: 65.

Amundson, R. 2001. The carbon budget in soils. *Annual Review of Earth and Planetary Sciences*, 29:535-562.

Anderson, D.M., Glibert, P.M. & Burkholder, J.M. 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. *Estuaries*, 25:704-726.

Anderson, R.C. 2002. Incentive-based policies for environmental management in developing countries. Washington: Resources for the Future.

Angelova, V.A., Akova, V.I., Ivanov, I.K. & Licheva, P.A. 2014. Comparative study of titrimetric methods for determination of organic carbon in soils, compost and sludge. *Journal of International Scientific Publication, Ecology and Safety*. 8: 430 - 440.

APHA, 1995. *Standard methods for the examination of water and wastewater.* American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA.

Apunyo, R. 2008. Managing wetlands with changing times – Uganda’s experience. Unpublished paper submitted to Makerere Institute of Social Research, Kampala, Uganda.

Aryamanya, M.H. 2011. *The future of wetland in Uganda*. Keynote presented at the public debate organized by Wetlands Inspection Division and the Uganda Wildlife Society at the Uganda Museum to mark the World Wetlands Day. Kampala, Uganda.

Azous, A. & Homer, R.R. (Eds.). 2000. *Wetlands and urbanization: implications for the future*. Boca Raton, USA: CRC Press.

Badiou, P., Edwards C. & Gloutney, M. 2010. *Wetland restoration for carbon sequestration in Prairie Canada*, TEEB web.org.

Baguma, I. 2001. Wetland Sector Strategic Plan. Uganda, Ministry of Water, Lands & the Environment (MWLE). Kampala, Uganda.

BakamaNume, B.B. (ed.). 2010. *A contemporary geography of Uganda*. African Books Collective. Tanzania: Mkuki na Nyota Publishers.

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E. & Munro, K. 2002. Economic reasons for conserving wild nature. *Science*, 297:950-953.

Banage, W.B. 1999. *Namanve Industrial and Business Park: An ecological and environmental study. Draft Report*. Kampala, Uganda. (Unpublished report).

Baranga, D., Basuta, G.I., Teichroeb, J. A. & Chapman, C.A. 2012. Crop raiding patterns of solitary and social groups of red-tailed monkeys on cocoa pods in Uganda. *Tropical Conservation Science*, 5:104-111.

Barbier, E.B. 1993. *Policy issues and options concerning linkages between the tropical timber trade and sustainable forest management*. International Institute for Environment and Development (IIED). London: Environmental Economics Centre (LEEC).

Barbier, E.B. 2000. Valuing the environment as input: review of applications to mangrove-fishery linkages. *Ecological Economics*, 35:47-61.

Barbier, E.B., Acreman, M. & Knowler, D. 1997. *Economic valuation of wetlands: a guide for policy makers and planners*. Gland: Ramsar Convention Bureau.

Barraclough, D., Smith, P., Worrall, F., Black, H. I. J. & Bhogal, A. 2015. Is there an impact of climate change on soil carbon contents in England and Wales? *European Journal of Soil Science*, 66:451-462.

Batjes, N.H. 1996. Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science*, 47:151-163.

Bennun, L. & Njoroge, P. 1999. *Important bird areas in Kenya.* A joint project of Nature Kenya (The East Africa Natural History Society) and the Ornithology Department, National Museums of Kenya, sponsored by the Royal Society for the Protection of Birds.

Bernal, B. 2012. Carbon sequestration in natural and created wetlands. Unpublished PhD thesis, The Ohio State University.

Bernal, B. & Mitsch, W.J. 2012. Comparing carbon sequestration in temperate freshwater wetland communities. *Global Change Biology*, 18:1636-1647.

Bernal, B. & Mitsch, W.J. 2013. Carbon sequestration in freshwater wetlands in Costa Rica and Botswana. *Biogeochemistry*, 115:77-93.

Bindal, D. 2013. A review of Markov Model for Estimating Software Reliability. *International Journal of Advanced Research in Computer Science and Software Engineering*, 3:27-35.

Birdlife International. 2004. *Threatened birds of the world*. Birdlife International, Cambridge, UK.

Blann, K.L., Anderson, J.L., Sands, G.R. & Vondracek, B. 2009. Effects of agricultural drainage on aquatic ecosystems: a review. *Critical Reviews in Environmental Science and Technology,* 39:909-1001.

Bourgeau-Chavez, L.L., Kasischke, E.S., Brunzell, S.M., Mudd, J.P., Smith, K.B. & Frick, A.L. 2001. Analysis of space-borne SAR data for wetland mapping in Virginia riparian ecosystems. *International Journal of Remote Sensing*, 22:3665-3687.

Boyd, J. & Wainger, L. 2003. Measuring ecosystem service benefits: the use of landscape analysis to evaluate environmental trades and compensation. *Resources for the Future Discussion Paper*, 2:63.

Boyer, T. & Polasky, S. 2004. Valuing urban wetlands: a review of non-market valuation studies. *Wetlands*, 24:744-755.

Brander, L.M., Florax, R. J. & Vermaat, J.E. 2006. The empirics of wetland valuation: a comprehensive summary and a meta-analysis of the literature. *Environmental and Resource Economics*, 33:223-250.

Bräuer, I., Müssner, R., Marsden, K., Oosterhuis, F., Rayment, M., Miller, C. and Dodoková, A., 2006. The use of market incentives to preserve biodiversity. *Ecologic*, *51*.

Breuer, B., 2012. *Effects of vegetation types and species composition of carbon stocks in semi-arid Ethiopian savannahs* (Doctoral dissertation, Makerere University).

Bridgham, S.D., Megonigal, J.P., Keller, J.K., Bliss, N.B. & Trettin, C. 2006. The carbon balance of North American wetlands. *Wetlands,* 26:889-916.

Brown, G.W. and Krygier, J.T., 1971. Clear-cut logging and sediment production in the Oregon Coast Range. *Water Resources Research*, 7:1189-1198.

Bruland, G.L., Hanchey, M.F. & Richardson, C.J. 2003. Effects of agriculture and wetland restoration on hydrology, soils, and water quality of a Carolina bay complex. *Wetlands Ecology and Management*, 11:141-156.

Burton, E.D., Phillips, I.R. & Hawker, D.W. 2004. Trace metals and nutrients in bottom sediments of the Southport Broadwater, Australia. *Marine Pollution Bulletin*, 48:378-384.

Busuulwa, H; Mafabi, P.G; & Ndawula, L.M. (2001). *A Compilation of Scientific Information on Nabugabo Ramsar Site-Uganda*. Proceedings of the Scientific Conference-Nabugabo. Josn Links (u) ltd. Uganda.

Byaruhanga, A. & Ssozi, L. 2012. The impact of population growth on the ecosystems and biodiversity of Kampala: lessons for sustainable urban development. *Sustainable Futures: Architecture and Urbanism in the Global South, Kampala, Uganda, 27-30 June, 2012*:191-196.

Carter, V. 1996. Wetland hydrology, water quality, and associated functions. *National Water Summary on Wetland Resources*: 35-48.

Chabreck, R.H. 1988. *Coastal marshes: ecology and wildlife management*. Minneapolis: University of Minnesota Press.

Chadwick, D.R. & Chen, S. 2002. Manures. In Haygarth, P.M. & Jarvis, S.C. (Eds.). *Agriculture, hydrology and water quality*. Wallington, UK. CABI: 57-82.

Cline, S.P. & McAllister, L.S. 2012. Plant succession after hydrologic disturbance: inferences from contemporary vegetation on a chronosequence of bars, Willamette River, Oregon, USA. *River Research and Applications*, 28:1519-1539.

Conly, F.M. & Van Der Kamp, G. 2001. Monitoring the hydrology of Canadian prairie wetlands to detect the effects of climate change and land use changes. *Environmental Monitoring and Assessment*, 67:195-215.

Costanza, R. and Greer, J., 1995. The Chesapeake Bay and its watershed: a model for sustainable ecosystem management. Barriers and Bridges for the Renewal of Regional Ecosystems, C. S. Holling and S. Light, eds., Chapter 4, 169-213, p.45.

Costanza, R., d'Arge, R., de Groot, R., Farberk, S., Grasso, M., Hannon, B. & Raskin, R.G. 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387:253.

Craft, C. 2007. Freshwater input structures soil properties, vertical accretion, and nutrient accumulation of Georgia and US tidal marshes. *Limnology and Oceanography*, 52:1220-1230.

Crafter, S.A., Njuguna, S.G. & Howard, G.W. 1992. *Wetlands of Kenya: Proceedings of the KWWG Seminar on Wetlands of Kenya, National Museums of Kenya, Nairobi, Kenya, 3-5 July 1991* (5). IUCN. Gland, Switzerland.

Crossman, N.D. & Bryan, B.A. 2009. Identifying cost-effective hotspots for restoring natural capital and enhancing landscape multifunctionality. *Ecological Economics*, 68:654-668.

Daniel, D.W., Smith, L.M. & McMurry, S.T. 2015. Land use effects on sedimentation and water storage volume in playas of the rainwater basin of Nebraska. *Land Use Policy*, 42:426-431.

Daniels, A.E. & Cumming, G.S. 2008. Conversion or conservation? Understanding wetland change in northwest Costa Rica. *Ecological Applications*, 18:49-63.

de Blaeij, A.T., Polman, N. and Reinhard, S., 2011. Economic governance to expand commercial wetlands: within-and cross-scale challenges. *Ecology and Society*, 16: 33.

de Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L. & Hussain, S. 2012. Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services*, 1:50-61.

de Groot, R., Stuip, M., Finlayson, M. & Davidson, N. 2006. *Valuing wetlands: guidance for valuing the benefits derived from wetland ecosystem services* (No. H039735). International Water Management Institute, Gland, Switzerland.

de Groot, R.S. 1992. *Functions of nature: evaluation of nature in environmental planning, management and decision making*. Groningen: Wolters-Noordhoff BV.

de Groot, R.S., Alkemade, R., Braat, L., Hein, L. & Willemen, L. 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, 7:260-272.

Dechka, J.A., Franklin, S.E., Watmough, M.D., Bennett, R.P. & Ingstrup, D.W. 2002. Classification of wetland habitat and vegetation communities using multi-temporal Ikonos imagery in southern Saskatchewan. *Canadian Journal of Remote Sensing*, 28:679-685.

Deller, S.C., Tsai, T.H.S., Marcouiller, D.W. & English, D.B. 2001. The role of amenities and quality of life in rural economic growth. *American Journal of Agricultural Economics*, 83:352-365.

Donato, D.C., Kauffman, J.B., Murdiyarso, D., Kurnianto, S., Stidham, M. & Kanninen, M. 2011. Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience*, 4: 293-297.

Donovan, C.K. 2000. Wetlands and water quality enhancement. School of Applied Environmental Sciences, University of Natal. SouthAfrica. Mondi Wetland Project.

Džubáková, K., Molnar, P., Schindler, K. & Trizna, M. 2015. Monitoring of riparian vegetation response to flood disturbances using terrestrial photography. *Hydrology and Earth System Sciences*, 19:195-208.

Eakin, H., DeFries, R., Kerr, S., Lambin, E.F., Liu, J., Marcotullio, P.J., Messerli, P., Reenberg, A., Rueda, X., Swaffield, S.R. and Wicke, B., 2014. Significance of telecoupling for exploration of land-use change. In *Rethinking global land use in an urban era*. MIT Press.

Ecaat, J., 2004. A review of the application of environmental impact assessment (EIA) in Uganda. A Report Prepared for the United Nations Economic Commission for Africa.

Edmondson, J.L., Davies, Z.G., McCormack, S.A., Gaston, K.J. & Leake, J.R. 2014. Land-cover effects on soil organic carbon stocks in a European city. *Science of the Total Environment*, 472:444-453.

Edmondson, J.L., Davies, Z.G., McHugh, N., Gaston, K. J. & Leake, J.R. 2012. Organic carbon hidden in urban ecosystems. *Scientific Reports*, 2:963.

Ellerbrock, R.H., Höhn, A. & Rogasik, J. 1999. Functional analysis of soil organic matter as affected by long-term manurial treatment. *European Journal of Soil Science*, 50:65-71.

Elmqvist, T., Maltby, E., Barker, T., Mortimer, M., Perrings, C., Aronson, J., De Groot, R., Fitter, A., Mace, G., Norberg, J. and Pinto, I.S., 2010. Biodiversity, ecosystems and ecosystem services. *TEEB Ecological and Economic Foundations. Earthscan, London,* 41-111.

Emerton, L. & Muramira, E. 1999. *Uganda biodiversity: economic assessment*. Uganda National Biodiversity Strategy and Action Plan. IUCN–World Conservation Union/National Environmental Authority, Kmpala, Uganda.

Emerton, L. 1998. *Economic tools for valuing wetlands in Eastern Africa*. IUCN-The World Conservation Union, Eastern Africa Regional Office. Nairobi, Kenya.

Emerton, L. 2000. *Community based incentives for nature conservation*, IUCN, Eastern African Regional Office, Nairobi, Kenya.

Emerton, L., Iyango, L., Luwum, P. & Malinga, A. 1998. The present economic value of Nakivubo urban wetland, Uganda. *Fish Farming,* 6:0-32.

FAO. 2010. *Gender: forests*. Food and Agriculture Organization for the United Nations (FAO). Available online at http://www.fao.org/gender/gender-home/gender-programme/gender-forests/en/.

Farley, J. & Costanza, R. 2010. Payments for ecosystem services: from local to global. *Ecological Economics,* 69:2060-2068.

Farmer, A. 2012. *Handbook of environmental protection and enforcement: Principles and practice*. Earth scan, London.

Filcheva, E.G. & Tsadilas, C.D. 2002. Influence of clinoptilolite and compost on soil properties. *Communications in Soil Science and Plant Analysis*, 33:595-607.

Forman, R.T.T. 2001. *Applying Ecological Principles to Land Management*. V. H. Dale, & R. A. Haeuber (Eds.). Springer Science & Business Media, New york.

Foster, J., Evan, L., Curtin, A., Hill, B., Ronan, M., Wainwright, P. & Blackhall, S. 2012. *The role of wetlands in the carbon cycle*. Department of Sustainability, Environment, Water, Population and Communities, Australian Government.

Fujiwara, D. & Campbell, R. 2011. *Valuation techniques for social cost-benefit analysis: stated preference, revealed preference and subjective well-being approaches: a discussion of the current issues*. London: HM Treasury.

Gao, F., Masek, J. and Wolfe, R.E., 2009. Automated registration and orthorectification package for Landsat and Landsat-like data processing. *Journal of Applied Remote Sensing*, 3: 033515.

Ghaemi, Z. & Panahi, M. 2011. Economic evaluation of recreational value of Choghakhor wetland, using travel cost method. *Journal of Natural Environment*, 64:55-63.

Gleason, R.A. 2001. Invertebrate egg and plant seed banks in natural, resorted, and drained wetlands in the Prairie Pothole Region (USA) and potential effects of sedimentation on decolonization of hydrophytes and aquatic invertebrates. South Dakota State University.

Goldberg, J., 1998. Remote sensing of wetlands: procedures and considerations. *Retrieved January*, *24*, p.2003.

Gómez-Baggethun, E., De Groot, R., Lomas, P.L. and Montes, C., 2010. The history of ecosystem services in economic theory and practice: from early notions to markets and payment schemes. *Ecological economics*, 69:1209-1218.

Goreau, T.J. & de Mello, W.Z. 2007. Minimising net greenhouse gas sources from mangrove and wetland soils. *Greenhouse Gas and Carbon Balances in Mangrove Coastal Ecosystems*: 239-248.

Green, E.D., 2006. Ethnicity and the politics of land tenure reform in central Uganda. *Commonwealth & Comparative Politics*, 44: 370-388.

Gül, A., Onuşluel Gül, G., Dikmen, A.Ç. & Kuzucu, A. 2014. Investigating hydrologic alterations for wetland systems in terms of river environmental flows. *Water and Environment Journal*, 28:329-339.

Güler, M., Yomralıoğlu, T. and Reis, S., 2007. Using landsat data to determine land use/land cover changes in Samsun, Turkey. *Environmental Monitoring and Assessment*, 127:155-167.

Gumm, E. 2011. The use and misuse of wetlands in Kampala. Independent Study Program (ISP) collection, paper 1022. Kampala, Uganda.

Haberl, H., Mbow, C., Deng, X., Irwin, E.G., Kerr, S., Kuemmerle, T. & Billie, L. 2014. *Finite land resources and land use competition*. MIT Press Cambridge, MA

Hadley, D., D'Hernoncourt, J., Franzén, F., Kinell, G., Söderqvist, T., Soutukorva, Å. & Brouwer, R. 2011. Monetary and non-monetary methods for ecosystem services valuation–specification sheet and supporting material. Spicosa Project Report, University of East Anglia, Norwich.

Hanley, N. & Barbier, E. 2009. *Pricing nature: cost-benefit analysis and environmental policy*. Edward Elgar Publishing, United Kingdom.

Hartter, J. & Ryan, S.J. 2010. Top-down or bottom-up?: decentralization, natural resource management, and usufruct rights in the forests and wetlands of western Uganda. *Land Use Policy*, 27:815-826.

Hatt, B.E., Fletcher, T.D. & Deletic, A. 2008. Hydraulic and pollutant removal performance of fine media stormwater filtration systems. *Environmental Science & Technology*, 42:2535-2541.

Haygarth, P.M. and Jarvis, S.C. (eds.), 2002. *Agriculture, hydrology, and water quality* (No. TD428. A37 A366 2002). CABI Pub.

Hein, L., Van Koppen, K., De Groot, R. S. & Van Ireland, E.C. 2006. Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics*, 57:209-228.

Heumann, B.W., 2011. An object-based classification of mangroves using a hybrid decision tree—Support vector machine approach. *Remote Sensing*, 3: 2440-2460.

Hodgson, M.E., Jensen, J.R., Mackey Jr, H.E. and Coulter, M.C., 1987. Remote sensing of wetland habitat: a wood stork example. *Photogrammetric Engineering and Remote Sensing*, 53(8):1075-1080.

Houhoulis, P.F. & Michener, W.K. 2000. Detecting wetland change: a rule-based approach using NWI and SPOT-XS data. *Photogrammetric Engineering and Remote Sensing*, 66:205-211.

Howe, A.J., Rodriguez, J.F. & Saco, P.M. 2009. Surface evolution and carbon sequestration in disturbed and undisturbed wetland soils of the Hunter estuary, southeast Australia. *Estuarine, Coastal and Shelf Science*, 84:75-83.

Hruby, T., Cesanek, W.E., & Miller, K.E. 1995. Estimating relative wetland values for regional planning. *Wetlands*, 15:93-107.

Huising, E.J. 2002. Wetland monitoring in Uganda. *International Archives of Photogrammetry and Remote Sensing*, 34:127-135.

Hunt, W.F., Jarrett, A.R., Smith, J.T. & Sharkey, L.J. 2006. Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *Journal of Irrigation and Drainage Engineering*, 132:600-608.

Hurtt, G.C., Chini, L.P., Frolking, S., Betts, R.A., Feddema, J., Fischer, G., Fisk, J.P., Hibbard, K., Houghton, R.A., Janetos, A. and Jones, C.D., 2011. Harmonization of land-use scenarios for the period 1500–2100: 600 years of global gridded annual land-use transitions, wood harvest, and resulting secondary lands. *Climatic change*, 109: 117-161.

Infield, M. and Namara, A., 2001. Community attitudes and behaviour towards conservation: an assessment of a community conservation programme around Lake Mburo National Park, Uganda. *Oryx*, 35: 48-60.

Isunju, J.B., 2016. *Spatiotemporal analysis of encroachment on wetlands: hazards, vulnerability and adaptations in Kampala city, Uganda*. (Doctoral dissertation, Stellenbosch University).

IUCN. 2004. *Assessment of the economic value of the wetlands of Bushenyi District in Western Uganda.* Kampala.

IUCN. 2006. *Can Lao PDR afford not to invest in conserving its biodiversity? Exploring the need for innovative financial mechanisms*, Vientiane. Laos: The World Conservation Union.

IUCN. 2011. Regional expert advisory workshop report: Wetland valuation. Vientiane, Laos. 01 March, 2011.

Jensen, J.R. 2005. *Introductory digital image processing: a remote sensing perspective*: Upper Saddle River, NJ, USA: Pearson Prentice Hall.

Jones, M.B. & Humphries, S.W. 2002. Impacts of the C4 sedge *Cyperus papyrus* L. on carbon and water fluxes in an African wetland. *Hydrobiologia*, 488:107-113.

Joshi, P. K., Rashid, H. & Roy, P.S. 2002. Landscape dynamics in Hokersar Wetland, Jammu & Kashmi: an application of geospatial approach. *Journal of the Indian Society of Remote Sensing*, 30:1-5.

Kakuru, W., Turyahabwe, N. & Mugisha, J. 2013. Total economic value of wetlands products and services in Uganda. *The Scientific World Journal*, 2013. Article ID 192656, 13 pages http://dx.doi.org/10.1155/2013/192656.

Kalembasa, S.J. & Jenkinson, D.S. 1973. A comparative study of titrimetric and gravimetric methods for the determination of organic carbon in soil. *Journal of the Science of Food and Agriculture*, 24:1085-1090.

Kamanyire, M. 2000. Sustainability indicators for natural resource management & policy. *Natural Resource Management and Policy in Uganda: Overview Paper, Economic Policy Research Centre, Kampala*.

Kamanyire, M. 2002. *Natural resource management in Uganda: the effects of policy and institutional environment on natural resource management and investment by farmers and rural households in East and Southern Africa*: 21-32, EPRC.

Kansiime, F. & Van Bruggen, J.J.A. 2001. Distribution and retention of faecal coliforms in the Nakivubo wetland in Kampala, Uganda. *Water Science and Technology*, 44:199-206.

Kansiime, F., Kateyo, E., Oryem-Origa, H. & Mucunguzi, P. 2007. Nutrient status and retention in pristine and disturbed wetlands in Uganda: management implications. *Wetlands Ecology and Management*, 15:453-467.

Kanyiginya, V., Kansiime, F., Kimwaga, R. & Mashauri, D.A. 2010. Assessment of nutrient retention by Natete wetland Kampala, Uganda. *Physics and Chemistry of the Earth, Parts A/B/C*, 35:657-664.

Karanja, F., Emerton, L., Mafumbo, J. & Kakuru, W. 2001. Assessment of the economic value of Pallisa district wetlands, Uganda. *Biodiversity Economics for Eastern Africa & Uganda's National Wetlands Programme,* IUCN Eastern Africa Programme.

Kataata, K.D. 2003. *Wetland conservation: institutional constraints and community awareness*. UNEP, EIA, Training Resource Manual.

Kimble, J.M., Lal, R., Birdsey, R. & Heath, L.S. (Eds.). 2000. *The potential of US forest soils to sequester carbon and mitigate the greenhouse effect*. Boca Raton, FA, USA: CRC Press.

King, D., Goudie, D. & Dominey-Howes, D. 2006. Cyclone knowledge and household preparation: some insights from Cyclone Larry. *Australian Journal of Emergency Management*, 21:52.

King, D.M. & Mazzotta, M. 2010. *Putting an economic value on wetlands. Concepts methods & considerations*. Authority of the Minister of the Environment, Canada.

Kingsford, R.T. & Thomas, R.F. 2002. Use of satellite image analysis to track wetland loss on the Murrumbidgee River floodplain in arid Australia, 1975-1998. *Water Science and Technology*, 45:45-53.

Kiyimba, J. 2013. *Implication of land policies and laws on water and sanitation rights and services delivery in Uganda*. Water aid, Uganda.

Kolok, A.S. 2010. Sediments and emerging contaminants: on the menu and in the air. University of Nebraska-Lincoln’s Water Current 42:6.

Konen, M.E., Jacobs, P.M., Burras, C.L., Talaga, B.J. & Mason, J.A. 2002. Equations for predicting soil organic carbon using loss-on-ignition for north central US soils. *Soil Science Society of America Journal*, 66:1878-1881.

Kongsager, R., Napier, J. & Mertz, O. 2012. The carbon sequestration potential of tree crop plantations. *Mitigation and Adaptation Strategies for Global Change*, 18:1197-1213.

Krejcie, R.V. & Morgan, D.W. 1970. Determining sample size for research activities. *Educational and Psychological Measurement*, 30:607-610.

Krull, E., Baldock, J. and Skjemstad, J., 2001, April. Soil texture effects on decomposition and soil carbon storage. In *Net Ecosystem Exchange CRC Workshop Proceedings* (103-110). Canberra, Australia.

Krutilla, J.V. 1967. Conservation reconsidered. *The American Economic Review*, *57*(4):777-786.

Kyophilavong, P. 2011. *Economic evaluation of wetland ecosystems in Lao PDR: case study of BKN*, Champasak, Laos: UNDP.

LaGrange, T.G., Stutheit, R., Gilbert, M., Shurtliff, D. & Whited, P.M. 2011. Sedimentation of Nebraska's playa wetlands: a review of current knowledge and issues. Nebraska Game and Parks Commission, Lincoln.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science*, 304:1623-1627.

Lal, R. 2008. Soil carbon stocks under present and future climate with specific reference to European ecoregions. *Nutrient Cycling in Agroecosystems*, 81:113-127.

Langdale-Brown, I., Osmaston, H.A. & Wilson, J.G., 1964. *The vegetation of Uganda and its bearing on land use*. Kampala: Government of Uganda.

Lannas, K.S. & Turpie, J.K. 2009. Valuing the provisioning services of wetlands: contrasting a rural wetland in Lesotho with a peri-urban wetland in South Africa. *Ecology and Society*, 14:18.

Leimona, B. 2011. Fairly efficient or efficiently fair: success factors and constraints of payment and reward schemes for environmental services in Asia. Unpublished PhD Thesis, Wageningen University, Wageningen, the Netherlands.

Leisenring, M., Clary, J., Lawler, K. & Hobson, P. 2011. *International storm water best management practices (BMP) database pollutant category summary: solids (TSS, TDS and Turbidity)*:1-28.

Liddicoat, C., Schapel, A., Davenport, D. & Dwyer, E. 2010. *Soil carbon and climate change*. PIRSA Discussion Paper. Adelaide, SA: Rural Solutions SA.

Liguori, G., Gugliuzza G. & Inglese, P. 2009. Evaluating carbon fluxes in orange orchards in relation to planting density. *Journal of Agricultural Science*, 147:637-645.

Liu, Y., Sheng, L. and Liu, J., 2015. Impact of wetland change on local climate in semi-arid zone of Northeast China. *Chinese geographical science*, 25: 309.

Loomis, J., Kent, P., Strange, L., Fausch, K. & Covich, A. 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. *Ecological Economics*, 33:103-117.

Lu, D., Mausel, P., Brondizio, E. and Moran, E., 2004. Change detection techniques. *International journal of remote sensing*, 25:.2365-*2401*.

Lunetta, R.S. and Elvidge, C., 1999. *Remote sensing change detection*. CRC Press. Taylor & Francis, London.

Lung'ayia, L.H. & Kenyanya, S.M. 2001. The nutrient enrichment of Lake Victoria (Kenya waters), Kenya, *Hy-drobiologia*, 458:75-82.

Lwasa, S., Mugagga, F., Wahab, B., Simon, D., Connors, J. and Griffith, C., 2013. Urban Climate.

Lwasa, S. 2004. Informal urban land markets and residential housing development in Kampala: processes and implications to planning. Geography. Kampala, Makerere: 215.

Lwasa, S. 2010. Adapting urban areas in Africa to climate change: the case of Kampala. *Current Opinion in Environmental Sustainability,* 2:166-171.

Lwasa, S., Nyakaana, J.B. & Sengendo H. 2005. *Assessment of environmental impacts of land use and cover change*: *A challenge of urban planning in metropolitan Kampala*. Brno, Czech Republic: Masaryk University.

Lyon, J.G. & McCarthy, J. (Eds.). 1995. *Wetland and environmental applications of GIS*. Boca Raton, Florida, USA: CRC Press.

Mabasi, T. 2009. Assessing the impacts, vulnerability, mitigation and adaptation to climate change in Kampala City. In *World Bank Fifth Urban Research Symposium, Marseille, France*.

Macharia, J.M., Thenya, T. & Ndiritu, G.G. 2010. Management of highland wetlands in central Kenya: the importance of community education, awareness and eco-tourism in biodiversity conservation. *Biodiversity*, 11:85-90.

MacKinnon, F. 2001. Analysis of Vegetation Types and Heights in Wetlands. *Nova. Scotia Geomatics Centre Research Report*. Nova Scotia, Canada.

Maclean, I.M., Tinch, R., Hassall, M. & Boar, R. 2003. *Social and economic use of wetland resources: a case study from Lake Bunyonyi, Uganda*. Environmental Change and Management Working Paper, 09. University of East Anglia, Centre for Social and Economic Research on the Global Environment, Uganda.

Mafabi, R.J.B.P.G. 2003. Towards sustainable wetlands management: The Ugandan experience. *Wetlands of Ethiopia*, p. 97.

Mahan, B.L., Polasky, S. & Adams, R.M. 2000. Valuing urban wetlands: a property price approach. *Land Economics*, 76:100-113.

Malick, A.K.J. 2004. *Environmental and social management framework for Kampala industrial business park at Namanve*. Final report, No. E936, Uganda Investment Authority.

Maltby, E. & Barker, T. (Eds.). 2009. *The wetlands handbook, 2 Volume set*. John Wiley & Sons, South Sussex, United Kingdom

Maltby, E. (Ed.). 2009. *Functional assessment of wetlands: towards evaluation of ecosystem services*. CRC Press publishers, United Kingdom. Abington Hall, Granta ParkGreat Abington, Cambridge

Mangangka, I.R. 2013. Role of hydraulic factors in constructed wetland and bio retention basin treatment performance. (Doctoral dissertation Queensland University of Technology)

Mathooko, J.M., M'Erimba, C.M., Kipkemboi, J. & Dobson, M. 2009. Conservation of highland streams in Kenya: the importance of the socio-economic dimension in effective management of resources. *Freshwater Reviews*, 2:153-165.

Matovu, G.L. 2006. *Challenges in monitoring and enforcement of environmental laws in Uganda*. National Environmental Management Authority, Uganda.

Mburu, N., Thumbi, G. & Mayabi, A. 2008. Removal of bacteria pathogens from domestic wastewater in a tropical subsurface horizontal flow constructed wetland. In *Proceedings of Taal2007: The 12th World Lake Conference*: 1010-1015.

McClain, M.E., Bilby, R.E. & Triska, F.J. 1998. Nutrient cycles and responses to disturbance. In *River ecology and management: lessons from the Pacific Coastal ecoregion.* New York, NY: Springer: 347-372.

McGranahan, D.A. 2008. Landscape influence on recent rural migration in the US. *Landscape and Urban Planning*, 85:228-240.

MDDP (Mukono District Development Plan) (2010). *Mukono five year district development plan* 2010 – 2015:17. NPA, Kampala Uganda.

MEA (Millennium Ecosystem Assessment). 2005. *Ecosystems and human wellbeing: wetlands and water synthesis*. Washington, DC World Resources Institute: 80.

Megan, L. & Nater, E.A. 2006. *Biophysical aspects of terrestrial carbon sequestration in Minnesota*. St. Paul: University of Minnesota.

Mhonda, A.I.D.A.N. 2013. Evaluating flash flood risk reduction strategies in built-up environment in Kampala. University of Twente.

Ministry of Water Lands and Environment (MWLE). 2003. National biomass study technical report. Government of Uganda, Kampala.

Ministry of Water Lands and Environment (MWLE). 2011. Republic of Uganda. A national water policy. Kampala, Uganda.

Miththapala, S. 2008. Integrating environmental safeguards into disaster management. *The Disaster Management Cycle*, 2. Colombo: Ecosystems and Livelihoods Group, Asia, IUCN. vi+43

Mitra, S., Wassmann, R. & Vlek, P.L. 2005. An appraisal of global wetland area and its organic carbon stock. *Current Science*, 88:25.

Mitsch, W.J. 1986. Riparian wetlands. In Mitsch, W.J. & Gosselink, J.G. 2007, (eds.), *Wetlands.* New York: Van Nostrand Reinhold Company: 353-389.

Mitsch, W.J., Bernal, B., Nahlik, A.M., Mander, Ü., Zhang, L., Anderson, C.J., Jørgensen, S.E. & Brix, H. 2013. Wetlands, carbon, and climate change. *Landscape Ecology*, 28:583-597.

Mitsch, W.J., Nahlik, A., Wolski, P., Bernal, B., Zhang, L. & Ramberg, L. 2010. Tropical wetlands: seasonal hydrologic pulsing, carbon sequestration, and methane emissions. *Wetlands Ecology and Management*, 18:573-586.

Moran, D., Laycock, H. & White, P.C. 2010. The role of cost-effectiveness analysis in conservation decision-making. *Biological Conservation*, 143:826-827.

Moses, O. 2008. An institutional analysis of the management of wetland resources: a comparative study of Flóahreppur municipality in south Iceland and Oyam district in Uganda. *Land Restoration Training Programme,* Agricultural University of Iceland.

MTTI. 2008. *The National Industrial Policy: A framework for Uganda's transformation, competitiveness and prosperity*. Ministry of Tourism, Trade & Industry. Kampala, Uganda.

Muganwa, H.K. 1995. *Uganda National Wetlands Policy*. Ministry of Natural Resources, Kampala, Uganda.

Mukoome, L.F. 2009. *Higher local government statistical abstract*. Mukono District, Uganda.

Munyati, C. 2000. Wetland change detection on the Kafue Flats, Zambia, by classification of a multitemporal remote sensing image dataset. *International Journal of Remote Sensing*, 21:1787-1806.

Muradian, R., Corbera, E., Pascual, U., Kosoy, N. and May, P.H., 2010. Reconciling theory and practice: An alternative conceptual framework for understanding payments for environmental services. *Ecological economics*, 69:.1202-1208.

Musamba, E.B., Boon, E.K., Ngaga, Y.M., Giliba, R.A. & Dumulinyi, T. 2012. The recreational value of wetlands: activities, socio-economic activities and consumers' surplus around Lake Victoria in Musoma Municipality, Tanzania. *Journal of Human Ecology*, 37:85-92.

Musoke, S. 2001. *The District Wetland Inventory Report* (DIR). Mukono / Kayunga. Unpublished report, submitted to the National Environment and Management Authority. Kampala, Uganda

Muwanga, A. & Barifaijo, E. 2006. Impact of industrial activities on heavy metal loading and their physico-chemical effects on wetlands of Lake Victoria basin (Uganda). *African Journal of Science and Technology*, 7:51-63.

Muyomba-Tamale, L., Tumushabe, G., Amanigaruhanga, I., Bwanika-Semyalo, V. & Jones, E. 2009. *Local government councils' performance and public service delivery in Uganda*. Mukono District Council Score Card Report 2009/10. ACODE Policy Research Series, No. 45, 2011. Kampala.

Nabulo, G., Origa, H.O., Nasinyama, G.W. & Cole, D. 2008. Assessment of Zn, Cu, Pb and Ni contamination in wetland soils and plants in the Lake Victoria basin. *International Journal of Environmental Science & Technology,* 5:65-74.

Namakambo, R. 2000. *Wetland inventory for Kampala*. Wetland Inspection Division, Kampala, Uganda.

National Bureau of Statistics (NBS). 2003. Kampala, Uganda.

Naugle, D.E., Higgins, K.F., Nusser, S.M. & Johnson, W.C. 1999. Scale-dependent habitat use in three species of prairie wetland birds. *Landscape Ecology*, 14:267-276.

Ndikumana, L. 2001. *Financial markets and economic development in Africa*. Political Economy Research Institute, University of Massachusetts, Amherst, USA.

Nelson, D.W. & Sommers, L.E. 1975. A rapid and accurate procedure for estimation of organic carbon in soil. *Indiana Academy of Science*, 84:456-462.

NEMA (National Environment Management Authority). 1996. *State of the Environment Report for Uganda*. Kampala, Uganda.

NEMA (National Environment Management Authority). 1997. *State of the Environment Report for Mukono*, Uganda.

NEMA (National Environment Management Authority). 2000. *State of the Environment Report for Kampala*, Uganda.

NEMA (National Environment Management Authority). 2001. *State of the Environment Report for Kampala*, Uganda.

NEMA (National Environment Management Authority). 2002. *District State of the Environment Report for Mukono*. Kampala, Uganda.

NEMA (National Environment Management Authority). 2004. *District State of the Environment Report for Mukono*. Kampala, Uganda.

NEMA (National Environment Management Authority). 2005. *State of the Environment Report for Jinja*. Kampala, Uganda.

NEMA (National Environment Management Authority). 2006. *Third National Biodiversity Report*. Kampala, Uganda.

NEMA (National Environment Management Authority). 2010. *District State of the Environment Report for Mukono*. Kampala, Uganda.

Newcome, J., Provins, A., Johns, H., Ozdemiroglu, E., Ghazoul, J., Burgess, D. & Turner, K. 2005. The economic, social and ecological value of ecosystem services: A literature review. Economics for the Environment Consultancy (EFTEC, London.

NFA (National Forest Authority). 2008. *National Biomass Study Report*. Kampala, Uganda.

Nguyen, T.T.H. & Pham, T.T.T. 2016. Incorporating ancillary data into Landsat 8 image classification process: a case study in Hoa Binh, Vietnam. *Environmental Earth Sciences*, 75: 1-8.

Nikitin, B.A. 1999. Methods of soil humus determination. *Journal of Agricultural and Food Chemistry*, 5:91-93.

Novara, A., Rühl, J., La Mantia, T., Gristina, L., La Bella, S. & Tuttolomondo, T. 2015. Litter contribution to soil organic carbon in the processes of agriculture abandon. *Solid Earth*, 6:425.

Nsereko, P. 2010. Contribution of wetland resources to household incomes of riparian communities: A case study of Katonga wetland in Mpigi District. (Master’s dissertation, Makerere University). Kampala, Uganda.

Ntambirweki, J. 1998. The evolution of policy and legislation on wetlands in Uganda. *Case Study prepared for the Technical Consultation on Designing Methodologies to Review Laws and Institutions Relevant to Wetlands* Gland, Switzerland, 3.

Nyakaana, J. B. & Sengendo, H. 2004. Population, urban development and the environment in Uganda: the case of Kampala City and its environs. Kampala, Uganda. A paper presented at a conference, Nairobi, Kenya.

Obua, J., Agea, J.G. & Ogwal, J.J. 2010. Status of forests in Uganda. *African Journal of Ecology*, 48:853-859.

Oduor, F.O., Raburu, P.O. & Mwakubo, S. 2015. To conserve or convert wetlands: Evidence from Nyando wetlands, Kenya. *Journal of Development and Agricultural Economics*, 7:48-54.

Oglethorpe, D.R. & Miliadou, D. 2000. Economic valuation of the non-use attributes of a wetland: a case-study for Lake Kerkini. *Journal of Environmental Planning and Management*, 43:755-767.

Olesen, J.E., Rubæk, G.H., Heidmann, T., Hansen, S. & Børgensen, C.D. 2004. Effect of climate change on greenhouse gas emissions from arable crop rotations. *Nutrient Cycling in Agroecosystems*, 70:147-160.

Ostrom, E. 1999. Design principles and threats to sustainable organizations that manage commons. In Berdegue, J.A., *Paper for electronic conference on Small Farmer's Economic Organizations, Santiago, Chile, March*.

Owino, A.O. & Ryan, P.G. 2007. Recent papyrus swamp habitat loss and conservation implications in western Kenya. *Wetlands Ecology and Management*, 15:1-12.

Ozdemiroglu, E., Tinch, R., Johns, H., Provins, A., Powell, J. & Twigger-Ross, C. 2006. Valuing our natural environment. Final Report. EFTEC, London. [URL: http://earthmind.net/rivers/docs/ukdefra-eftec-valuing-our-natural-environment].

Özemi, S. L. (2000) Satellite Remote Sensing of Wetlands and a Comparison of Classification Techniques, p. 220.

Ozesmi, S.L. & Bauer, M.E. 2002. Satellite remote sensing of wetlands. *Wetlands Ecology and Management*, 10:381-402.

Özyavuz, M. 2010. Determination of temporal changes in lakes Mert and Erikli using remote sensing and geographic information systems. *Journal of Coastal Research*, 27:174-181.

Paerl, H.W., Fulton, R.S., Moisander, P.H. & Dyble, J. 2001. Harmful freshwater algal blooms, with an emphasis on cyanobacteria. *The Scientific World Journal*, 1:76-113.

Parish, F. & Looi, C.C. 2011. Carbon fluxes and storage in wetland ecosystems. In *Wetland systems: Storm water management control.* London: Springer: 127-147.

Pascual, U., Muradian, R., Brander, L., Gómez-Baggethun, E., Martín-López, B., Verma, M. & Farley, J. 2010. The economics of valuing ecosystem services and biodiversity. *TEEB–Ecological and Economic Foundation*. Taylor and Francis, 183-256. DOI: 10.4324/9781849775489

Patton, C.J. and Kryskalla, J.R., 2003. *Methods of analysis by the US Geological Survey National Water Quality Laboratory: evaluation of alkaline persulfate digestion as an alternative to Kjeldahl digestion for determination of total and dissolved nitrogen and phosphorus in water* (No. 2003-4174).

Paul, A. 2008. Mitigating global climate change: which kinds of wetlands help, hurt, or have minimal effect? Presented at the Association of State Wetland Managers Annual Conference, September. Minnesota, USA**.**

Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R. & Wagner, F. 2003. *Good practice guidance for land use, land-use change and forestry*. IPCC. Hayama, Japan.

Payne, C. and Sand, P. eds., 2011. *Gulf War Reparations and the UN Compensation Commission: Environmental Liability*. Oxford University Press.

Perlman, D.L. & Milder, J. 2005. *Practical ecology for planners, developers, and citizens*. Washington: Island Press.

Petrics, H. & Russo, M. 2006. *Economic valuation of wetlands and participatory planning tools*, 492. Franco Angeli s, r, l., Milano, Italy.

Phyllis, K.W-S, Lawrence, K.D. 2007. Effects of total dissolved salts on aquatic organisms: A review of literature and recommendation for salmonid species. *American Journal of Environmental Science*, 3:1-6.

Pomeroy, D. 2004. The birds of Makerere Hill, Kampala: a loss of biodiversity. *Uganda Journal*, 48:1-16.

Ponomariova, V.V. & Plotnikova, T.A. 1980. Humus and soil formation (methods and results) - Nauka, Leningrad, 1-222 (in Russian).

Querner, E.P. 2000. The effects of human intervention in the water regime. *Ground Water*, 38:167-171.

Ramachandra, T.V. & Rajinikanth, R. 2004. Economic value of wetlands. Technical report, Energy and Wetland Research Group, Center for Ecological Sciences, Indian Institute of Science, Bangalore.

Ramsar, 2002. Wetlands and agriculture: Partners for growth. Ramsar world wetlands day, Valencia, Spain.

Randolph, J. 2004. *Environmental land use planning and management*. Washington: Island Press.

Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H. & Stringer, L.C. 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of environmental management*, 90:1933-1949.

Rees, R.M., Bingham, I.J., Baddeley, J.A. & Watson, C.A. 2005. The role of plants and land management in sequestering soil carbon in temperate arable and grassland ecosystems. *Geoderma*, 128:130-154.

Reid, M.A. and Brooks, J.J., 2000. Detecting effects of environmental water allocations in wetlands of the Murray–Darling Basin, Australia. *Regulated Rivers: Research & Management*, 16: 479-496.

Reja, U., Manfreda, K.L., Hlebec, V. & Vehovar, V. 2003. Open-ended vs. close-ended questions in web questionnaires. *Developments in Applied Statistics*, 19:159-177.

Resolution, V.I.I.I., 2002, November. 18: Invasive species and wetlands. Wetlands: water, life, and culture. In *8th Meeting of the Conference of the Contracting Parties to the Convention on Wetlands (Ramsar, Iran, 1971) Valencia, Spain, 18–26 Nov 2002*.

Richter, B.D., Baumgartner, J.V., Powell, J. and Braun, D.P., 1996. A method for assessing hydrologic alteration within ecosystems. *Conservation biology,* 10: 1163-1174.

Roggeri, H. 2013. *Tropical freshwater wetlands: a guide to current knowledge and sustainable management* (112). Springer Science & Business Media, Dordrecht.

Romsho, S.A. 2004. Radar remote sensing for monitoring of dynamic ecosystem processes related to biogeochemical exchanges in tropical peat lands. *Visual Geosciences*, 9:9-28.

Roulet, N.T. 2000. Peat lands, carbon storage, greenhouse gases, and the Kyoto protocol: prospects and significance for Canada. *Wetlands*, 20: 605-615.

Ruan, R., Zhang, Y. & Zhou, Y. 2008. Change detection of wetland in Hongze Lake using a time series of remotely sensed imagery. *Remote Sensing and Spatial Information Sciences*, 37:1545-1548.

Ruzzier, M. 2010. *Guidelines for economic evaluation of natural assets of the protected areas*. Zavod Republike Slovenije za varstvo narave. Závod, Slovakia.

Rwakakamba, T.M. 2009. How effective are Uganda's environmental policies? A case study of water resources in 4 districts, with recommendations on how to do better. *Mountain Research and Development*, 29:121-127.

Sadeghi, S.H. & Yaghmaei, H.I.V.A. 2015. Suspended sediments-associated water quality elements. *Proceedings of the International Association of Hydrological Sciences*, 366:194.

Sano, E.E., Ferreira, L.G., Asner, G.P & Steinke, E.T. 2007. Spatial and temporal probabilities of obtaining cloud-free Landsat images over the Brazilian tropical savanna. *International Journal of Remote Sensing*, 28:2739-2752.

Saunders, M.J., Jones, M.B. & Kansiime, F. 2007. Carbon and water cycles in tropical papyrus wetlands. *Wetlands Ecology and Management*, 15:489-498.

Saunders, M.J., Kansiime, F. & Jones, M.B. 2014. Reviewing the carbon cycle dynamics and carbon sequestration potential of Cyperus papyrus L. wetlands in tropical Africa. *Wetlands Ecology and Management*, 22:143-155.

Scholz, M. 2011. Carbon storage and fluxes within wetland systems. In *Wetland systems.* London: Springer: 127-147.

Schumacher, B.A. 2002. Methods for the determination of total organic carbon (TOC) in soils and sediments. *Ecological Risk Assessment Support Center*: 1-23.

Schuyt, K. 2002. Land and water use of wetlands in Africa: economic values of African wetlands. *International Institute for Applied Systems Analysis.* Interim Report. Laxenburg.

Schuyt, K.D. 2005. Economic consequences of wetland degradation for local populations in Africa. *Ecological Economics*, 53:177-190.

Setlhogile, T., Arntzen, J., Mabiza, C. & Mano, R. 2011. Economic valuation of selected direct and indirect use values of the Makgadikgadi wetland system, Botswana. *Physics and Chemistry of the Earth, Parts A/B/C*, 36:1071-1077.

Seto, K.C. & Kaufmann, R.K. 2003. Modeling the drivers of urban land use change in the Pearl River Delta, China: Integrating remote sensing with socioeconomic data. *Land Economics*, 79:106-121.

Seto, K.C. & Reenberg, A. 2014. *Rethinking global land use in an urban era*. Boston, USA: MIT Press.

Seto, K.C., Güneralp, B. & Hutyra, L.R. 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences*, 109:16083-16088.

Seyam, I.M., Hoekstra, A.Y., Ngabirano, G.S. & Savenije, H.H.G. 2001. The value of freshwater wetlands in the Zambezi basin. *Value of Water Research Report Series*, (7):22.

Shabman, L. and Scodari, P., 2004. Past, present, and future of wetlands credit sales. Resources for the Future Discussion Paper 04-48, December 2004. Resources for the Future.

Shafroth, P.B., Stromberg, J.C. & Patten, D.T. 2002. Riparian vegetation response to altered disturbance and stress regimes. *Ecological Applications*, 12:107-123.

Sharpley, A.N., Kleinman, P. & McDowell, R. 2001. Innovative management of agricultural phosphorus to protect soil and water resources. *Communications in Soil Science and Plant Analysis*, 32:1071-1100.

Singb, A., 1989. Digital change detection techniques using remotelyWsensed data. *International Journal of Remote Sensing*, 10: 989L1003.

Sjogersten, S., Black, R.C., Evers, S., Santillan, J. H., Wright, E.L. & Turner, B.L. 2014. Tropical wetlands: The missing link in the global carbon cycles? *Global Biochem Cycles*, 12:1371-1386.

Smith, P. 2008. Land use change and soil organic carbon dynamics. *Nutrient Cycling in Agroecosystems*, 81:169-178.

Sorensen, K.W. 1993. Indonesian peat swamp forests and their role as a carbon sink. *Chemosphere*, 27:1065-1082.

Sottolichio, A., Le Hir, P. & Castaing, P. 2000. Modeling mechanisms for the stability of the turbidity maximum in the Gironde estuary, France. *Proceedings in Marine Science*, 3:373-386.

Spiegel, H., Filcheva, E., Hegymegi, P., Gal, A. & Verheijen, F.G.A. 2007. Review and comparison of methods used for soil organic carbon determination. Part 1. Review of the methods. *Soil Science Agrochemical Ecology*, 41:3-17.

Stevenson, R.J., Rier, S.T., Riseng, C.M., Schultz, R.E. & Wiley, M.J. 2006. Comparing effects of nutrients on algal biomass in streams in two regions with different disturbance regimes and with applications for developing nutrient criteria. *Hydrobiologia*, 561:149-165.

Stuip, M.A.M., Baker, C.J. & Oosterberg, W. 2002. *The socio-economics of wetlands*. Wageningen, the Netherlands: *Wetlands International and RIZA.*

Su, T.M., Yang, S.C., Shih, S.S. & Lee, H.Y. 2009. Optimal design for hydraulic efficiency performance of free-water-surface constructed wetlands. *Ecological Engineering*, 35:1200-1207.

Sugumaran, R., Harken, J. & Gerjevic, J. 2004. Using remote sensing data to study wetland dynamics in Iowa. *Iowa Space Grant (Seed) Final Technical Report, University of Northern Iowa, Cedar Falls*: 1-17.

Sun, G., McNulty, S.G., Amatya, D.M., Skaggs, R.W., Swift, L.W., Shepard, J.P. & Riekerk, H. 2002. A comparison of the watershed hydrology of coastal forested wetlands and the mountainous uplands in the Southern US. *Journal of Hydrology*, 263: 92-104.

SUPRE (State of Uganda's Population Report). 2012. *Uganda at 50 years: population and service delivery: challenges, opportunities and prospects*. Republic of Uganda, Kampala.

Tabacchi, E., Lambs, L., Guilloy, H., Planty-Tabacchi, A.M., Muller, E. & Decamps, H. 2000. Impacts of riparian vegetation on hydrological processes. *Hydrological Processes*, 14: 2959-2976.

Tang, Z., Gu, Y., Drahota, J., LaGrange, T., Bishop, A. & Kuzila, M.S. 2015. Using fly ash as a marker to quantify culturally-accelerated sediment accumulation in playa wetlands. *JAWRA: Journal of the American Water Resources Association*, 51:1643-1655.

Tejuoso, O.J., 2006. *Wetland uses/Dynamics For agricultural purposes and its health implications in Lower Ogun River Basin, Lagos*. Nigeria. Technical Report submitted to International Development Research Centre (IDRC) Ecosystem approach to human health team.

Thompson, K. 2012. *Hydrological assessments of ten wetlands in the Wellington Region and recommendations for sustainable management: a holistic approach*. Prepared for the Greater Wellington Regional Council by Bogman Ecological, Hamilton, USA.

Tong, L., Xu, X., Fu, Y. and Li, S., 2014. Wetland changes and their responses to climate change in the "three-river headwaters" region of China since the 1990s. *Energies, 7*: 2515-2534.

Töyrä, J. & Pietroniro, A. 2005. Towards operational monitoring of a northern wetland using geomatics-based techniques. *Remote Sensing of Environment*, 97:174-191.

Tsai, J.S., Venne, L.S., McMurry, S.T. & Smith, L.M. 2007. Influences of land use and wetland characteristics on water loss rates and hydroperiods of playas in the Southern High Plains, USA. *Wetlands*, 27:683-692.

Turner, R.K., Pearce, D. & Bateman, I. 1994. *Environmental economics: an elementary introduction*. London: Harvester Wheatsheaf.

Turner, R.K., Van Den Bergh, J.C., Söderqvist, T., Barendregt, A., Van Der Straaten, J., Maltby, E. & Van Ierland, E.C. 2000. Ecological-economic analysis of wetlands: scientific integration for management and policy. *Ecological Economics*, 35:7-23.

Turpie, J., Lannas, K., Scovronick, N. & Louw, A. 2010. *Wetland ecosystem services and their valuation*: *A review of current understanding and practice*. Water Research Commission South Africa.

Turyahabwe, N., Kakuru, W., Tweheyo, M. & Tumusiime, D.M. 2013(a). Contribution of wetland resources to household food security in Uganda. *Agriculture & Food Security*, 2:1.

Turyahabwe, N., Tumusiime, D.M., Kakuru, W. & Barasa, B. 2013(b). Wetland use/cover changes and local perceptions in Uganda. *Sustainable Agriculture Research*, 2:95-105.

U.S. EPA. 2008. *Methods for evaluating wetland condition*: *Wetland hydrology*. Office of Water, U.S. Environmental Protection Agency, Washington, DC.EPA-822-R-08-024.

UBOS (Uganda Bureau of Statistics). 2010. *Uganda National Household Survey: Socio-economic Module*. Abridged Report. Kampala, Uganda

UBOS (Uganda Bureau of Statistics). 2014. *National population and housing census*. Revised edition. Republic of Uganda, Kampala.

Umar, T., 2010. *Implementation of Mitigation Measures Resulting from Environmental Impact Assessment in Selected Industrial Projects in Kampala District* (Doctoral dissertation, Makerere University). Kampala, Uganda.

UNDP. 2009. *Sustainable land management to combat desertification and land management. Extending wetland protected areas through community conservation and initiatives* (COBWEB), Kampala, Uganda.

UNEP. 2009. *Enhancing wetlands' contribution to growth, empowerment and prosperity*. Kampala: NEMA Poverty Eradication Initiative, Uganda.

Vaccari, F.P., Lugato, E., Gioli, B., D'Acqui, L., Genesio, L., Toscano, P. & Miglietta, F. 2012. Land use change and soil organic carbon dynamics in Mediterranean agro-ecosystems: The case study of Pianosa Island. *Geoderma*, 175:29-36.

Vengosh, A., Jackson, R.B., Warner, N., Darrah, T.H. and Kondash, A., 2014. A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States. *Environmental Science & Technology*, 4:8334-8348.

Vepraskas, M.J. & Craft, C.B. (Eds.). 2016. *Wetland soils: genesis, hydrology, landscapes, and classification*. Boca Raton, FA: CRC Press.

Vermeiren, K., Van Rompaey, A., Loopmans, M., Serwajja, E. and Mukwaya, P., 2012. Urban growth of Kampala, Uganda: Pattern analysis and scenario development. *Landscape and Urban Planning*, 106:199-206.

Walkley, A. & Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, 37:29-38.

Wasswa, H., Mugagga, F. & Kakembo, V. 2013. Economic implications of wetland conversion to local people's livelihoods: the case of Kampala - Mukono Corridor (KMC) wetlands in Uganda. *Academia Journal Environmental Sciences*, 1:066-077.

Weber-Scannell, P.K. & Duffy, L.K. 2007. Effects of total dissolved solids on aquatic organism: a review of literature and recommendation for salmonid species. *American Journal of Environmental Sciences*. 3: 1 – 6.

Wegener, M. 2001. New spatial planning models. *International Journal of Applied Earth Observation and Geoinformation*, 3: 224-237.

Westbrook, C.J., Brunet, N., Phillips, I. & Davies, J.M. 2011. *Wetland drainage effects on Prairie water quality: final report*. Centre for Hydrology, University of Saskatchewan.

WHO (World Health Organization). 1996. *Guidelines for drinking-water quality: health criteria and other supporting information*, (2). 2nd ed. Geneva, Switzerland.

Wilcox, D.A., 1995. Wetland and aquatic macrophytes as indicators of anthropogenic hydrologic disturbance. *Natural Areas Journal*, 15(3), 240-248.

Wills, I.R. 1997. *Economics and the environment: a signalling and incentives approach*. Allen & Unwin, St Leonards, Australia.

Wissel, S. and Wätzold, F., 2010. A conceptual analysis of the application of tradable permits to biodiversity conservation. *Conservation Biology*, 24: 404-411.

Woodcock, C.E., Allen, R., Anderson, M., Belward, A., Bindschadler, R., Cohen, W., Gao, F., Goward, S.N., Helder, D., Helmer, E. and Nemani, R., 2008. Free access to Landsat imagery.

Woltemade, C.J. 2000. Ability of restored wetlands to reduce nitrogen and phosphorus concentrations in agricultural drainage water. *Journal of Soil and Water Conservation*, 55:303-309.

WRI. (2009). Mapping a better future: how spatial analysis can benefit wetlands and reduce poverty in Uganda. World Resources Institute, Washington, DC and Kampala, available at http://www. wri. org/publication/mapping-better-future. Accessed on the 10th June 2015.

Xu, C., Sheng, S., Zhou, W., Cui, L. & Liu, M. 2011. Characterizing wetland change at landscape scale in Jiangsu Province, China. *Environmental Monitoring and Assessment*, 179: 279-292.

Yang, W., Wang, X., Liu, Y., Gabor, S., Boychuk, L. & Badiou, P. 2010. Simulated environmental effects of wetland restoration scenarios in a typical Canadian prairie watershed. *Wetlands Ecology and Management*, 18:269-279.

Yasuoka, Y., Yamagata, Y., Tamura, M., Sugita, M., *et al*. 1995. Monitoring of Wetland Vegetation Distribution and Its Change by Using Microwave Sensor Data. In *Proc. of the 16th Asian Conference on Remote Sensing, 20-24 November* 1995, *Nakhon Ratchasima, Thailand.*

Yu, J., Dong, H., Li, Y., Wu, H., Guan, B., Gao, Y., Zhou, D. & Wang, Y. 2014. Spatiotemporal distribution characteristics of soil organic carbon in newborn coastal wetlands of the Yellow River Delta estuary. *CLEAN–Soil, Air, Water*, 42:311-318.

Yu, Z. 2011. Holocene carbon flux histories of the world's peatlands global carbon-cycle implications. *The Holocene*, 21:761-774.

Zedler, J.B. & Kercher, S. 2005. Wetland resources: status, trends, ecosystem services, and restorability. *Annual Review of the Environment and Resources*, 30:39-74.

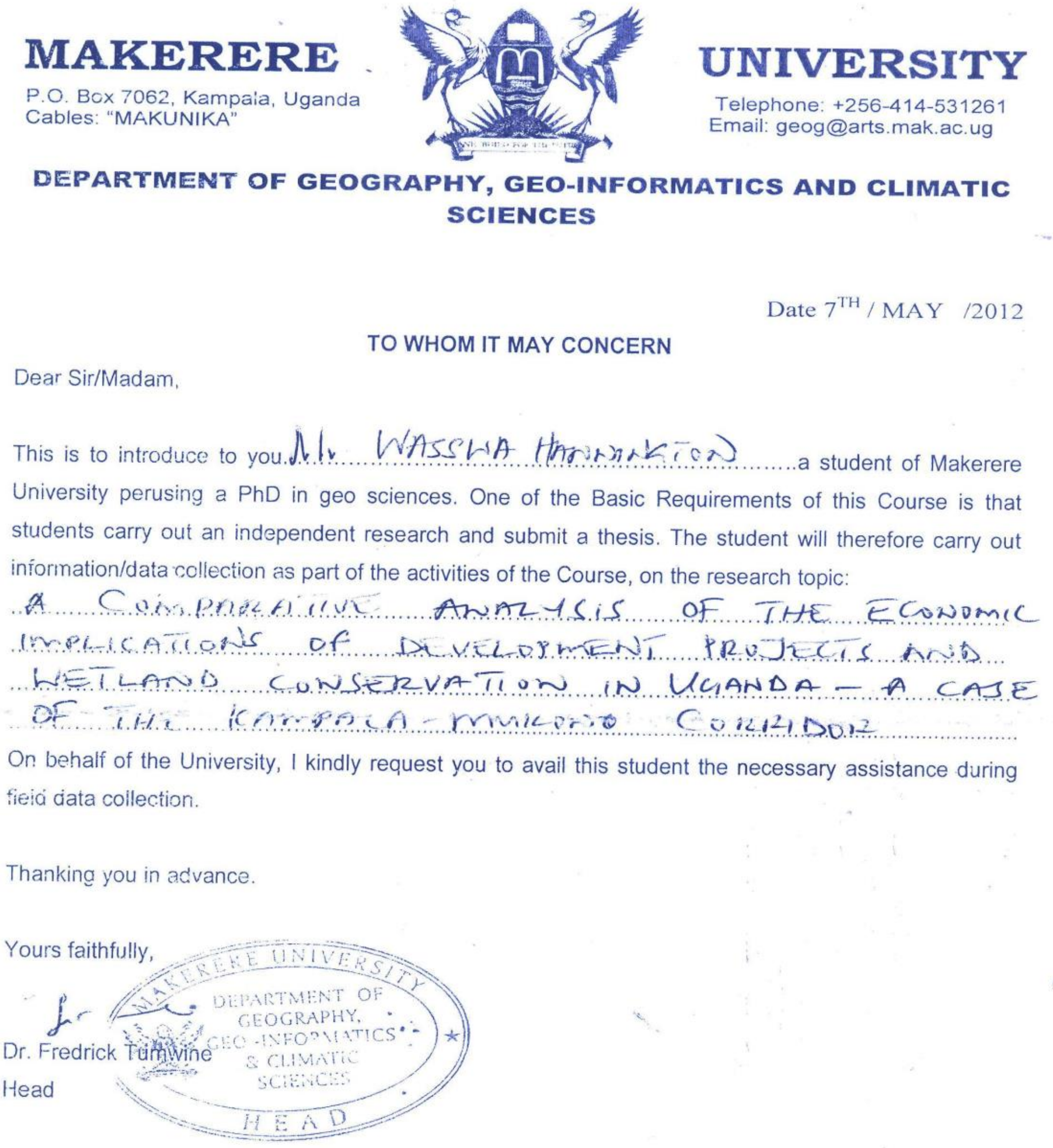
Zhang, J.Z., Fischer, C.J. & Ortner, P.B. 2004. Potential availability of sedimentary phosphorus to sediment resuspension in Florida Bay. *Global Biogeochemical Cycles*, 18(4) GB4008, doi: 10.1029/2004GB002255.

Zhang, X., Wang, L., Jiang, X. & Zhu, C. 2016. *Modeling with digital ocean and digital coast*. Springer International Publishing, Switzerland.

Zhang, Y., Lu, D., Yang, B., Sun, C. & Sun, M. 2011. Coastal wetland vegetation classification with a Landsat thematic mapper image. *International Journal of Remote Sensing*, 32:545-561.

APPENDICES:

Appendix A: General Introductory Letter



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DEPARTMENT OF GEOGRAPHY, GEO-INFORMATICS AND CLIMATIC SCIENCES

Date 7TH / MAY /2012

TO WHOM IT MAY CONCERN

Dear Sir/Madam,

This is to introduce to you Mr WASSWA HANNINGTON a student of Makerere University perusing a PhD in geo sciences. One of the Basic Requirements of this Course is that students carry out an independent research and submit a thesis. The student will therefore carry out information/data collection as part of the activities of the Course, on the research topic:

A COMPARATIVE ANALYSIS OF THE ECONOMIC IMPLICATIONS OF DEVELOPMENT PROJECTS AND WETLAND CONSERVATION IN UGANDA – A CASE OF THE KAMPALA - MUKONO CORRIDOR

On behalf of the University, I kindly request you to avail this student the necessary assistance during field data collection.

Thanking you in advance.

Yours faithfully,

Dr. Fredrick Tumwine
Head

MAKERERE UNIVERSITY
DEPARTMENT OF
GEOGRAPHY,
GEO -INFORMATICS
& CLIMATIC
SCIENCES
HEAD

Appendix B 1: Questionnaire for producers of selected wetland goods

For the Valuation of the Gross Value for wetland goods to producers

Introduction: -

I am a student of Nelson Mandela University of South Africa, carrying out a study on the Economic and Ecological Trade-offs of Wetland Conversion for DPs, a Case of the Kampala –Mukono Corridor. You have been selected in this exercise to provide relevant information for this study. Please kindly respond for the information gathered will be used for academic purpose only and will be treated with utmost confidentiality.

Questionnaire for primary producers (harvesters) and consumers of selected wetland goods

Instructions;

Fill in what applies to you, or tick appropriate response.

Fill in NA where not applicable.

Background information

1. (a) Name (optional) ……………………………….

(b) Sex: Male ☐ Female ☐

(c) Age ……………………………………………….

2. Site/wetland …………………………………

3. The table below contains two categories of actors in the wetland i.e.

Harvesters and Consumers:

In category (A) identify the type of good you harvest, quantity harvested per unit period, average size of land where harvest comes from i.e. (2sq meters, 4sq meters etc**)**, proportion sold from the harvest, price per unit sold, and the number of times the good (s) is harvested per year.

In category (B) of the same table (household consumers) identify the type of good consumed, the unit quantity of the good consumed per day/month, and the minimum price (market price) and maximum price at which you would be willing to pay for the selected unit of a good consumed.

Category (A)

Harvester / Primary producers.

Selected Goods;	Goods consumed; *(tick where appropriate)*		Quantity harvested per unit Period. *Per (day, week, and or month.)* *in barrows, heaps, bundles,* tins (ddebe), sacks etc	Average size of land for harvest. *eg.2msq, 4msq, etc*	Proportion sold from harvest. *e.g. in barrows, heaps, bundles,* tins (ddebe), sacks etc *etc*	Price per unit sold. *in Ushs,* *E.g. price per heap etc*	No of harvests per year. *In terms of months only.* *E.g. 7 months in a year*
	Yes	**No**					
Thatch (Essubi)							
Clay							
Yams							
sweet potatoes							
Water							

Category B *(Household consumers)*

Consumer	**Yes**	**No**	**Type of good consumed** *(Identify by ticking)*	**Units consumed per day/week**. *(in (bundles, heaps, tins, etc)*	**Minimum price you buy per unit.** (*e.g. shillings per bundle, etc)*	**Maximum price you buy per unit of a good.** (*E.g. shillings per bundle, etc.)*
Households			Yams			
			Sweet potatoes			
			Water			
			Yams			
			Thatch			
			Bricks			

3). In the table below, estimate the numbers of selected consumers you supply with any of the following goods you harvest in the wetland

Selected goods;	**Type of consumer;**	**No. of consumers;**
1.Thatch	Brick layers	
	Farmers mulching	
2.Clay	Brick makers	
	Pot makers	

Selected goods;	**Type of consumer;**	**No. of consumers;**
	Charcoal stove makers	
3. Crops-yams	Households	
	traders	
4. Sweet potatoes	Households	
	traders	
5.Water	Households	
	Farmers	
	Brick makers	
	Clay extractors	

4) In the table below, state the type and amount of equipment or any other variable inputs used in the harvesting or production of the above good (per unit period), the cost of each equipment or any other input, and the period in a year that the same equipment or any other input would serve you before being replaced.

(To determine the net value of wet land goods to producers)

Equipment input:	**Numbers required at one time:**	**Life time:**	**Cost per unit:**
1.For crops:			
Hoes			
Panga			
Boots			

Equipment input:	**Numbers required at one time:**	**Life time:**	**Cost per unit:**
License			
Others *(specify)*			
2.For clay *(specify)*			
3.For thatch *(specify)*			
Boots			
Hoes			
Panga			
License			
Others *(specify)*			
4.For Water*(specify)*			

5. Rank the importance of wetlands to your livelihood.

Very high ☐ average ☐ low ☐ very low ☐

6. Rank the importance of DPs to wetland degradation

Very high ☐ average ☐ low ☐ very low ☐

7. Are you aware of wetland economic values in your area? Yes………. No…… *(Tick)*

Appendix B 2: Questionnaire for traders of the selected wetland goods

(Valuation of value added to wetland goods by traders)

Instructions:

Fill in what applies to you, or tick the appropriate responses

NB. N/A for not applicable.

Background/information

1. (a) Name (optional) …………………….

(b) Sex Male ☐ Female ☐

(c) Age …………….

Site/wetland where goods come from …………………….

2. In the table below, identify the type of good(s) traded/sold by you, the source of goods you have identified, the proportion of the same goods (s) got from the selected wetlands the quantity of the good(s) sold per unit period, price of each unit of a good sold, and the number of traders for clay charcoal stoves.

Selected goods;	**Yes** *(Tick)*	**Source of good** ……………… *(fill in name of wetland)*	**Proportion got from selected wetlands**	**Quantity sold per unit period.** *E.g. per week, month etc*	**Price per unit of a good.** *(In Ug. shs)*	**Number of traders from the selected wetland**
Charcoal stoves						
Clay pots						
Clay bricks						

3. In the table below state the type of equipment or any other variable inputs (including capital), required in the marketing of the goods(s) sold, the amount of equipment or input used, the cost and the period in a year when the same equipment/input would serve you before being replaced.

4. In the table below, state any other trading costs required to trade a unit of the good per month.

Type of equipment input (including capital.	**Numbers required to trade one unit of a good.**	**Cost per kg/ bundle/tin**	**Life time of equipment before being replaced**

5. State the number of months in a year when you are actively involved in trading the above good………………………

END

Thank You

Appendix B3: Questionnaire for the valuation of water purification service by wetlands in the KMC

To be filled by the financial manager of the selected water treatment plant.

Introduction

I am a student of Nelson Mandela University of South Africa, carrying out a study titled The Economic and Ecological Trade-offs of Wetland Conversion for DPs, a Case of the Kampala – Mukono Corridor. In this study, I am required to enumerate the economic value of water purification service rendered by wetlands, which is reflected by the total cost of providing artificial water treatment facilities. Your treatment plant has been selected in this exercise to provide relevant information relating to this cost. Please kindly respond for the information gathered will be used for academic purposes only and will be treated with utmost confidentiality.

Instructions:

Fill in what applies to you.

Section A

Background information

(a) Name (optional) ………………………………………………………

(b) Age ……………………………………………………………………

(c) Sex: Male ☐ Female ☐

Designation …………………………………………………………

Name of treatment plant …………………………………………….

1. State the average water requirements in litres per household or per person in a day

   i) Per person /day………………………………. (Litres)

   ii) Per household / day ………………………. (Litres)

2. What is the average amount of water (in litres/day) pumped by this station to the users?

………………………………………………………………………..……………

3. How many people are served by this plant?

………………………………………………...…

4. Table (1) below seeks to find out the costs incurred in pumping and storage of water at this station.

a) Please indicate in the table below, the equipment required in pumping and storage of water, the unit cost/equipment, life time of the equipment and other variable inputs like fuel attendants, etc

Equipment	**Unit cost**	**Life time of equipment**

Table 2 seeks to find out the water treatment costs.

Please state the requirements used in treating water, average amounts of these requirements used per month and the total costs incurred.

Requirements	**Amounts used per Month**	**Total cost incurred (***In UGX)*

Thank You

Appendix B4: Questionnaire for valuation of flood control

(Protection of infrastructure (roads), crop gardens and household dwelling from floods.)

Instructions;

Fill in what applies to you or tick the correct response.

Background information;

(i) Name (optional) …………………………… (ii) Age …………………….

(iii) Sex male ☐ (iv) Female ☐ (v) site………………………

State the number of months when you experience floods per year.

………………………………………………………………………………………

How much would it cost you to protect your dwelling (house) from floods in a rainy month?

……………………………………………………………………………………….

How much can it cost you to protect 50 meters of road from floods?

…………………………………………………………………………………………

How much would it cost you to protect a plot of 100 x 50ft. area of farmland from floods?

………………………………………………………………………………………

END

Thank You

Appendix B5: Interview guide for the FGD with consumers and producers of wetland goods

1. Do you consume any of the following wetland goods i.e. water, clay, thatch and crops like yams sweet potatoes?

2. If so, state in units (i.e. Kgs, sacks, bundles etc.) the average quantities of each selected good consumed per day week or month (consider the time frame that suits you)

3. What is the minimum price (market price) you would be willing to pay for a unit of each selected good here in?

4. State the maximum price that you would be will to pay for a particular unit of each of the selected goods

5. State the type and amount of equipment or any other variable inputs used in the harvesting of the above goods (e.g. per week, month or per year), the cost of each equipment or any other input, and the period in a year that the same equipment or any other input would serve you before being replaced.

6. Rank the importance of wetlands to your livelihood.

Very high ☐ average ☐ low ☐ very low ☐

7. Rank the importance of DPs to wetland degradation

Very high ☐ average ☐ low ☐ very low ☐

8. Are you aware of wetland economic values in your area?

Yes………. No…………

END

Appendix B 6: Observation schedule for wetland goods, products and activities carried out in the wetlands

1. Do the selected wetlands produce any of the following goods; water, clay, thatch, and crops like yams, sweet potatoes? …………………...

2. If so, are these goods traded in the open market? ………………………………………

3. Are there potential consumers for the selected goods or products made from them?

………………………………………………………………………………………………..

4. Do the selected wetlands reflect similar goods and services? ………………………………

5. Are there price tags reflected on the wetland goods/products produced?

………………………………………………………………………………………………..

6. If so, which are these? ………………………………………………………………………..

7. How much of a particular good is produced or harvested per day?

………………………………………………………………………………………………..

8. What are the units of production of each selected good? ……………………………………

9. What type and amount of equipment are evidently used in the production or harvesting of the above selected wetlands goods?

…………………………………………………………………………………………………

10. How many labourers are present on site during the production of the selected wetland good?

…………………………………………………………………………………………………

11. Is there evidence of any of these activities in the areas of study, i.e.; Brick making, growing of sweet potatoes and yams, making of mats from papyrus, use of thatch in building, pot making charcoal stove making?

………………………………………………………………………………..

Appendix B 7: Criteria for selecting villages to provide valuation information

Three villages adjacent to these wetlands were considered and the criteria for their selection were:

1. Villages / local councils adjacent to the selected wetlands.
2. Local councils / villages where the selected wetland goods and services generated significant local benefits.
3. Villages where more households, that certainly portrayed more people directly or indirectly carrying out economic activities in the selected wetland, were envisaged.
4. Where the harvesting or sale of wetland goods was particularly significant or widespread.

Appendix C: Major units of analysis that formed a major focus for this study

Wetland goods	**Units of analysis considered**
1. Water	• Households
2. Clay	• Brick makers • Clay miners • Pot makers • Charcoal stove producers
3. Grass thatch	• Thatch traders that supply to brick makers
4. Crops (yams and sweet potatoes)	• Farmers of the selected crops
Wetland services 1. Flood control 2. Water purification	• Households and farmers • Attendants of artificial water purification plants

Appendix D: Specified data required to calculate economic values of wetland benefits in the KMC

Wetland benefit;	Valuation method;	Indicators of economic value;	Data requirements per unit of a good, by unit of time;
			For primary harvesters -Amount harvested -Proportion sold -Price sold at -Labor requirements for harvesting -Type amount of equipment / inputs used -Cost of equipment/inputs -Life time of equipment -For some good (crops) amount of land area to produce a given amount of good. **For artisans, households and traders;** Amount produced. -Proportion sold. -Price sold at. -Labor requirements. -Equipment used (type). -Time spent selling products. -Transport costs of goods for sale. -Other market costs (license, transportation costs. -Cost equipment/inputs. -Life time of equipment
Crops (sweet potatoes and yams)	Market price of selected crops.	-Net value -Net cash income from selected crops. -Returns to labor -Subsistence consumption value of selected crops.	
Clay	Market price of raw clay, clay bricks, pots, clay charcoal stoves.	-Net value -Net cash income of clay bricks, pots and charcoal stoves. -Returns to labor -Returns to land (licenses) Subsistence consumption	
Grass thatch	Market price of grass thatch	-Net value -Net cash income to traders. -Returns to labor -Returns to land(licenses)	
Water	Market price of water	-Net cash income to water. -Subsistence consumption value -Returns to labor	
Water purification	Replacement cost	Gross value	- Cost of providing artificial water treatment facilities
Flood Control	Contingent gross value Approach	Gross value	-Cost of protecting households, Infrastructure, crops from floods

Appendix E: Selected indicators of economic value and their expression

Economic indicator	How calculated
- Gross value	Units harvested, used, produced, or sold X price per unit.
- Net value	Gross value – cost of inputs.
- Gross cash income	Units sold X price per unit.
- Net cash income	Gross cash income – cost of inputs.
- Subsistence consumption value	Gross value - gross cash income or units used at home X price per unit.
- Gross /net / cash returns to land	Value ÷ hectares of land from which goods harvested/produced / sold.
- Gross /net/cash returns to labor	Value ÷ no. of days required to harvest, use, produce or sell goods.
- Total net economic value	Net economic value of wetland goods + Net economic value of wetland services

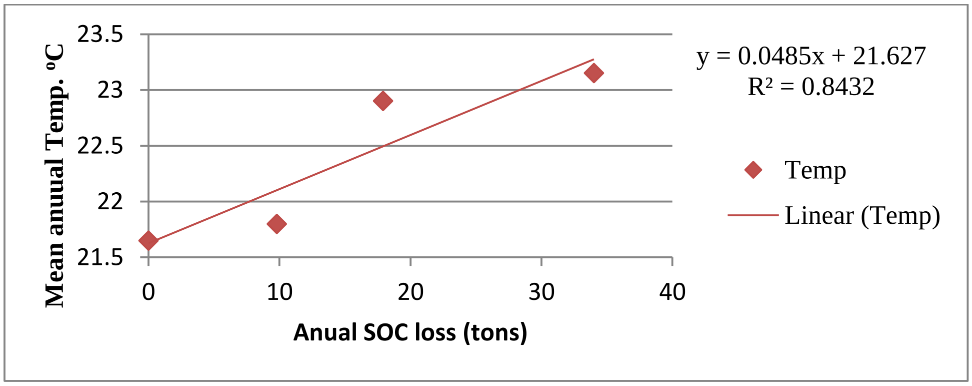
Appendix F: Mean annual rainfall and temperature data for the KMC between 1974 and 2013

Year	Annual Rainfall Totals (mm)	Annual Mean Maximum Temperature (ºC)	Annual Mean Minimum Temperature (ºC)
1974	1063.6	25.9	17.4
1975	995.4	26.8	18.0
1976	1179.5	26.5	17.8
1977	938.9	26.3	18.0
1978	1165.9	26.1	17.8
1979	1092.0	24.5	17.7
1980	1051.0	25.8	17.7
1981	1119.6	25.9	17.6
1982	992.7	25.9	17.6
1983	782.9	25.9	17.6
1984	1191.0	26.0	17.6
1985	1713.4	26.0	17.6
1986	1237.1	26.0	17.6
1987	866.5	25.8	17.7
1988	1393.8	27.2	17.7
1989	1420.2	27.6	17.7
1990	1095.3	26.6	17.7
1991	1396.4	26.2	17.8

Year	Annual Rainfall Totals (mm)	Annual Mean Maximum Temperature (ºC)	Annual Mean Minimum Temperature (ºC)
1992	1062.8	26.3	17.9
1993	1137.2	29.2	17.7
1994	1390.0	28.3	17.7
1995	1549.6	28.3	17.6
1996	1487.2	27.9	16.8
1997	1575.8	28.0	16.6
1998	1366.5	28.3	17.6
1999	1687.8	26.9	17.5
2000	1086.2	27.3	17.7
2001	1490.8	26.9	17.3
2002	1436.0	27.4	17.2
2003	1414.9	27.7	17.8
2004	1456.0	27.7	18.5
2005	1170.5	28.9	18.7
2006	1419.5	27.4	18.4
2007	1585.9	27.5	18.3
2008	1365.0	27.2	16.8
2009	1116.4	28.0	17.9
2010	1261.7	28.0	17.6
2011	1576.9	27.8	16.9
2012	1167.2	27.9	16.5
2013	1392.7	28.1	18.2

Source: Uganda National Meteorological Authority (UNMA), Postel Building, 10th floor, Clement hill Road, Kampala.

Appendix G: Relationship between SOC loss and atmospheric temperature in the KMC wetlands between 1974 to 2013



Appendix H: Data for Economic valuation of the KMC wetland goods and services

WETLAND GOODS

NB. Values in UGX not converted to USD. Conversions later made at USD buying at 2500UGX

The net value of yam production in the KMC wetlands

1.Subsistence consumption value of yams	Mean
Average number of tins(yams) harvested per month	25.5781
Average Number of harvests per year in terms (of months)	2.43
Average Number of tins harvested per year by a single farmer	52.6296
Average Number of tins consumed per year by a single farmer	46.3077
Average price per tin	3969.72
Annual gross consumption value of yams to consumer	183,828.6
Average total costs incurred in the production of yams/year	6,814.6908
Net subsistence consumption value of yam consumption per farmer	177,013.91
Number of yam producers	28
Estimated Annual subsistence consumption value accruing to the yam producers in the wetlands	4,956,389.54
2. Value added through the sale of yams	
Average Value added to yams after selling	428.4404
Proportion of yams sold per year to a farmer (tins)	6.32
Value added to yams through trading per year/ farmer	2,707.5
Number of yam traders	12
Estimated value added through the sale of yams accruing to yam traders	32,490
Estimated total economic value of yams in the selected wetlands of the Kampala-Mukono corridor per year	**4,988,879.54 UGX**

The net value of sweet potato production in the KMC wetlands

1. Subsistence consumption value of sweet potatoes	Mean
Average number of tins (sweet potatoes) harvested per month	25.0286
Average Number of harvests per year in terms (of months)	4.43
Average Number of tins harvested per year by a single farmer	88.3524
Average Number of tins consumed per year by a single farmer	80.0000

Subsistence consumption value of sweet potatoes (continued)	Mean
Average price per tin	2,803.57
Annual gross consumption value of sweet potatoes to consumer	224,285.6
Average total costs incurred in the production of sweet potatoes / year	6,814.6908
Net subsistence consumption value of sweet potatoes consumption per farmer	217,470.9092
Number of sweet potatoes producers	24
Estimated Annual subsistence consumption value accruing to the yam producers in the wetlands	5,219,301.8
2. Value added through the sale of sweet potatoes	
Average Value added to sweet potatoes after selling	682.1429
Proportion of sweet potatoes sold per year to a farmer (tins)	8.3524
Value added to sweet potatoes through trading per year/ farmer	5,697.5
Number of sweet potatoes traders	17
Estimated value added through the sale of yams accruing to yam traders	96,857.5
Estimated total economic value of sweet potatoes in the selected wetlands of the Kampala-Mukono Corridor per year	**5,316,159.3 UGX**

The net value of grass thatch in the KMC wetlands

Value of thatch harvesting used in brick making	Mean
Average price of a thatch bundle	1,406.707
Average number of thatch bundles harvested per year per harvester	89.62651
Gross revenue incurred in harvesting thatch per harvester per year	126,078.24
Average cost in harvesting a thatch bundle per harvester	808
Average costs incurred in harvesting thatch/year per harvester	72,380.9524
Net annual revenue accruing to the harvesting of thatch per thatch harvester	53,697.2
Number of thatch harvesters in the selected wetlands	140
Estimated Net Annual value accruing to the number of thatch harvesters in the selected wetlands	**7,517,613.3 UGX**

The net value of clay extraction in the KMC wetlands

Value of clay extraction	Mean
Average number of clay heaps harvested per month/harvester	44.1045
Average number of harvests per year in terms (of months)	7.57
Average number of clay heaps harvested per year	334.2537
Average Price per clay heap	9,974.63
Gross revenue incurred in the extraction of clay per harvester per year	3,334,056.25
Average costs incurred in extracting clay/year	31225.6590

Value of clay extraction (Continued)	Mean
Net annual revenue accruing to the extraction of clay per extractor in brick making	3,302,830.55
Number of clay extractors in the selected wetlands	140
Estimated Annual Net value accruing to the number of clay extractors in the selected wetlands	**462,396,276.8 UGX**

Value added to clay through brick making in the KMC wetlands

Value added to clay through brick making	Mean
Average number of bricks sold per year per harvester	53,769.02
Average price of a brick	201.00
Average cost per brick	17.58074
Net value per brick	183.4193
Estimated gross revenue accruing to the average number of bricks sold in a year per brick maker	10,807,569
Estimated total cost accruing to the sale of bricks per year per brick maker	945,299
Estimated net revenue accruing to the average number of bricks sold in a year per brick maker	9,862,274
Number of brick makers in the selected wetlands	140
Estimated Annual Net value accruing to the number of clay brick makers in the selected wetlands	**1,380,718,363 UGX**

Estimated net value added to clay through pot making in the KMC wetlands

Value added to clay through pot making	**Mean**
Average number of pots sold in a year per pot maker	284.6000
Average price per unit sold	18,964
Average number of months for which pot making is done in a year	7.20
Gross revenue accruing to the sale of pots in a year per pot maker	5,397,154.4
Average total costs incurred in the sale of pots per pot maker, per year	489,117
Estimated net revenue accruing to the sale of pots in a year per pot maker	4,908,037.4
Number of pot makers in the selected wetlands	4
Estimated Annual Net value accruing to the number of clay pot makers in the selected wetlands	**19,632,149.6 UGX**

Net Value added to clay through charcoal stove making in the KMC wetland

Value added to clay through charcoal stove making	**Mean**
Average number of charcoal stoves sold in a year per charcoal stove maker	489.0000
Average price per unit sold	2,235.0000
Average number of months for which charcoal stove making is done in a year	9.31
Gross revenue accruing to the sale of charcoal stoves in a year per charcoal stove maker	1,092,915
Average total costs incurred in the sale of charcoal stoves per charcoal stove maker, per year	628,937

Value added to clay through charcoal stove making (Continued)	Mean
Estimated net revenue accruing to the sale of charcoal stoves in a year per pot maker	463,978
Number of charcoal stove makers in the selected wetlands	7
Estimated Annual Net value accruing to the number of clay charcoal stove makers in the selected wetlands	**3,247,846 UGX**

The net subsistence consumption value of wetlands water recharge / supply to households in the KMC

Subsistence consumption value of water	**Mean**
Average No of water (jericans) consumed by a household in a month	58.3347
Number of harvests per year (in terms of months)	7.88
Average No of jericans consumed in a year	464.2612
Average price of a water jerican	166.67
Gross subsistence consumption value of water to a household per year	77,378.4142
Average costs incurred on jericans per household /year	5609.9291
Net subsistence consumption value of water per house hold per year	71,768.4851
Subsistence consumption value of water	**Mean**
Number of hose holds occupied by the selected wetlands	2,234
Number of households consuming water from the selected wetlands	92% = 2,055.28
Estimated annual net subsistence consumption value of water in the selected wetlands	**147,504,188.2 UGX**

WETLAND SERVICES

Economic value of wetlands flood attenuation to gardens in the KMC

Economic value of protecting upstream gardens from floods	**Mean**
Average size of gardens per household/ farmer in the selected wetlands	100 x 50ft
Average Number of trenches dug to protect a garden of 100 x 50ft from floods	3.4290
Average cost of protecting a garden of 100 x 50ft from floods	19,345.00
Average number of rain fall seasons per year	2.00
Estimated annual cost of protecting a garden of 100 x 50ft from floods	38,690
Average number of gardens on subsistence farmers with above size of gardens (based on sweet potatoes=24 and yam producers=28)	52
Estimated annual economic value of protecting upstream gardens accruing to the 52 farmers / households in the selected wetlands	**2,011,880 UGX**

Economic value of wetlands flood attenuation to motorized feeder roads in the KMC

Economic value of protecting motor truck roads from floods	**Mean**
Estimated Distance (km) of motorized feeder roads in the study area	56.6 kms
1 km (1000m) is equivalent to 20 roads with a linear distance of50 meters	20.0
56.6 Kms of motorized feeder roads in the study area will be equivalent to	56,600 meters
56,600meters (56.6km) of roads is equivalent to 1,132 meters of roads with linear distance of 50 meters	1,132 meters
Average annual cost of protecting a 50-meter motorized truck road from floods through constructing road side trenches	626,745.310
Estimated annual economic value of protecting 1,132 motorized road linear distances with 50m in the selected wetlands from floods	**709,475,690.9 UGX**

Economic value of protecting dwellings from floods in the KMC

Economic value of protecting dwellings adjacent the selected wetlands from floods	**Mean**
Average cost of protecting a dwelling from floods per house hold year	301,294.2
Estimated number of dwellings (based on number of households) in the selected wetlands	2,234
Estimated economic value of protecting dwellings from floods	**673,091,224.8 UGX**

Economic value of wetlands' water purification in the KMC

Total population of villages dependent on water recharged by wetlands (Population & Housing Census 2002)	9,171
92% of the population (8,437.3) depend on water recharged by selected wetlands	92.00
Number of villages dependent on water recharged by selected wetlands	7
Average population per village	1,205
Per capita consumption of water in liters	18.984
Average water requirement in liters per day/village	22,875.72

1. Equipment for Pumping/storage	**Unit cost**	**Number required**	**Total cost**	**Life time in years**	**Cost per year**
Motor pump	60,000,000	1.0	60,000,000	10.0	6,000,000.0
LIPH PUMP	320,000	1.0	320,000	10.0	32,000.0
FUEL (litters) for the pumps (Diesel)	3,100	150.0 liters (per day)	465,000		167,400,000
Stand by Generator	6,000,000	1.0	6,000,000	10.0	600,000.0
Fuel for the generator for at least one day of load shedding/week	3,100	25 liters Per day of load shedding	77,500		3,720,000
Reservoir tank	80,000,000	1.0	80,000,000	10.0	8,000,000.0
Attendants (Salaries) monthly	400,000	2.0	800,000		9600,000
Askari (Salaries) monthly	150,000	2.0	300,000		3,600,000.0
Subtotal for the required equipment at the UCU Plant for 4500 users 198,952,000Ugshs					
ii. Water treatment costs					
ALUM	2000.0	30.0	60,000 per day		21,600,000
CHLORINE	6500.0	0.5	3,250 per day		1,170,000
Annual water treatment cost at UCU plant for 4500 users					**22,770,000**
Total costs (treatment & equipment) per year					**221,722,000**
Number of water purification plants (UCU) type required for (8,437.3) users **2 purification plants**					
Estimated Total annual replacement cost of water purification and treatment for 8,437.3 Users of un safe water in the KMC 443,444,000 UGX					

Appendix I: SOC field data

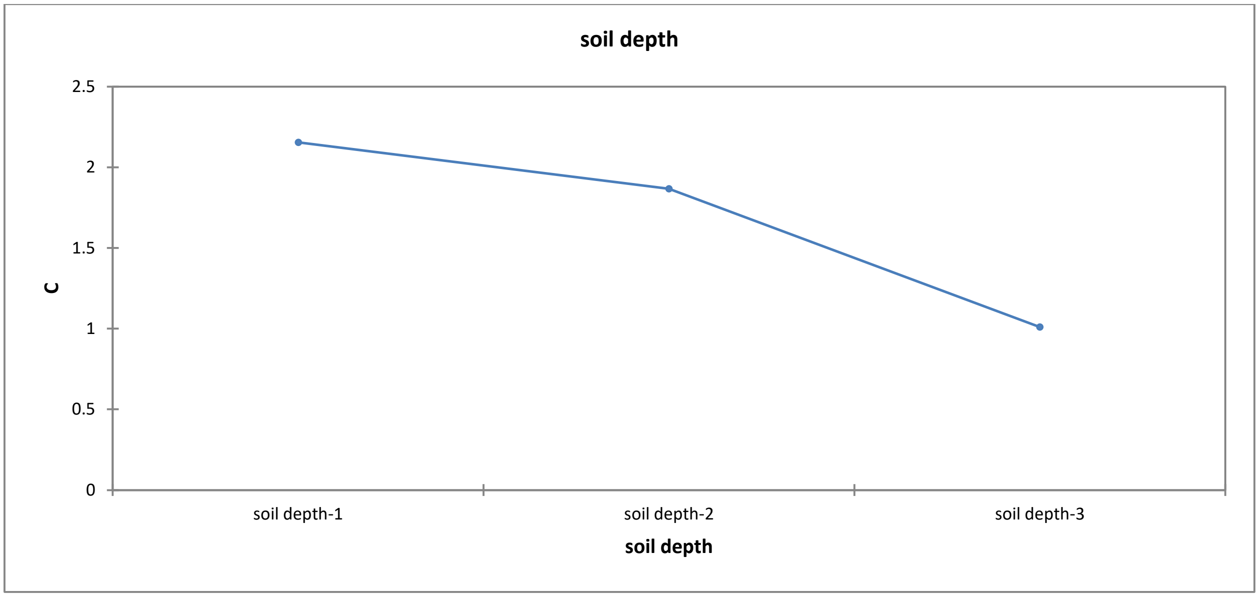
SOC descriptive

Wetland type	SOC /soil sample	TSOC	Average	STDV	Standard error
1	0.517				
1	1.207				
1	0.344				
1	0.111				
1	1.207				
1	0.689				
1	0.862				
1	1.034				
1	0.689	6.66	0.74	0.3783	0.1261
2	3.448		0		0
2	4.812		0		0
2	4.828		0		0
2	1.376		0		0
2	0.972		0		0
2	1.034		0		0
2	1.034		0		0
2	1.458		0		0
2	1.244	20.206	2.245111	1.644639	0.548213
3	1.034		0		0
3	1.207		0		0
3	1.723		0		0
3	0.508		0		0
3	1.207		0		0
3	1.723		0		0
3	0.77		0		0
3	1.034		0		0
3	1.178	5.948	0.660889	0.394856	0.131619
4	3.805		0		0
4	1.724		0		0
4	2.758		0		0
4	4.137		0		0
4	0.862		0		0
4	2.499		0		0

Wetland type	**SOC /soil sample**	**TSOC**	**Average**	**STDV**	**Standard error**
4	0.517		0		0
4	0.517		0		0
4	0.517	17.336	1.926222	1.439117	0.479706
5	2.758		0		0
5	3.793		0		0
5	3.448		0		0
5	3.448		0		0
5	3.193		0		0
5	3.793		0		0
5	3.361		0		0
5	2.585		0		0
5	1.034	27.413	3.045889	0.859045	0.286348
6	3.34		0		0
6	2.413		0		0
6	2.413		0		0
6	0.111		0		0
6	6.473		0		0
6	1.551		0		0
6	0.862		0		0
6	0.342		0		0
6	0.772	18.277	2.030778	1.982986	0.660995
7	1.203		0		0
7	2.586		0		0
7	2.413		0		0
7	3.792		0		0
7	1.724		0		0
7	0.503		0		0
7	0.689		0		0
7	2.068		0		0
7	0.517	15.495	1.721667	1.1126	0.370867

Key: 1 – Wetlands converted to industry, 2 – Papyrus swamp marsh and bog, 3 – Wetlands converted to settlement, 4 – palms and thickets, 5 – Wetlands converted to agriculture, 6 Forest swamps

Mean C storage for different soil depths



Unit SOC (tons) per hectare

Class name	**C /sampled wetland class (g)C/900g soil)**	**Wetland Area (ha) by 2013**	**TTC(g) per wetland class area by 2013**	**Average C in ton\ha by wetland class**	**Standard error tones / ha**
Wetlands converted to Industrial	6.66	2,370	7,892,100	0.00333	0.0000001
Papyrus swamp Marsh & bog	10.103	3,360	16,973,040	0.0100892	0.0000003
Wetlands converted to settlement	5.948	3,280	9,754,720	0.002974	0.0000001
Palms & thickets	17.336	2,050	17,769,400	0.0086341	0.0000005
Wetlands converted to agriculture	27.413	1,010	13,843,565	0.0137065	0.0000003
Forest swamps	18.277	0.0	0.0	0.00912902824	0.0000000

Appendix J: Hydrological assessment field data

Wetland COD	Sample	TP (µg/L)	TN (µg/L)	TDS (ppm)	TSS (mg/L)	speed m/s	widith	width cm	waterlevel cm	surface	flow	load kg	Mean bed load
1	1	30.956	40.6455	80	1.18	0.5	6	180	11	1980	990	1168.2	980.4
1	2	66.272	45.129	76	1.2	0.5	5.5	165	11	1815	907.5	1089	
1	3	57.225	43.071	81	1.14	0.5	4	120	10	1200	600	684	
2	1	5.123	50.6415	88	0.88	0.6	8	240	14	3360	2016	1774.08	3466.4
2	2	5.45	40.9395	84	0.8	0.8	7	210	32	6720	5376	4300.8	
2	3	4.142	47.922	82	0.84	0.4	5.5	165	78	12870	5148	4324.32	
3	1	5.232	28.4445	65	0.82	0.6	5	150	15	2250	1350	1107	1342.56
3	2	5.232	54.243	66	0.88	0.6	7	210	16	3360	2016	1774.08	
3	3	4.36	52.4055	65	0.78	0.7	5	150	14	2100	1470	1146.6	
4	1	2.834	27.4155	97	0.6	0.5	11	330	25	8250	4125	2475	2940.68
4	2	3.379	20.286	96	0.88	0.7	10	300	29	8700	6090	5359.2	
4	3	4.796	28.224	96	0.98	0.2	8	240	21	5040	1008	987.84	
5	1	2.289	25.0635	97	0.51	0.3	8	240	38	9120	2736	1395.36	1236.336
5	2	1.962	32.4135	100	0.32	0.9	3.5	105	40	4200	3780	1209.6	
5	3	3.488	23.814	82	0.33	0.8	3.4	102	41	4182	3345.6	1104.048	
6	1	3.597	33.81	104	1.04	0.9	3.5	105	34	3570	3213	3341.52	3600.36
6	2	3.379	39.69	104	0.22	0.1	7.5	225	44	9900	990	217.8	
6	3	4.905	22.5645	104	0.12	0.3	6	180	19	3420	1026	123.12	

Correlations of the continuous variable Wetland type with the selected quantitative variables (Pearson's Phi):

Variable labels	Correlation coefficient	Test value	p-values
TDS (ppm)	0.676	3.341	0.002
TSS (mg/L)	-0.660	3.184	0.003
TP (µg/L)	-0.640	3.001	0.004
TN (µg/L)	-0.606	2.712	0.008
water level cm	0.314	0.850	0.204
surface	0.277	0.637	0.266
flow	0.133	-0.257	0.600
speed m/s	0.033	-1.307	0.895
load kg	0.029	-1.393	0.909
width cm	0.021	-1.597	0.935

Appendix K: Transformation table for the analysis of gains and losses for different wetland cover types (1974 - 2013) in KMC

Wetland type	**1986 Area (ha)**	**2006 Area (ha)**	**2013 Area (ha)**
FS	-55.5	-3	0
PSM&B	-5.7	-1	-1
P&T	40	-6	-18
AG	8.4	-3	2.6
IND	4	1.1	12.9
SETT	9	11	5
OPEN WATER	0.5	-1	-0.5

Key: AG – Wetlands converted to agriculture, IND – Wetlands converted to industrial estates, FS- Forest Swamp, P&T – Palms and thickets, PSM&B – Papyrus swamp marsh and bog, SETT – Wetlands converted to settlement, OPW – Open Water

Appendix L: Wetland cover classes as adopted by NBS (with some modifications)

Wetland category Cover class	**Wetland category Cover class**
Seasonal	Broad-leaved woodlots
	Swamp forest
	Bushes and Thickets
	Grassland
	Pastures
	Farmland
	Commercial farmland
	Built-up area
Permanent	Woodlots
	Swamp forest
	Bushes and Thickets
	Grassland
	Pasture
	Cyprus and Typha (Papyrus and other sedges)
	Reeds
	Floats
	Farmland
	Commercial farmland
	Built-up area

Appendix M: Sample size determination for wetland valuation of goods and services in the selected wetlands

WETLANDS	Namanve	N	S	Lwajjali	N	S	Nakiyanja	N	S	Total Size
GOODS:										
Clay/ harvesters/ brick makers		42	36		40	36		58	48	140
Thatch harvesters		42	36		40	36		58	48	140
Crops:										
Sweet potatoes		12	10		8	8		4	4	24
Yams		9	9		8	8		11	10	27
Households dependent on water from wetlands		13	12		32	29		36	33	74
Services:										
Flood to dwellings / Infrastructure		13	12		32	29		36	33	`
Gardens (based on yams farmers)		9	9		8	8		11	10	27
Water purification				Attendant from UCU plant. Provided information required to calculate the replacement cost water purification in selected wetlands. 1						
Pot makers in the region					4	4				4

WETLANDS	Namanve	N	S	Lwajjali	N	S	Nakiyanja	N	S	Total Size
Charcoal stove makers					7	7				7
Total number of sampled respondents			**124**			166			**186**	

Computations based on Krejcie and Morgan, (1970). Determining Sample Size for Research Activities

Key: "N" is population size

"S" is sample size.

Source: *Adopted from National Biomass Wetland Classification (2003)*

Appendix N: Divergence metrics (separability) for the classified wetland use/cover types

Year	Wetland types	Separability divergence metrics
1974	Water body	(1.95054144 - 1.94034504)
	Island	(2.00000000 - 2.00000000)
	Papyrus marsh and bog	(1.96950159 - 1.98044761)
	Forest swamp	(1.99999889 - 2.00000000)
1986	Water body	(2.00000000 - 2.00000000)
	Island	(2.00000000 - 2.00000000)
	Wetlands converted to industrial use	(1.99999971 - 2.00000000)
	Wetlands converted to settlement	(1.99823105 - 2.00000000)
	Wetlands converted to agriculture use	(1.99999810 - 2.00000000)
	Palms and thickets	(2.00000000 - 2.00000000)
	Papyrus swamp marsh and bog	(1.99999993 - 2.00000000)

Year	**Wetland types**	**Separability divergence metrics**
2006	Water body	(2.00000000 - 2.00000000)
	Island	(1.99998769 - 2.00000000)
	Wetlands converted to industrial use	(1.953535320 - 2.0000000)
	Wetlands converted to settlement	(2.00000000 - 2.00000000)
	Wetlands converted to agriculture use	(1.89736362 - 1.98643353)
	Palms and thickets	(2.00000000 - 2.00000000)
	Papyrus swamp marsh and bog	(1.96734632 - 2.00000000)
2013	Water body	(2.00000000 - 2.00000000)
	Island	(1.89855604 - 1.99999646)
	Wetlands converted to industrial use	(1.89855604 - 1.99999646)
	Wetlands converted to settlement	(1.99546608 - 1.99837885)
	Wetlands converted to agriculture use	(1.79196905 - 1.88294691)
	Palms and thickets	(1.99435284 - 1.99999998)
	Papyrus swamp marsh and bog	(1.96905500 - 2.00000000)