SPATIO-TEMPORAL CHANGES IN LAND COVER IN RESPONSE TO ANTHROPOGENIC AND HYDRODYNAMIC FACTORS IN NYANDO WETLAND, KENYA

OKOTTO-OKOTTO JOSEPH

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DECLARATION AND RECOMMENDATION

Declaration by the Candidate:

This thesis is my original work and has not, wholly or partially, been presented for an award of a degree in any other University.

Signature: ………………………………… Date: ………………………………

Joseph Okotto-Okotto (NM11/1999/07)

Recommendation by the Supervisors:

This thesis is the candidate’s work and has been prepared with our guidance and assistance. It is submitted with our approval as University supervisors.

Signature: ………………………………… Date: ………………………………

Dr. Gilbert Obati Obwoyere
Faculty of Environment and Resources Development
Department of Natural Resources Management
Egerton University

Signature: ………………………………… Date: ………………………………

Dr. John Momanyi Mironga
Faculty of Environment and Resources Development
Department of Geography
Egerton University

Signature: ………………………………… Date: ………………………………

Prof. Phillip Okoth Raburu
University of Eldoret
School of Natural Resources Management
Department of Fisheries and Aquatic Sciences

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"I am a slow walker, but I never walk back".

Abraham Lincoln (1809-1865)

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"*At times, our own light goes out and is rekindled by a spark from another person. Each of us has a cause to think with deep gratitude of those who have lighted the flame within us*."

"Albert Schweitzer"

ABSTRACT

In the last three decades, wetlands have received much attention worldwide due to their declining coverage and spatial distribution with more than 50% lost since the 1950s. Like other wetlands worldwide, Nyando Wetland, the second largest lacustrine wetland ecosystem on the Kenyan shores of Lake Victoria, is facing a major threat of degradation from both the fluctuations of Lake Victoria water levels and anthropogenic factors operating in its neighbourhoods. This study was conducted to determine how the spatial and temporal changes in land use/cover in response to anthropogenic and hydrodynamic factors such as land use, human population growth and lake level changes affected the area covered by the wetland between 1984 and 2010. Remote sensing, ground-truthing, socio-ecological tools such as questionnaires, focus group discussion protocols and data analysis tools such as Geographical Information System, logistic, simple and multiple regression models were used to achieve the objectives of the study. The Driver-Pressure-State-Impact-Response model was used as a framework for analysis. Results showed that there is an increasing trend for small-scale agriculture (+58 ha/yr) against a decreasing trend for water area (-29 ha/yr) and a reduction by 31% of the area of Nyando Wetland over the study period. Population growth was found to indirectly but significantly (SSAg $p = 0.01$, $R^2 = 0.89$; RFTw $p = 0.01$, $R^2 = 0.80$) influence the decline in wetland area through agricultural activities. The receding shoreline had a significant ($p = 0.02$, $R^2 = 0.89$) influence on the spatial decline of the wetland. The study concludes that anthropogenic and hydrodynamic factors are significantly affecting the wetland and could compromise its ecological integrity. It is recommended that long-term health of the wetland should be contingent upon sound and effective ecotone zone planning and management. Thus integrated participatory and adaptive research should be conducted to stimulate quick responses and regenerative actions that could be used to restore and conserve the wetland ecosystem.

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LIST OF ACRONYMS AND ABBREVIATIONS

1HB04	Lake Level Gauging Station Code
AOI	Area of Interest
CVA	Change Vector Analysis
DPSIR	Driver-Pressure-State-Impact-Response
ECOLIVE	Ecology of Livelihoods
ENVI	Environment for Visualization of Images
ERDAS	Earth Resources Data Analysis System
ETM+	Enhanced Thematic Mapper
FAO	Food and Agricultural Organization
FCC	False Colour Composite
GCPs	Ground Control Points
GIS	Geographical Information Systems
IBA	Important Bird Areas
ICRAF	International Centre for Research in Agro Forestry (Currently- World Agro Forestry Centre)
JICA	Japan International Coorperation Agency
KNBS	Kenya National Bureau of Statistics
Landsat TM	Landsat Thematic Mapper
LBDA	Lake Basin Development Authority
LVBC	Lake Victoria Basin Commission.
MEMR	Ministry of Environment and Mineral Resources
NWWG	National Wetlands Working Group
OECD	Organization for Economic Co-operation and Development
OPGb	Open Grassland, Mixed Bushes with Exposed Bare Ground in Hectares.
RFTw	Rice Farms and Turbid Paddy Water Surfaces in Hectares
RMSE	Root Mean Square Error
SM	Soil Moisture Content

SPOT	French *Satellite Pour l'Observation de la Terre' (*English; Satellite for Observation of Earth")
SPOT HRV	Satellite Probatoired'Observation de la Terre (SPOT) High Resolution Visible
SPSS	Statistical Package for Social Sciences
SSAg	Small-Scale Agriculture
TOPEX/Poseidon	A joint satellite mission between the U.S. space agency (NASA) and the French space agency, CNES, to map ocean surface topography: **TOPEX** means the NASA-built Nadir pointing Radar Altimeter using C band (5.3 GHz) and Ku band (13.6 GHz) for measuring height above sea surface while **Poseidon** means the French CNES-built solid state Nadir pointing Radar Altimeter using Ku band (13.65 GHz)
NASA	National Aeronautics and Space Administration
CNES	Centre National D'études Spatiales (National Centre for Space Studies)
MGDR-B	The (Merged Geophysical Data Record-B) dataset containing altimeter and microwave radiometer data
U0	Unclassified
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
VIRED	Victoria Institute for Research on Environment and Development
WATr	Water (Area Covered by Lake Victoria within the Study Area Used in the Study as a Proxy for Shoreline Recession)
WGS	World Geodetic System
WTLa	Wetland Area

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Wetlands are ecotone systems between terrestrial and aquatic landscapes. They are among the most productive ecosystems of the earth (Dugan, 1993; Maltby, Hogan, Immiri, Tellam and van der Peijl, 1994; Mitsch and Gossellink, 2000). They have high potential for all season agricultural activity and provide both food and income as well as a wide range of ecosystem services for riparian communities (Millennium Ecosystem Assessment, 2005; Dobiesz, *et al.*, 2010; Kihwele, Mnaya, Meng'ataki, Birkett and Wolanski, 2012). Wetlands have been described as *"the kidneys of the landscape*" because of the functions they perform in the hydrological and chemical cycles (Barbier, Acreman and Knowler, 1997 and Dobiesz, *et al.*, 2010). They have also been called *"biological supermarkets*" because of the extensive food webs and rich biodiversity they support (Barbier, *et al*., 1997). Wetlands are therefore some of the most important ecosystems of the earth, but which are significantly endangered in the world today (Millennium Ecosystem Assessment, 2005).

In the last three decades, wetlands have received much attention worldwide due to the threats they are facing that are causing their rapid decline in coverage and spatial distribution. Threats posed by human activities have been blamed as a major cause of wetland decline and the resultant land degradation and loss of biodiversity. Since the 1950s, over 50% of worlds' wetlands have been lost and the trend of this decline must be curtailed if their role in the provision of ecosystem goods and services has to be maintained (Spiers, 1999; Dobiesz, *et al.,* 2010). Even as the number and spatial spread of wetlands continue to dwindle, it is feared, especially in the developing world, that some of these important ecosystems are fast disappearing or are already extinct without any documentation. Research activities that could generate the desired information and undertake documentation of these important ecosystemsare scarce (Hues and Hues, 1992; Spiers, 1999; Millennium Ecosystem Assessment, 2005). Accordingly, there is little knowledge on the linkages between human activities and the dynamics of wetland ecosystems.

In Africa for instance, the percentage of wetland area is uncertain but estimated to be between 1% and 16% of the total land area (Bullock, *et al.*, 1998). Although the exact extent of wetlands area in Kenya is unknown owing to lack of a detailed wetlands inventory at a localized scale and resolution, they are estimated to occupy about 3% to 4% of the land surface which is approximately 14,000 km^2. This figure fluctuates up to 6% during the rainy seasons (Kenya Wetlands Forum 2012; Republic of Kenya, 2013, Republic of Kenya, 2014). In the Lake Victoria basin where the study area is located, however, the wetlands that surround the lake are estimated to occupy about 535,453 hectares (LVBC, 2011). They thus cover an extensive area and support a wide range of economic activities that sustain a significant proportion of the population in the basin (Kairu, 2001).

Many plant and animal species found in the wetlands of the Lake Victoria basin are important sources of food, income and recreation for the local communities. The wetlands are biologically diverse and provide essential habitats for many species such as water birds, amphibians and wetland-dependent mammals such as hippopotamus and sitatunga. They are also important fish spawning grounds and major sources of livelihoods, many of which are important for the economic progress of the local communities. The wetlands also provide physical stability, critical water filtration functions and pollution abatement for Lake Victoria (LVBC, 2011). With a catchment population density of 170 persons per km^2 (Twesigye, Onywere, Getenga, Mwakalila and Nakiranda, 2011), approximately 30% (about 30-39 million people) of the Lake Victoria basin population largely draw their livelihoods from the wetlands or wetland related resources (Kairu, 2001; Dobiesz, *et al.*, 2010; Adero and Kiema, 2011; LVBC, 2011). However, like many other wetlands elsewhere, most of these wetlands are undergoing severe stress even as they stand out as very important ecosystems to the riparian communities (Kassenga, 1997; Kairu, 2001; Syphard and Garcia, 2001; Kipkemboi, 2006).

The Nyando Wetland, located at the mouth of River Nyando on the shores of Lake Victoria in Kisumu County, within the basin, which is the subject of this study is one of such wetlands. It is the second largest wetland in the Lake Victoria basin after Yala swamp (175 km^2) and by 1970, the wetland had an area of more than 90 km^2 (Hues and Hues, 1992; Khisa, *et al.*, 2013). During the last half of the century or so, this wetland and the livelihoods it supports, like many others in the basin, has become more and more threatened. The wetland's ecological integrity is jeopardized by the interactions between the ecosystem and increasing anthropogenic activities and Lake water level fluctuations (Ryan, 2007; Maitima, Olson, Mugatha, Mugisha and Mutie, 2010). These situations create multiple stresses leading to degradation and loss of the wetland (Davis, *et al.,* 2010).

In order to address this rapidly evolving scenario, a better understanding of interactions between the activities of riparian community and dynamics of wetland ecosystems at both spatial and temporal scales is needed (Kareri, 1992; Bronsveld, Chutrittanapan, Pattanakanok, Suwanwerakamtorn and Trakooldit, 1994; Odada, Ochola and Olago, 2009; Davis, *et al.*, 2010). Such an understanding will enable proper and better scientific planning, design and implementation of appropriate and sustained mitigation and management measures which are still scarce in the Nyando Wetland area (Kipkemboi, 2006; Owino and Ryan, 2007; Maitima, *et al*., 2010; Khisa, *et al*., 2013).

The major constraints in studying pristine wetland habitats are their inaccessibility and difficulty in navigating during physical examination. The use of remote sensing and Geographic Information Systems (GIS) when integrated with social-economic tools can provide better opportunities for data generation and prediction of future trends in interactions between wetland dynamics and human activities. Information generated from these techniques are valuable for monitoring, modeling, predicting, and determining land cover and land use changes as well as pressures on the wetland ecosystems and resources through human use (Kareri, 1992; Ozesmi and Bauer, 2002; Mironga, 2004; Liverman and Cuesta, 2008).

According to Ghirlanda, Enquist and Perc (2010), further research work should focus more on both the dynamics of resource consumption and the cultural evolution of beliefs that influence population growth and patterns of resource use. To determine such, large amounts of information are often required and it is necessary to integrate application of spatial renditions (mapping) and social research procedures. But the necessary research tools and procedures that integrate wetland dynamics and socio-economic situations for spatio-temporal description are still less well developed and applied. This study integrated some these tools such as Geographical Information Systems (GIS), Remote Sensing (RS) and socio-economic tools to address spatio-temporal links and factors driving ecological and human actions that are threatening the ecological integrity of Nyando Wetland. The aim is to generate data and information that can be used to design sustainable conservation and policy measures that could be used to restore and conserve Nyando wetland.

1.1.1 Statement of the Problem

Nyando Wetland is facing a major threat of degradation due to anthropogenic and hydrodynamic drivers, which could irreparably destroy the wetland, disrupt the ecological balance and negatively impact on the livelihood of the riparian communities. The natural landscape of this wetland is rapidly being converted to human uses; but the temporal and spatial dimensions of the conversions are still unclear (Ong and Orengo, 2002). Such uncertainty could lead to a total decimation and collapse of the entire Nyando Wetland ecosystem in the near future. Furthermore, human population change in the locations surrounding the wetland seem to be a critical driver to the observed wetland use and conversions. This trend is expected to continue. Notably, the characteristics of the population that drive these changes, even as the population itself increases, are yet to be clearly understood making it difficult to plan, design and implement sustainable management measures for the wetland. In addition, the Lake Victoria water level has also been fluctuating and receding over the last three decades. This has exposed large areas of wetland predisposing it to the danger of deleterious conversions by local communities. The extent and nature of wetland exposure by the fluctuation of the lake's water level, which may lead to rapid changes and destruction in the wetland, is also still a matter of conjecture. Studies that could generate scientific data and give insight into the linkages between community actions as the human population grows around the wetland, their decision making mechanisms in livelihood systems and other drivers of the wetland change such as the lake level fluctuation, are scarce. These studies are essential for designing sustainable management measures and such a scarcity could lead to irreversible destruction of Nyando Wetland.

1.2 Broad Objective

The broad objective of the study was to investigate spatio-temporal changes of land use/cover types caused by anthropogenic and hydrodynamic factors in Nyando Wetland so as to generate data and information that could be used to design conservation and policy measures to conserve the wetland.

1.2.1 Specific Objectives

The specific objectives were as follows:

1) To examine spatio-temporal land cover/use changes in Nyando Wetland between 1984 and 2010.
2) To examine the influence of human population growth on land cover /use in Nyando Wetland between 1984 and 2010.
3) To evaluate how the lake/water level variations influence land use decisions in the wetland between 1984 and 2010.

1.2.2 Hypotheses

H_{01}: There are no significant spatio-temporal changes in land use/cover types that can be attributed to changes in the size of Nyando Wetland.

H_{02}: There are no significant changes in human population growth that can be attributed to the changes in the size of Nyando Wetland.

H_{03}: Fluctuation in lake levels do not significantly contribute to changes in the size of Nyando Wetland leading to human encroachment.

1.3 Justification

For decades, the land cover/use in Nyando Wetland has continued to change but studies on the spatial magnitude and what influences the changes over time are scarce or lacking. This has resulted in limited knowledge on spatial and temporal changes taking place in and around the wetland. This situation also makes it difficult to understand the drivers and their characteristics necessary for the design of measures for the sustainable management of the wetland. The allegations that both human activities and Lake level changes are drivers of change in Nyando Wetland are yet to be fully investigated, analyzed and documented. Consequently, these changes continue unabated. This is likely to result in the degradation and destruction of the integrity of the wetland and could adversely reduce its ability to effectively perform ecological and livelihood functions.

Nyando Wetland is an important ecological filter for Lake Victoria besides being an important habitat of immense biodiversity. Its degradation could have far reaching impacts not only on the local communities but also other riparian communities sharing Lake Victoria as a resource in the East African Region. There is need for data and information that could help in the prioritization and design of intervention strategies to save, restore and manage the wetland for the present generation and posterity. For any restoration measures to be effective, it must be founded on sound knowledge of the past and present state of the wetland, the complex and dynamic interactions between its various biotic and abiotic components, and the key factors driving its decline (Azza, 2006). Many knowledge gaps still exist in these areas in Nyando Wetland making it difficult to arrive at the most critical interventions required for the various stages of restoration.

Previous studies have concentrated more on the impact of Lake level changes on fish catches, aquatic plants and organisms (Kairu, 2001; LVBC, 2006; Obiero, Raburu, Okeyo-Owuor and Raburu, 2012) with minimal attention to the interrelationships between Lake level changes, human population growth and the wetland ecosystem dynamics. In the past few decades however, sharp oscillatory changes in water levels have been occurring in Lake Victoria due to factors that are yet to be fully understood, a phenomenon that if combined with the increasing population pressure, could negatively affect lacustrine ecosystems such as Nyando Wetland. This study was therefore, aimed at generating scientific information that will contribute to better understanding of the current changes and the socio-ecological and hydro-dynamic drivers as embodied in Lake level changes to better inform the development of policy instruments and management plans for the wetland.

1.4 Scope and Limitations of the Study

The study covered a temporal extent of 26-years starting from March, 1984 to January, 2010 and a spatial extent of 9 administrative locations riparian to the wetland. The base year for the study was fixed at 1984 because the study utilized remote sensing approaches, which began delivering relatively good quality satellite images suitable for the purposes of the study at that time. In this regard, one of the most important limitations of the study was the availability of the required high resolution imagery. Although satellite images were available since the mid-1970s, the high resolution imageries that were most suitable for this kind of study such as SPOT-6 or SPOT-7 images (1.5 m Pan/Pan sharpened, 6.0 m resolution), recent coverage turned out to be quite expensive beyond the financial resources that were available for the study. Some good resolution imagery identified as the alternative data sources such as those of Landsat-5 TM and Landsat-6 Enhanced Thematic Mapper Plus ETM +, with image resolutions of 30 m in Multi-Spectral Scanner-MSS mode and 20 m - panchromatic mode were however, freely available from the United States Geological Society (USGS) website. The acquisition and availability of these images started in 1984. Consequently, the limitations were circumvented by accessing these images free from www.http/*landsat.usgs.gov/* and complementing them with aerial photographs covering parts of the study area. This was further supported by a slightly higher level of inputs from ancillary data sources implying more fieldwork and increased resource requirements for the study.

The other limitation was that the ideal result of image pre-processing is that all images after image pre-processing should appear as if they were acquired from the same sensor (Hall, Strebel and Nickeson, 1991) to increase interpretability and comparability of image data in a time series study such as the present one. The possibility of minor variations that may have existed between images acquired by different sensors at different dates of the year could be a concern for comparability and accuracy in the study. This limitation was overcome by securing images of the same season (dry) rather than the same dates since it was not possible to secure same date images across the study period. Same season spectral signatures were comparable and ideal for the purposes of the study, which aimed at patterns rather than specifics of species level mapping. Consequently, due to the limitation of spatial resolution of the Landsat products secured for the study and the heterogeneous nature of the environment of the study area, the mapping of cover types, especially vegetation related ones could therefore be carried out only at community level rather than at species level. While species level mapping could have provided much higher accuracies, it was possible to map at community level with reasonably comparable accuracies by integrating the results of image interpretation with ancillary data.

The highly dynamic nature of the basic population enumeration units such as sub-locations in the study area also limited the comparability of population data in the time series analysis to administrative locational units rather than at the basic enumeration units which could have resulted in higher accuracies. Finally, there might be some other relevant factors, which significantly influence the interactions between human populations, land use, lake levels and the Nyando Wetland. However, the discussion of other relevant factors was considered as being beyond the scope of this work. The study has limited its discussions to human population growth, land use through its proxies comprising various cover types and lake level fluctuations. The study has also covered the influence of these factors on the area covered by Nyando Wetland over the study period.

1.5 Definition of Key Terms

Anthropogenic; A variant whose character relates to or results from the influence of human beings on the environment

Classification; an abstract of representing the situation in the field using well-defined diagnostic criteria to order or arrange objects into groups or sets on the basis of their relationships.

Digital signature; a unique spectral response of each object on the earth's surface to the electromagnetic energy

Driver; any natural or human-induced factor that causes a change in a system

Ecosystem; a community of living organisms in conjunction with the nonliving components of their environment (things like air, water and mineral soil), interacting as a system

Hydrodynamic; the motions and actions of water bodies as influenced by forces from within and without it

Image classification; the process of extracting information classes from a multiband raster image by grouping all pixels in the image into one of the several land cover classes, or "themes" on the basis of their digital signature similarities.

Image resolution: description of the level of detail an image holds.

Kappa coefficient; an index of the agreement between two images ranging from 0 to +/-1 where 1 = full agreement (images are identical, no change), -1 = full disagreement (the images are opposite, complete transformation in a consistent manner), 0 - no correlation (change is random).

Land cover; the observed physical or biological material cover on the earth's surface including vegetation of various types such as papyrus or grassland, water or bare soil.

Land use; the expression of man's management of various ecosystems for the welfare of human populations or the human activity that occurs on land such as agriculture or grazing.

Mixel; expresses the mixed nature of the contents of the smallest unit area or cell on an image whose size is determined by the aperture of the source or the receiving optics of the sensing system.

Overall accuracy; percentage of correctly classified points from the field visited set.

Photomorphic regions; image segments or areas with similar properties of size, shape, tone/colour, texture and pattern or areas of relatively uniform tone and texture on an image

Pixel; smallest unit area or cell on the image whose size is determined by the aperture of the source or the receiving optics of the sensing system

Pressure; ways in which drivers are expressed physically, reflecting the inter-linkages between a human activity and the surrounding natural environment i.e. the actual consequences of a driver on a system to which the system reacts.

Producer's accuracy; measure of the error that a ground truth point is correctly mapped, and reflects the error of omission

Resampling; digital process of changing the sample rate or dimensions of digital imagery by temporally or aerially analyzing and sampling the original data

Resolution; minimum distance between two adjacent features or the minimum size of a feature, which can be detected by a remote sensing system

Spatio-temporal; a variant that operates on the earth's surface and is a function of time

Spatial resolution; a measure of the smallest area identifiable on an image as a discrete separate unit. In raster data, it is often expressed as the size of the raster cell.

User's accuracy; a measure of the error of commission for a category, and reflects the probability that a polygon or point on the map is correctly identified.

Wetland; areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water, the depth of which at low tide does not exceed six metres.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Definition of Wetlands

Wetland ecosystems exist in landscapes where the water balance ensures an adequate water supply at or near the surface. They are restricted to locations where, on average, precipitation exceeds evaporation loss, or where sustained inflows from surface or subsurface sources alleviate the water deficit (Price, Branfireun, Waddington and Devito, 2005). These ecosystems include lakes, rivers, rice fields, marshes, fens, peatland, riparian and coastal zones adjacent to the wetlands, or islands or bodies of marine water, the depth of which does not exceed six (6) metres at low tide, lying within such environments (Crafter *et al.*, 1992; Dugan, 1993; Mitsch and Gosselink, 2000; Hollis, Holland, Maltby, and Larson, 2000; Millennium Ecosystem Assessment, 2005; Mitsch, Gosselink, Anderson and Zhang, 2009). As defined by the Ramsar convention on Wetlands of 1971, wetlands are *"areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water, the depth of which at low tide does not exceed six metres"* (Ramsar Convention Secretariat, 2010). This definition has been adapted in Kenya to include swamps, marshes, bogs, shallow lakes, ox-bow lakes, dams, riverbanks, floodplains, rice paddies, water catchment areas, fishponds, lakeshores and seashores. Also included are deltas, estuaries, mud flats, mangroves, salt marshes, sea grass beds and shallow reefs (Republic of Kenya, 2014).

Wetlands are dynamic systems; not only connected physically and socially with processes occurring over a much wider territory, but also provide many services that contribute to human well-being and poverty alleviation (Hollis, *et al.,* 2000; Amezaga, Santamaria and Green, 2002; Janssen, *et al.*, 2005; Kipkemboi, 2006; Mitsch, *et al.*, 2009). Cowardin, *et al.* (1979) and Maltby (1986) referred to wetlands as "*a water logged wealth*" whose functionality attains a unique and peculiar position in the ecosystems of the world due to their hydrologic conditions and their ecotonal characteristics.

Ecotonalism in wetlands implies that they share features of both terrestrial and aquatic systems and are remarkably productive ecosystems (Maltby, 1986; Maltby, *et al.*, 1994;

Mitsch, and Gossellink, 2000). This gives them, high agricultural potential and provides opportunities for an all season agricultural activity (Gibbs, and Partners, 1956). These ecotonal characteristics have attracted human activities to these fragile ecosystems. The wetlands are the new frontiers of development and thus threatening their very existence as natural ecosystems of value to humans and the environment at large. Even though the Ramsar Convention has been in force in Kenya since 1990, an environment-friendly Constitution was promulgated in 2010 and contains provisions on proper environmental stewardship as a basic human right. This includes sustainable management of ecosystems such as wetlands. The Environmental Management and Coordination Act (1999) and its by-laws contain a number of innovative wetland provisions. The prolonged absence of a national wetlands policy and a sector-specific wetlands law has impeded to the sustainable management of these vital but fragile ecosystems (MEMR, 2012) and contributed immensely to their degradation.

2.2 Threats Facing Wetlands

During the last three decades, human societies have been faced with land scarcity, demographic growth, rising poverty, severe economic stresses (Dugan, 1992) and precarious weather patterns in a drying up climate (Urama and Ozor, 2010; FAO, 2011). Consequently, communities and their various development institutions have continued to view wetland ecosystems as a panacea for addressing these challenges. Wherever wetlands are seen in the landscape, they are largely valued in terms of their potential to provide farmland for food. This normally results in the alteration of the natural physical and biochemical processes of these ecosystems. Such practices often leads to an unprecedented change of use, degradation and loss of wetlands in space, their quality and ability to perform their functions over time (Dugan, 1992; Barbier, *et al.*, 1997; Kairu, 2001; Kipkemboi, 2006).

The primary drivers of this loss include the pressure arising from population growth; increasing economic development for wealth creation and poverty alleviation; infrastructure development; effects of invasive species; conversion to and reclamation for agriculture; increased pollution including silt loading; over-exploitation; unclear government policies and even more recently; the advent of global climate change (Geist and Lambin, 2002; Dixon, 2005; Millennium Ecosystem Assessment, 2005; Grünbühel, 2005; Mironga, 2005a; Hecky, Bootsma and Odada, 2006; Hierl, Loftin, Longcore, McAuley and Urban, 2007; Wood and van Halsema, 2008; Odada, *et al.*, 2009; Tomer, *et al.*, 2009). These works have sketched a compelling evidential framework that depicts a gloomy future for wetlands worldwide. They indicate that as much as 50% of the globally known wetland areas have been lost since AD, 1900.

Within Africa, especially in the upper Nile and the Congo basins, time series data show that more than 70% of swamps have been lost within a period of less than 20 years (MacLean, 2004). A case study on four African wetlands has gone further to identify agriculture, which is an element of land use, as the main human activity that changes, modifies and creates immense pressure on wetland ecosystems across the continent. This leads to major losses of pristine characteristics of the ecosystems (Schuyt, 2005). Kenya's case is however more grim with about 10% of the original national wetland area estimated to be surviving and still pristine (Mironga, 2005a). Owino and Ryan (2007) have shown that about 50% of the papyrus wetland in the Kenyan part of Lake Victoria and in particular, the Kusa wetland area, was lost over the period between the years of 1969 and 2000, largely, to anthropogenic uses. Their work has attributed phenomenal losses of wetland habitats, to human activities. However, nothing much exists in terms of accurate spatial and temporal estimates. Where they exist, they are inconsistent and incomparable. As a result, an exact estimate of the total extent of wetlands as well as the magnitudes of changes taking place in space and time and factors driving the changes within them are grey areas for research.

The implications of wetlands' cumulative spatial and biophysical losses at the local, national, regional, continental and global scales are still the subject of critical research interests (Mironga, 2005b). The interest are generated by the fact that the information is essential for effective management of wetlands, which, however, requires accurate and comprehensive spatial data on location, size, classification, and connectivity in the landscape (Mironga, 2005b; Murphy, Ogilvie, Connor and Arp, 2007). Pereira (1991) and Sandstrom (1995) placed emphasis on the need for precise predictions of the nature of stresses and impacts that could be triggered by land use conversions, which lead to reductions in the area covered by such ecosystems. They averred that the nature of stresses and impacts have over the years remained precarious and location specific. It has been noted that ecosystems undergoing such stresses are likely to be less stable and could fail to provide the necessary ecosystem services and resources in the long run (Dobiesz, *et al*., 2010; Davis, *et al*., 2010).

According to Whitlow (1983), there is evidence that anthropogenic activities epitomized in changes in land uses on the landscape can disrupt environmental balances, especially in wetland ecosystems. Such ecosystems could be irreparably destroyed within a matter of few years. This could affect, both directly and indirectly, the livelihoods of the riparian communities who benefit from the resources that these important ecosystems provide (Hollis, *et al.,* 2000; Silvius, *et al.,* 2000; Amezaga, *et al.,* 2002). While, the values of wetlands are well-documented (Maltby, 1986, Mitsch and Gosselink, 2000), the extents of spatial damage to the wetlands still remain as relative estimates, especially in developing countries. Unlike in the other parts of the globe, there is a dearth of scientific investigation and inconsistent mapping policies and practices in Africa, to determine where and when these losses occur and design intervention measures (Murphy, *et al.,* 2007).

A compelling scientific evidence of the changes that have been taking place in wetlands in Kenya (as in the study area) over the last thirty years or so have been graphically presented in the Kenya Wetlands Atlas (MEMR, 2012). Using satellite imagery, various kinds of changes in wetland ecosystems including agricultural encroachment, urban growth into wetland areas, altered hydrology, modified and degraded coastal areas and the impacts of climate change all over the country have been described. Unfortunately, limited efforts were made to quantify losses specific to individual wetland such as the Nyando Wetland. This makes the information in the atlas largely useful for spurring initiation of management and conservation issues at the national level rather than at the unique ecosystem level. Degradation and loss is still a widespread problem that needs to be urgently addressed with a focus on individual wetland ecosystems level.

2.2.1 Land Use/Cover Changes

Land is a fundamental factor of production, and through much of the course of human history, it has been tightly coupled to economic growth (Richards, 1990). It is therefore important as a key and finite resource for most human activities including agriculture, industry, forestry, energy production, settlement, recreation, and water catchment and storage for human progress. Land is thus a finite resource and its use and management is normally constrained by environmental factors such as soil characteristics, climate, topography, and vegetation and socio-political and economic considerations (Schimel, *et al.,* 1991). As a result, control over land and its use is often an object of intense human interactions with ecosystems in the environment. Human activities that make use of, and hence change or maintain, attributes of land cover are considered to be the proximate sources of change. They range from the initial conversion of natural forest into cropland to on-going grassland management (Turner, 1989; Hobbs, *et al*., 1991; Schimel, *et al.*, 1991).

Gils, Huizing, Kannegieter and Zee (1991) terms the expression of man's management of various ecosystems for the welfare of human populations as land use. Land use is further more elaborately defined by Liverman and Cuesta (2008) as the human activity that occurs on land such as agriculture or grazing. This may include additional social characterizations such as subsistence or commercial agriculture. Land cover on the other hand is defined as the physical and biological cover on land including vegetation of various types such as papyrus or grassland, water or bare soil. Land cover normally indicates the kind of activity to which the specific location on the ecosystem is assigned by human reasoning. Such human reasoning leads to various land use decisions, which therefore modify the land characteristics in ways that often introduce new uses, (Bronsveld, *et al.*, 1994). The conversions from one cover type to another are referred to as land use changes. The changed uses cannot be measured directly but are often estimated through the observation and measurement of indicators of use such as the predominant land cover types on the affected land areas (Bronsveld, *et al.*, 1994 and Duram, Bathgate and Ray, 2004). Land use and land cover changes are therefore important phenomena that define the relationship between humans, the economic system and the environment such as a wetland ecosystem. It needs to be measured, monitored and wisely managed for the sustainability of such ecosystems. This is to ensure that current and future human actions take into account effects on the environment, economy and society; and that what is done today should not compromise the well-being of future generations (Strange and Bayley, 2008; UNEP, 2011).

Several studies such as those of Dixon and Wood (2003), Walters and Shrubsole (2003) and Houlahan, Keddy, Makkay and Findlay (2006), examined the issue of wetland connectivity to adjacent land uses in connection with the changes as cover type conversions expand. They concluded that differences in the land-use-diversity relationships among different plant functional groups suggest that adjacent land uses affects wetland plant communities. These studies focused on relative relationships without spatial and temporal considerations. The cultural inclinations and practices that are often a function of the human populations that live around these wetland ecosystems have also received limited attention. Mironga (2005 a and b) and Makalle, Obando and Bamutaze (2008) found out that some of the cultural inclinations and practices lead to unsustainable land use practices that drive the processes of loss and degradation not only of other ecosystems but also of wetlands. Consequently, changes in land use in a wetland ecosystem cannot be examined in isolation of the riparian human institutions, perceptions and attitudes as they exploit the wetlands (Mironga, 2005 "a" and "b"). Those who live in areas where wetlands play an important role in the sustenance of livelihood support systems are highly dependent on the services that wetlands render to humanity. They are directly harmed by changes to uses that degrade wetlands and are therefore part of these ecosystems and its sustainable management (Hollis, *et al.,* 2000; Amezaga, *et al.,* 2002; Schuyt, 2005).

Unfortunately, wetland benefits that accrue from these relationships such as the fertile land with water all-year-round that attract agricultural land uses, are regarded as a type of public good since they display characteristics of non-excludability and non-rivalry in consumption (Hodge and McNally, 2000; Wood and Halsema, 2008). The tragedy is therefore that communities have for centuries generally treated wetlands such as the Nyando Wetland ecosystem as common property resources. Each community has had its own traditions and practices in their utilization and management based on their indigenous knowledge. However, as noted by Gordon (1954) and Hardin (1968), an asset that is everyone's property, as is the case in most wetland ecosystems such as the Nyando is in essence no one's property and they are often mismanaged or overused to the detriment of the very users. This results in both a decline in quantities and deterioration in the quality of these ecosystems (Gustard and Wesselink, 1993; Fruhling, 1996; Sahin, 1996; Schuyt, 2005). Orwa, Raburu, Njiru and Okeyo-Owuor (2012), has shown that human disturbances of this nature have reductive consequences on habitat quality and compromises species richness in the Nyando ecosystem over time and space. They however did not quantify the spatial and temporal extents of these disturbances, largely agricultural land uses, in the wetland. Past research on the relationships between these riparian land users and wetlands (Wilson, 1996), is also rather limited in Kenya and internationally (Mironga, 2005 b; Khisa, *et al.,* 2013, Rongei, *et al.,* 2013).

2.2.2 Human Population Growth

A close association has been inferred between population growth and land use changes in terrestrial and ecotonal landscapes such as wetlands. Ben-Edigbe (2009) did some work on population growth and land use change and found that they are interdependent, with population growth being a function of land use change. This is because population is sustained by food, shelter and clothing, all of which are derivatives of the manner in which land is used and a source of pressure on the ecosystem. Hence the expanding world population is seriously increasing demands on the earth's resources (Benedick, 2000; Liverman and Cuesta, 2008), which includes wetlands. In addition, human societies are becoming more organized. This is not only in ensuring that people have sufficient land and natural resources for basic needs, but also to support the multifarious activities of the increasingly complex social and economic behaviour patterns emerging in the world (Burrow and MacDonnell, 1998; Walingo, *et al.*, 2009; Maitima, *et al.,* 2010). Consequently, the primary cause of land use conversions in most locations on the earth's surface remains the need to meet the demands of the ever-increasing human population. Similar observations have been made within the Lake Victoria basin, where the study area is found, by Pereira (1991) and ICRAF (1986).

Benedick (2000) indicated that many of the trends of global environmental problems affecting wetlands are influenced directly or indirectly by demographic dynamics such as population size, population growth rates, population densities, and migration of people. Changes in the size, composition and distribution of human populations affect these areas by changing land use and land cover (Creel, 2003; AFIDEP and PAI, 2012). However, there exist mediating factors such as income levels, consumption patterns, technological structure, and economic and political institutions (Cohen, 1999; Ben-Edigbe, 2009; AFIDEP and PAI, 2012). These intervening factors often make it difficult to establish, with scientific precision, clear correlations between population pressures and environmental degradation and therefore, a grey area for further research (Holdren, *et al.*,1993) which this study sort to explore.

Hopfenberg and Pimentel (2001) showed that human population growth, like those of other animal species in an ecosystem, is subject to the same dynamic processes. They vary according to food availability, which influences the extent of use of their environmental resources. A concomitant increase in the population causes a decline in those of other species whose habitats are interfered with in favour of food production. Furthermore, studies have indicated that this is aggravated by the current perspective in both the scientific and lay communities that food production must be increased in order to support a growing human population (Anifowoshe, 1990; Brundtland, 1993; Waggoner, 1994; Postel, 2001). The increases are often horizontal rather than vertical. This leads to spatial and temporal conversions of ecosystems with most studies focusing on mono-disciplinary investigations that do not capture the whole story of the changes (Holdren, *et al.,* 1993). The position has been supported by Dobiesz, *et al.,* (2010) in a study to determine metrics for use in measuring ecosystem status. They found that transitioning systems (such as wetlands which have ecotonal characteristics) vary widely. They vary in spatial and temporal trends and face a variety of increasing anthropogenic pressures. There are however, minimal efforts to integrate metrics that assess the pressures they face in a precise way.

According to Pereira (1991), human populations have doubled in the last three or so decades in most developing countries; but with a continued heavy dependence on subsistence agriculture over the same period as the source of food. The UN population projections predicts that the populations of developing countries will rise to about eight billion by 2025 and nine billion by 2050 (Young, 1999). This growth is expected to be much faster in Africa whose population has been increasing rapidly and will add 1.0 billion to rise from 13 to 20 per cent of the world’s population during the period (The United Nations, 2004). This is due to the fact that several countries in Sub-Saharan Africa are experiencing high rates of population growth, at varied population sizes (UNFPA, 2012; Zuberi and Thomas, 2012). For instance, while the population increases for Tanzania mainland and Zanzibar are 10,163,585 (30.4%) and 321,814 (32.8%) respectively since 2002, Nigeria's population size increased by 57 million from 1990 to 2008, a 60% growth rate in less than two decades (Agwanda and Amani, 2014; United Nations, 2015).

Kenya is no exception from these population growth trends. High fertility, combined with declining child mortality, gave Kenya one of the world's fastest population growth rates in the 1970s and 1980s (Thuku, Gachanja and Obere, 2013). The total population rose from about 10 million at independence in 1963 to 15 million by 1978 and to about 40 million in 2009 (Republic of Kenya, 1989; Republic of Kenya, 2010). Within the study area, the population of Nyanza Province alone, for instance, rose from 1 million in 1962 to 2.1 million in 1969 and from 4.5 million in 1993 to an estimated 5.4 million in 2009 (Republic of Kenya, 1989; Republic of Kenya, 2010). While various government interventions such as family planning and education and awareness campaigns have ameliorated the growth levels, there is still concern that the expansion, which is rapid will exert undue pressure on land and water resources (Thuku, *et al.*, 2013). It has been suggested that population related pressures on ecosystems will continue to intensify in the future in direct proportion with the rapidly expanding population in the study area (ICRAF, 1986; Oucho, 1993). The increasing population needs clothing, food and shelter that have to be met from the natural resource base including the wetlands. The responses to these pressures have traditionally been to increase land area under agriculture (Hopfenberg and Pimentel, 2001). Future major problems are therefore predicted for vulnerable habitats such as wetlands. Already, horizontal agricultural expansion activities have spread to these marginal areas which are too fragile to support sustainable crop production (Schuyt, 2005). The extent of the incursions is, however, in argument.

Wetland riparian communities have livelihood strategies that combine subsistence agriculture with utilization of wetland resources for a wide range of purposes (Silvius, *et al.*, 2000). Such communities operate within the framework of the distance decay principle as explained by Waldo Tobler's First Law of Geography (Sui, 2004). This Law asserts "*Everything is related to everything else, but near things are more related than distant things"*. This means that the closer the populations settle in proximities of wetland ecosystems, the more intense the interactions and pressure on the wetland and its resources. This is influenced by a host of factors including kinships, travel time and costs (Verma, Ramyaa and Marru, 2013). Thus the consequences of the rapid increases in human populations is expected to bear serious effects (Madulu, 2004; McWhinney and Angela, 2007) on catchment hydrology and natural resources including wetland resources of the study area.

The combined effects of population growth and environmental changes precipitated by the accompanying land-use changes are increasing environmental degradation, including wetland depletion and poverty. Unfortunately, they are not usually prioritized, analyzed and addressed together in Kenya's strategies for development (AFIDEP and PAI, 2012). The role of population growth and attendant effects on climate change has been recognized in Kenya's Vision 2030, which is the long-range development blue print covering the government's development intentions over the coming years. The document, nevertheless, fails to link population growth to the decline of areas of wetlands at the local and regional levels in the country. The issues have only been marginally included in the Vision's Second Medium Term Plan for 2013-2017. Although, major efforts have been made towards the formulation of a policy on wetland conservation to address the wetland issues, this has remained in a draft form since the 1998 (Republic of Kenya, 2013). It is only recently that the policy was passed through the National Environment Council, the cabinet and received parliamentary approval in 2014 as sessional paper number 12 of 2014. However, strategies for its operationalization are yet to be developed which may require substantial amount of information as inputs from studies such as the present one.

2.2.3 Lake-water Level Changes

The main characteristic of wetland areas is that they are areas with the water table at or near or above the land surface for long enough to promote hydric soils, hydrophytic vegetation, and biological activities adapted to wet environments (Warner & Rubec, 1997). Most wetlands are therefore easily impacted upon by hydrological changes, both natural and human induced. Assel, Quinn and Sellinger (2004), for instance, associated high air temperatures with unusually high evaporation rates and decreased basin runoff, producing the largest single-year drop in the levels of Lakes Michigan, Huron and Erie in over 150 years of record. They observe that periodic lower water levels will normally allow wetland plants to germinate while periodic high water levels are often needed to maintain wetlands. Their study reports that lake or water level fluctuations may lead to a myriad of unforeseen ecological impacts. This may include decreased water quality, floods and progressive drying up of parts of the wetland landscapes. This is likely to lead to the cascading of impacts through both vegetative and physical changes that make them predisposed to invasion by humans (Khisa, *et al.*, 2013). If not addressed, these impacts could potentially affect the human populations in regard to health, long-term economic uncertainties and survival.

According to Gikuma-Njuru (2010), many shoreline wetlands, which are infested by the water hyacinth, suffer from recession of lake level not only due to accumulation of dead biomass and invasion by the elephant grass but also due to climatic variability and sedimentation. This has impacted on the shallower wetland areas during the past decade or so, for example those of Lake Victoria basin where the study area is located. Awange, Aluoch, Ogallo, Omulo and

Omondi (2008) and Adero and Kiema (2011) variously support this position. Such modifications not only change habitats and affect biodiversity but also make shallow areas of wetlands vulnerable to invasion by communities (Jensen, 2009; Rongei, *et al.,* 2013). Evidence for their rapid loss due to these natural fluctuations and how these influence consequent land use decisions is beginning pilling up (Hues and Hues, 1992; Williams and Lyon, 1997; Spiers, 1999); but with minimal spatial and temporal characterization.

Sokol, *et al.* (2001) reiterated that the level of moisture saturation, chemistry, topography and climate influence both the human decisions to invade the wetlands and the development of wetland ecosystems. The ability to accurately measure water level changes in wetlands is critical for ecology and natural hazards mitigation. This includes improved storm surge modelling and for the design of management measures. However, for many reasons, the water level and gauging stations are often scarce or even absent in the floodplain/wetlands. This is apparently due to the difficulty in physical access to the sites and logistics in data gathering (Lee, *et al.,* 2009). Satellite remote sensing can provide useful measurements to monitor the water level variation over such regions (Sokol, *et al.,* 2001; Lee, *et al.,* 2009).

A study carried out by Lee, *et al.* (2009) on Lousiana wetlands concluded that TOPEX altimetry data is capable of measuring accurate water level changes beneath heavy vegetation canopy in swampy areas. It also showed that satellite remote sensing could reliably reveal wetland dynamic flow characteristics along tracks with a spatial scale of 660m or longer. Al-Khudhairy (2002) also used multi-temporal Landsat TM imagery and simultaneous ground-based measurements of water levels to infer statistical relationships. The study showed that satellite imagery has much to offer in providing a historical perspective of wetland hydrology that otherwise would not be available. Most of these are helpful in monitoring changes in the hydrological regime of wetlands.

2.3 Application of Remote Sensing and GIS Tools in Wetland Research

Research in wetland ecosystems using remote sensing techniques has been less comprehensive when compared to terrestrial ecosystems (Penuelas, *et al.,* 1993; Marshall and Lee, 1994; Ozesmi and Bauer, 2002; Nelson, Cheruvelil and Soranno, 2006; Underwood, *et al.,* 2006; Dahl, 2006). This is probably due to the difficulties often experienced in mapping cover types that signify land use changes in semi-aquatic ecosystems such as wetlands using remote sensing data sources. Their problematic nature was reported by Wolter, *et al.*, (2005) who averred that because water absorbs much of the electromagnetic spectrum used in remotely sensing these cover types, clear distinction and detection depends on the stage of growth and canopy size. For instance, the depth of the macrophyte canopy and rice stalks in the water column is, especially, critical for their detection and accurate delineation as distinctive land use categories (Han and Rundquist, 2003; Peñuelas, Gamon, Griffin and Field, 1993; Wolter, *et al.*, 2005). Studies of Valta-Hulkkonen, Kanninen, Ilvonen, and Leka, (2005) and Wolter, *et al*. (2005) have shown that non-canopy forming submerged vegetative species in wetland ecosystems are often misclassified leading to inaccuracies in mapping outputs. The situation is even more complicated with increased turbidity (Underwood, *et al.*, 2006). Consequently, researchers have primarily used remote sensing to detect dense homogenous clusters of cover types in these ecosystems (Nelson, *et al.*, 2006).

However, Pinnel, Heege and Zimmermann (2004) were able to successfully distinguish between two submerged macrophyte groups of the *Chara* and *Potomageton* using hyper-spectral sensors. The effect of canopy coverage on the spectral signature of the emergent macrophyte known as the yellow pond lily (*Nuphar polysepalum*) which is a wetland cover type was also examined by Jakubauskas, Kindscher, Fraser, Debinski and Price (2000) using hand held hyper spectral sensors. They found that the amount of reflectance decreased in the green and infrared parts of the spectrum as the coverage of emergent macrophyte decreased. This gives hope that such applications are plausible in other remote sensing platforms and applications. Airborne hyper-spectral images, aerial photographs and satellite images are all products of remote sensing platforms. They have been used to remotely acquire spatial and temporal information from wetland cover types (Madden, 2004; Gidley, 2009).

Cost consideration makes aerial photography more accessible to researchers and a large amount of archival data derived from these sources exists (Underwood, *et al.*, 2003). Many disadvantages of use of aerial photography, however, limit their utilization for wetland studies. These include poor spectral resolution of aerial photographs and the labour intensive nature of their visual interpretation. Consequently, the ability of satellite images to contain variations in brightness caused by "light fall off" and bidirectional effects in these platforms, their panoramic nature and time series availability has made multispectral satellite imagery the preferred choice over aerial photography for mapping tasks in intermixed wetland cover types (Jensen, *et al.,* 1986; Moore, *et al.,* 2000; Nelson, *et al.,* 2006). Madden (2004) however, notes that developments in aerial photography have improved both the spatial and spectral resolution making aerial photographs just as good as high resolution satellite imagery. Their limitation is that they require multiple passes to cover the same area otherwise acquired at one point in time by satellite imagery. This could introduce changes in light and atmospheric conditions, which in turn can affect classification attempts (Congalton, and Green, 1999; Jensen, 2007). Consequently, high spectral and spatial resolution satellite imagery are preferred for the acquisition of more detailed temporal and spatial spectral information that can be used to classify and map aquatic macrophyte species relative to traditional photography (Jensen, Hodgeson and Christensen, 1986).

Classification attempts by most researchers have varied in approaches and the number of distinguishable classes mapped depending on the task and the resolution of the imagery used (Anderson, Hardy, Roach *and* Witmer, 1976). In broad terms, the number of classes, used by most investigations vary from 5-10 categories (Jensen, *et al.,* 1986; Mackey, *et al.,* 1992; Olmanson, Bauer and Brezonik, 2002; Sawaya, Olmanson, Heinert, Brezonik and Bauer, 2003; Valta-Hulkkonen, *et al.,* 2005*;* Wolter, *et al.,* 2005; Everitt, Yang and Deloach, 2008). In their classification approaches, cover types especially, vegetation types are aggregated broadly by plant structure (Vis, *et al.,* 2003; Nelson, *et al.,* 2006) into broad ecological categories (Everitt *et al.,* 2005) without delving into the species levels. Laba, *et al.* (2008) for instance mapped twenty classes, some at the species level; but most of his classes were based on ecological categories (such as wooded swamp, scrub/shrub and salt meadow). The focus of a study influences the choice of resolution of imagery and hence number of classes (Everitt, *et al.,* 2008; Underwood, *et al.,* 2006).

The lower spatial and spectral resolutions of earlier satellites such as the early Landsat series were unable to identify mixed cover types. Unless in places they dominated the beds and normally lead to lower accuracies in classifications (Underwood, *et al.,* 2006; Laba, *et al.,* 2008; Everitt, *et al.,* 2008). More recent satellite platforms, such as Landsat TM, Quickbird and IKONOS, have provided more detailed results when it comes to spatial and spectral resolution (Jakubauskas, *et al.,* 2000; Sawaya, *et al.,* 2003; Everitt, *et al.,* 2005; Laba, *et al.,* 2008; Everitt, *et al.,* 2008). The use of remote sensing approaches presupposes large data volumes. This makes it challenging for use by resource managers without sufficient expertise and data processing capabilities (Madden, 2004). Timoney (2002) found out that lack of socio-ecological understanding to generate the desired information to design response measures by resource managers is confounded by problems of data quality, quantity, scale, ecological complexity and failure to consult or analyze historical datasets. This is mainly the case with the spatial aspects, as a basis for planning the future of important ecosystems such as wetlands. This could, however, be resolved by the integration of high resolution data from remote sensing platforms and ground based socio-ecological surveys (Fuller, Wyatt and Barr, 1998).

The present extent and quality of wetland information is insufficient to support effective management of the dwindling wetland resources. Particular attention needed to be paid to the potential of linking upcoming tools in this area such as GIS and remote sensing with socio-economic data to determine their impacts on wetland resource health. These tools are capable of not only predictive analysis but also accessing required data and information in the difficult terrains that are in wetland environments, (Ringrose, Matheson and Boyle, 1988; Williams, 1990; Mackey 1993; Markham, Dudley and Stolton, 1993; Jensen, Rutchey, Koch, and Narumalani, 1995; Haack, 1996; Burrow and MacDonnell, 1998; Mironga, 2004). Consequently, adequate progress in understanding the human causes of land-cover change is frustrated by temporal, spatial and conceptual inconsistencies between social, satellite and physical science data sets. These are adequately addressed in geospatial analytical environments.

Investigations done by Liverman and Cuesta (2008) presented a similar argument and averred that most studies have failed to link the social and natural sciences through the study of land-use and land-cover changes. Local case studies have also failed to link these tools with larger scale modelling efforts and scientific research with the needs of local stakeholders. This has led to lack of understanding on the processes of land use change as driven by human needs. These gaps provide grounds for most drivers of change in wetland environments to operate stealthily to catastrophic levels and impede their sustainable management.

GIS and the human context analysis tools to understand the human population dynamics such as growth, density and migration in and around protected areas or areas such as wetlands and how they affect resources in such areas has been recommended by McWhinney and Angela (2007). These methods rely heavily on rasterized cartographic products for overlay analysis. Capturing the right data in space and time could improve understanding of the current state of threatened wetland ecosystems. This could allow for comparisons of their responses to stressors thereby providing more reliable insights into future changes in the health of these ecosystems locally and globally (Dobiesz, *et al.,* 2010). Turchin (2009) contends that in order to capture such data and make them amenable to studies of this nature, there are challenges. These include the need to focus on smaller areas because population change, which is one of the stressors, may be asynchronous in different regions of focus. Besides selecting the appropriate spatial scale, there is also need to decide on the temporal scale at which dynamics of the human populations can be conveniently studied and linked to changes occurring on the landscape. In Kenya, the temporal scale of the national census time-steps is truncated into decade time scales. These needs to be captured in a GIS for efficient spatial and temporal time scales for modelling of changes and the relationships between such changes and the resources such as those of the wetlands upon which many communities depend for livelihoods.

2.5 The Research Gaps

Few studies have been carried out in the Nyando Wetland that address spatial and temporal dynamics of vegetation cover types of the ecosystem and how they respond to pressures of surrounding population growth. Some of the studies that have attempted to address the subject (Ong and Orengo, 2002; Obiero, *et al.*, 2012; Rongei, Kipkemboi, Okeyo-Owuor and van Dam, 2013), have expressed concern at the rate at which the wetland is being converted into agriculture with cautions on the perceived consequences but without clear determination of the rates of decline or increase. They have not estimated or examined the spatial and temporal extents of these conversions, which are essential in establishing the rapidity and direction of the changes important in the design of intervention measures. Owino and Ryan (2007) used aerial photographs at three small but Important Bird Areas (IBAs) at Dunga, Koguta and Kusa wetlands which are 15 km to the north west, 13 km to the south west and 500 m to the south of the study area respectively to asses papyrus area and habitat losses as a result of human activities. While the temporal resolution of 31 years covered by the work is good enough for ecosystem change evaluation; the spatial scale of the study sites do not cover the Nyando Wetland area and is focused on peripheral wetland areas of IBAs, which may not adequately cover what is going on in the main Nyando Wetland. The study does also not consider the influence of the other factors such as the receding lake levels which are predisposing these habitats to accelerated losses.

Consequently, literature survey revealed that agencies and scientists working in wetlands, such as Nyando approach wetland problems from their own sectoral (e.g. fisheries, agriculture, water) backgrounds. This lacks an integrated vision on problems facing the wetlands. Most of the scientific research tend to be mono-disciplinary. The literature is replete with empirical observations of ecosystem dynamics such as hydrodynamics interpreted in mathematical models and developed into the adaptive management approaches for responding to ecosystem change (Reid, *et al.*, 2006). Serious attempts to integrate the social dimension are scarce in resilience work. This is reflected in the numbers of sciences involved in explorative studies and new discoveries of linked social-ecological systems (Folke, 2006; Berkes, Kofinas and Chapin, 2009).

In recognition of the fact that humans cannot stand outside the nature-society system, there is urgent need to link and integrate the empirical observations with the social systems to moderate and mitigate decisions that the society makes to exploit the ecosystem resources (Berkes and Folke, 2002; Mamun, 2010). The study is therefore concerned with those human and hydrologic factors that alter the land surface and its vegetation cover types. These aspects effectively make land-use/land-cover changes, which affect the wetland a hybrid category system that involves technology in the social-ecological modifications of the landscape. The research gaps identified above are important issues that need to be understood and addressed if sustainable management plans are to be drawn for wetland ecosystems such as that of Nyando Wetland.

The main gap addressed by this study, therefore, is the spatial and temporal dynamics of land use in and around the Nyando Wetland ecosystem and how the wetland cover type responds to pressures of surrounding population growth and the declining Lake Victoria water levels. In the present study, these are essentially the linkages between observed pixel characteristics and the socio-ecological factors that drive the processes of change.

2.6 Conceptual Framework

This study is based on the premise that, the activities performed by mankind in an effort to use the land and it resources reflect human goals that are shaped by underlying social driving forces. These forces could be moderated by proximity to the resource in question. Proximate source variables change the land cover, with further environmental consequences that may ultimately feedback to affect the use of land itself (Meyer and Turner, 1992; Berkes and Folke, 2002). According to Waldo Tobler's first law of Geography, "everything is related to everything else, but near things are more related to each other than distant things (Tobler, 1970; Miller, 2004). In which case, there is a principle of distance decay that influences relationships within a socio-ecological context in all natural environments. This controls the interaction between humans and the natural resources of the earth's surface in spatial and temporal dimensions. Thus elements of the natural environment that are closer to each other are expected to interact more intensely than those far away from each other. Land use for instance is a human activity that directly alters the physical environment in direct proportion with increasing human numbers. Higher and greater magnitudes of impacts of these alterations are therefore expected on resources that are closer and accessible to human residential locations than those that are further away from where they live.

In order to address these basic principles of environmental interaction, this study required a robust analytical framework capable of integrating both realms of the natural and social science research that involve both social and ecological elements of the ecosystem. A useful starting point was to seek to better describe and understand the nature of driving forces and how they function and interface with the ecosystem. In particular, the effects they exert on the ecosystem in response to environmental pressures, both anthropogenic and non-anthropogenic was critical. This was found in the overall philosophy of the Pressure-State-Impact-Response (P.S.I.R.) concept as proposed by Timmerman and Ottens (1998) and Segnestam (2002). The P.S.I.R concept evolved over time to include the element of the drivers of such relationships and was subsequently referred to as the Drivers-Pressure-Impact-Response (DPSIR). This is one of the most widely used frameworks for analysis in these sorts of studies (OECD, 1994; Van der Grift, and Van Dael, 1999; Sear, *et al.*, 2001; Millennium Ecosystem Assessment, 2005; Grünbühel, 2005; Zhang and Fujiwara, 2007; Arthurton, *et al.*, 2008; Valkering,, Tabara, Wallman and Offermans, 2009). The framework owes its origins to Rapport and Friend, (1979) and was modified to improve its applicability and use this study.

2.6.1 Driver-Pressure-State-Impact-Response Framework of Analysis (D-P-S-I-R)

The D-P-S-I-R conceptual framework (Figure. 2.1) presupposes that for any given ecosystem on the earth's surface (defined in the present study as the Nyando Wetland), there exists a spatial distribution of natural resource systems and socio-economic activities which are anthropogenic in origin co-existing in an iterative relationship.

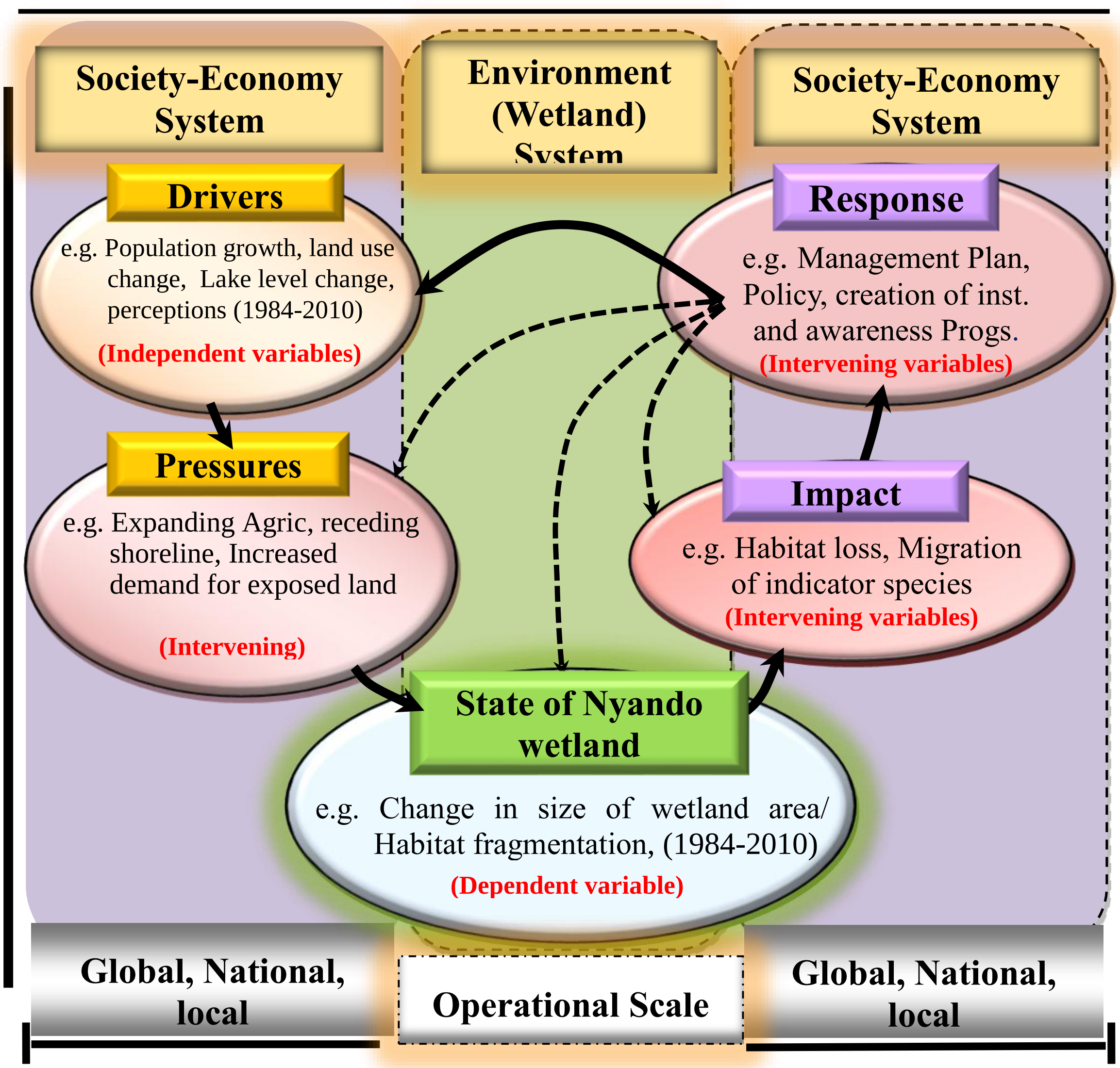

Figure 2.1: The DPSIR Conceptual Framework for the Nyando Wetland Study

(**Source:** Modified from Timmerman and Otten, (1998), MEA, (2005) and Turner, *et al.*, (1998)

Spatial distribution of the anthropogenic activities which are the independent variables i.e. population dynamics and land uses as well as various components of the ecosystem, reflects the overall demand relationship for a variety of goods and services. This creates impacts on the ecosystem which the society responds to in various ways to either correct or enhance the systems. For instance, changes in land use for food production from within and/or without the area will respond to endogenous or exogenous influences of human population increases. The consequence of these populations or other factor based demands is a build-up of environmental pressure e.g. increased conversion of wetland biotic cover types into agricultural cover types, over-harvesting of papyrus or other wetland products.

This is generated through the driving forces such as population increases, landlessness, food production and market values of wetland products. The driving forces and pressure causes a change in the ecosystem which is the dependent variable's state (e.g. reduced spatial extent of the wetland and reduced macrophyte quantities or quality).

Thus, the production activities will result in various types and quantities of residuals, as well as goods and services also measured variously. Such changes in the state of the ecosystem have impacts on the human and non-human receptors resulting in a number of perceived social welfare changes. The welfare changes result in a stimulus for management actions which will depend on the institutional structure, culture/value system and competing demands for the scarce resources and for other goods and services in the wetland. The concept has been recommended as simple and flexible enough to be conceptually valid over a range of spatial scales (Von Bodungen and Turner, 2001). The present study therefore, applied this modified framework of analysis.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

The Nyando Wetland is located between latitudes 00º 09' S and 00º 20' S and longitudes 34º 45' E and 35º 00' E. In 1948, the wetland was estimated to cover some 90 km^2. It lies astride the Nyakach and Kano Plains at the Mouth of River Nyando on the edge of Winam Gulf in Nyakach Bay on the shores of Lake Victoria (Osumba, Okeyo-Owuor and Raburu, 2010) (Figure 3.1).

3.1.1 Topography and Drainage

The altitude of the study area ranges between 1,100 m (at the lakeshore) and 1,110 m.a.s.l. (on the Plains). The main river that drains the wetland is River Nyando which has an approximate catchment area of 3,450 km^2 (JICA, 1992) and about 115 km long. The catchment extends from the shores of Lake Victoria at an altitude of 1,100 metres above sea level (m.a.s.l.) (where the study area is located), to over 3,112 m.a.s.l. at Mt. Londiani on the western fringes of the East African Rift Valley. Besides numerous surface drains and minor streams, three (3) other ephemeral streams (Nyaidho, Awach Kano, and Asawo) also feed into the wetland. According to Ongwenyi (1983), climate of the study area can be classified as semi-humid with an annual mean rainfall ranging from about 1,000 mm to about 1,600 mm which is bimodal.

3.1.2 Soils

The soils are mainly alluvium formed by large quantities of silt and sand carried by the Nyando River and several streams including the massive sheet washes that flow into the area from the neighbouring Nyakach uplands and from the highlands in the upper and mid catchment areas of the river Nyando basin. Black cotton soils, sandy red soils, and lateritic soils are common in the Nyakach and Kano Plains area. Sediments of lacustrine and fluviatiles, which are believed to have originated from Lake Victoria (DHV Consulting Engineers, 1987), are also common in the area, mainly at the edges. Commonly, patches of unformed reddish volcanic soils occur, especially on the flood plains around Gem Rae, Wasare and Apondo area, probably washed into the area from the uplands by huge surface run off and flood events that are frequent in the area.

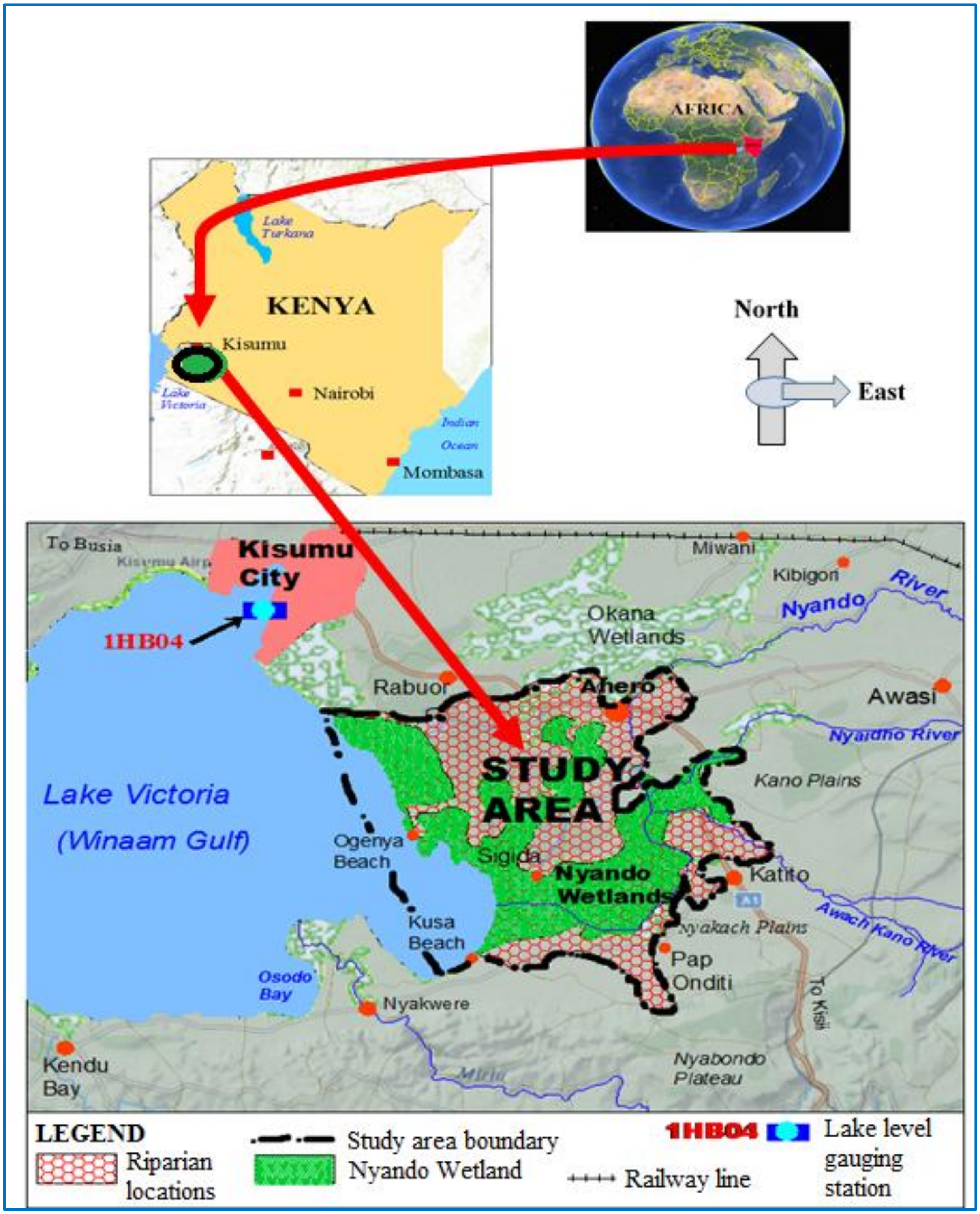

Figure 3.1: Location of the Study Area (Nyando Wetland) within the Nyando Basin

(**Source:** Modified from Jensen, 2009).

3.1.3 Human Population and Agriculture

Administratively, the area falls within the two sub-counties of Kisumu County. These are Nyando and Nyakach, and covers 8 locations and 23 sub-locations. Due to the desire to investigate the effect of distance on the drivers and resource constraints, the study was limited to the riparian locations and sub-locations adjoined to the wetland with a total population of 73,285 people and 13,817 households. Compared to the national figure of 66.4 persons per km^2 (Population Reference Bureau, 2011), the entire county including the study area had an estimated population density of 465 persons per km^2 with an annual growth rate of 2.5% per annum between 1999 and 2009 (Republic of Kenya, 2010).

The population in the study area that was engaged in agricultural activities has been estimated variously to range between 55% and 65% (ECOSYSTEMS, 1983; JICA, 1992). The major crops grown in the area consist of cereals, such as maize, rice and sorghum, followed by pulses such as beans, green-grams, cowpeas and groundnuts, and cotton, and tuber crops such as cassavas and sweet potatoes. There is also some sugarcane grown, though not in large quantities around the wetland, mainly on the Kano side of the wetland. Cultivation pattern and growth period of crops are largely affected by seasonal distribution of rainfall and flooding over the land.

3.1.4 Biodiversity

The study area is rich in endemic wetland plants characteristic of ecosystems along the shores of Lake Victoria (Gichuki, *et al.*, 2001; Raburu, Khisa and Masese, 2012). Besides *Cyperus papyrus*, the other dominant wetland plants in the area include *Phragmites australis* and *Vossia cuspidata* (Bennun and Njoroge, 1999). Nyando Wetland is one of the few remaining habitats for some of the endangered species such as the Sitatunga antelope (*Tragelaphus spekii*) and papyrus-endemic wildlife species such as pythons, *Hippopotamus amphibius*, crocodiles, wetland monkeys, wetland mongooses, papyrus-endemic wetland birds, and a host of fish species (Osumba, 2009; Raburu, *et al.*, 2012).

3.3. Research Design, Variables, Data Requirements, Sources and Types

3.3.1. Research Design

The multidisciplinary nature of the present research and the ECOLIVE project which partly sponsored the study, made it necessary for this research to adopt a mixed method design approach to address its objectives. The term mixed methods research was used in this research to refer to all procedures for collecting and analyzing both quantitative and qualitative data in the context of the present study (Driscoll, Appiah-Yeboah, Salib and Rupert, 2007). In this approach, qualitative observations and interviews were first made to offer the opportunity to provide subtle details that outline the problem during field reconnaissance visits. This was followed by the use of more detailed qualitative and quantitative tools, like a remote sensing, surveys and GIS to validate or invalidate observations made during the qualitative phase. Concurrent mixed method data collection strategies were employed to validate one form of data with the other, to transform the data for comparison, or to address different types of research questions and objectives.

Both the primary and secondary data were collected and applied to the conceptual framework and model. Secondary data were obtained by carrying out literature review on studies so far done on the subject matter in the study area or elsewhere. These included journal articles, reports, and published books in the subject matter of the research. Primary data were obtained through formal and informal interviews of randomly selected riparian households, key informants' interviews (KII) and focus group discussions (FGDs). In the application of socio-ecological tools, same individuals provided both qualitative and quantitative data in structured questionnaires with both closed and open ended questions so that the data could be more easily compared during the analysis stage (Driscoll, *et al.*, 2007). Furthermore, satellite images and ground truthing were used to carry out field measurements of spatial and temporal changes on cover types to estimate changes in land uses in and around the wetland. Data from remote sensing, lake level and population growth measurements were then integrated with the socio-ecological data in models and in a GIS environment to address the research questions and objectives.

While this approach relegates qualitative analysis to an exploratory tool and doesn't maximize quantitative analysis as a tool to both explore, define and investigate the problem and suggest potential solutions, some of the data generated were also vulnerable to the problem of collinearity. Thus some of the response categories were themselves linked as a consequence of the coding strategy and ended up limiting the extent to which various kinds of statistical procedures could be reasonably used, particularly the more rigorous parametric measures of association, such as t-tests and analyses of variance. The design however had several merits that made it suitable for the present research. It had the ability to complement one method with another to facilitate communication, promote collaboration, and provide good quality and dependable research outputs (Johnson and Onwuegbuzie, 2004), which were highly desirable in the study. The design also made it plausible to examine the research questions from different perspectives and combine different methods with different biases involving quantitative and qualitative techniques (Leech and Onwuegbuzie, 2009). Furthermore, this research design enabled quantitative data to generalize the assessment and shed new light on qualitative findings during the analysis stage in a triangulatory process (Morse, 1991; Johnson, Onwuegbuzie and Turner, 2007; Venkatesh, Brown and Bala, 2013). It thus used the strengths of both methodologies to provide a broader perspective on the overall subject of the research.

3.3.2. Research Variables

During this study, a range of variables were selected and measured to provide spatio-temporal data. These include time series land use/cover types and quantities, demographic characteristics (population size), lake water levels, and area left behind by receding shoreline changes. The dependent variable was held as the spatial extent of wetland (WTLa) cover type measured in hectares as an indicator of the extent of wetland replacement with other land uses. The independent variables were those whose changes led to changes in wetland cover type and size through a conversion or a replacement process i.e. area under subsistence small-scale agriculture (SSSAg), area under rice crop and turbid paddy water surfaces areas (RFTw), open grassland area, mixed bushes areas and bare ground area (OPGb) as well as areas left behind by receding shorelines (used as a proxy for the declining lake Victoria levels - WATr). All these measurements were converted from pixel quantities to ha for further analysis. Data for analyzing change in human population size were obtained from the national census figures for Kisumu, Nyando and Lower Nyakach divisions. Other sub-drivers on wetland change were measured through household questionnaire survey administered to respondents. These included the distance of respondents' homes to wetland (DR); water availability to respondent for agriculture (soil moisture content - SM), perceptions of soil fertility; flood frequency; yields of maize crops inside and outside the wetland (Maize returns) and grazing intensity/damage on wetland.

3.4 Application of GIS and Remote Sensing Tools

Full Scene digital and hard copy Landsat TM and Landsat ETM satellite images processed to level 1G were secured and used. Hardcopy images for use in reconnaissance and ground-truthing activities were processed, clipped to study area, enlarged and printed at the scale of 1:50,000 at the Department of Resource Surveys and Remote Sensing (DRSRS). In order to perform a multi-stage analysis to improve the accuracy, aerial photographs at the scale of 1:50,000 were obtained for specific sample sites from the Surveys of Kenya's photo-library in Nairobi. There was 15% cloud cover in both the photographs and the satellite images which was acceptable. To the advantage of the study, the image areas covering the study area in all the images were 100% cloud free. The season of photography or imagery was also taken into account to ensure that images used are those acquired during the period when maximum contrast among different land uses can be assured (Wilde, Jessen and Stevens, 1996). Due to the fact that wetland ecosystems are always wet, such a period only occurs during the dry season.

In the study area, the dry season was the period between December and March, which is normally a period of land preparation and distinctions between wetland and non-wetland areas is maximum. During this period the soil moisture content in wetland soils are higher than those of soils in non-wetland area and the differences between wetland and non-wetland cover types are maximum thus allowing for maximum contrast (Islam, *et al.,* 2008). They were also suitable months when land preparation is at its peak in the study area providing high contrast among cover types. This made it possible to isolate the intruding land uses in the wetland area. These seasonal considerations were designed to minimize false change results from differences between the dates due to soil moisture, temporary surface water from recent rainfall events, or leaf water content if wet season imagery were used.

Landasat-TM images in the time series analysis were for 1984, 1995, 1999 and 2010 (Figure 3.2) with 1984 chosen as a base year. The year 1984 was chosen as the base year because most dates before then had very coarse resolution imagery (56m by 79m = 1.1 acres) which could not adequately meet the needs of the study. The Landsat satellite started delivering good quality images in 1984. The base year for the time series was therefore pegged on this fact. Thus the TM imagery was considered appropriate for the study due to its relatively good resolution of 30 metres capable of providing sufficient information on patterns of land cover that were targeted in the study. Consequently, a 1984 (March, dry season) TM image was used to represent the decade of the 1980s. The decade of the 1990s was, however, represented by two images; one of 1995 TM image (March, dry season), and a similar 1999 TM (December, dry season) images. The 1999 image was meant to neutralize the within decadal variability and anchor the change vector analysis process. Finally a 2010 Landsat ETM image (January, dry season) was used to represent the decade of 2000s which was the study's decadal end time step. These data sources were considered adequate to cover the needs of the study since the objective was to measure broad categories of land cover/uses that influence the area covered by thev wetland. Since time series analysis requires a number of time steps to stabilize the change analysis process, more than two time steps was required. A decadal time step covering three decades between 1984 and 2010 was used. This was because patterns of change in land and land use phenomena, though dynamic depending on the driving forces, often have slow progress and require such periods to detect major spatial and temporal changes.

3.4.1 Procedures for Measuring Land Use Changes

3.4.2 Field Surveys for Collection of Reference Data

Field reconnaissance was carried out to familiarize and understand the images to be able to correlate the image features with ground features. Using image interpretation elements such as tone, texture, and association (Lillesand, *et al.*, 2007), coloured hardcopy images were used in the field to locate sites that typify various observable patterns of cover types occurring in the study area. Such sites were geo-referenced, ground features described (both instantaneously and retrospectively) and used as training sample sites.

The sample sites were selected using a systematic random approach. Reference data collected in the field were geo-referenced using a *Garmin 12 Global Positioning System* (GPS) with ±3 metres accuracy. Information sources such as government reports and existing vegetation maps were also collected at this stage. Furthermore, a preliminary classification system suitable for purposes of this study was created during these initial field trips and refined in later stages of the study in the office. Features of the sample sites were measured and; documented using hand-held camera and descriptive field notes.

3.4.3 Satellite Image Processing

Four (4) satellite full scene images pre-processed at source to level 1G were downloaded as single band *Geo*TIFF, 8 bit digital files from *www/http/landsat.usgs.gov/* and those that were not available at the site were secured from Regional Centre for Mapping of Resources, Nairobi for use in the study. Some of the characteristics and scene coverage data of the images are described in Table 3.1. The header information indicated that the secured images were already subjected to radiometric and geometric correction at source using a two-dimensional re-sampling procedure. These correction processes included elimination of systematic distortions due to the earth's rotation and curvature, panoramic effects and variations in orbital altitude with respect to the reference ellipsoid which is the normal pre-processing level for the level 1B images.

Table 3.1: Description of Characteristics of Image Scenes of 1984, 1995, 1999 and 2010 from which the Study Area was Clipped Out

Satellite Name	Date of Image	Path	Row	Image Orientation	No. of Bands	Spatial Resolution (M)	*% Cloud Cover*	
							Scene	Sub-Scene
Landsat Thematic Mapper (TM)	Mar. 08 1984	170	60	North Up	7	30	20%	0%
Landsat Thematic Mapper (TM)	Mar. 01 1995	170	60	North Up	7	30	8%	0%
Landsat Thematic Mapper (TM)	Dec. 17 1999	170	60	North Up	7	30	9%	0%
Landsat Enhanced Thematic Mapper (ETM)	Jan. 23 2010	170	60	North Up	7	30	15%	0%

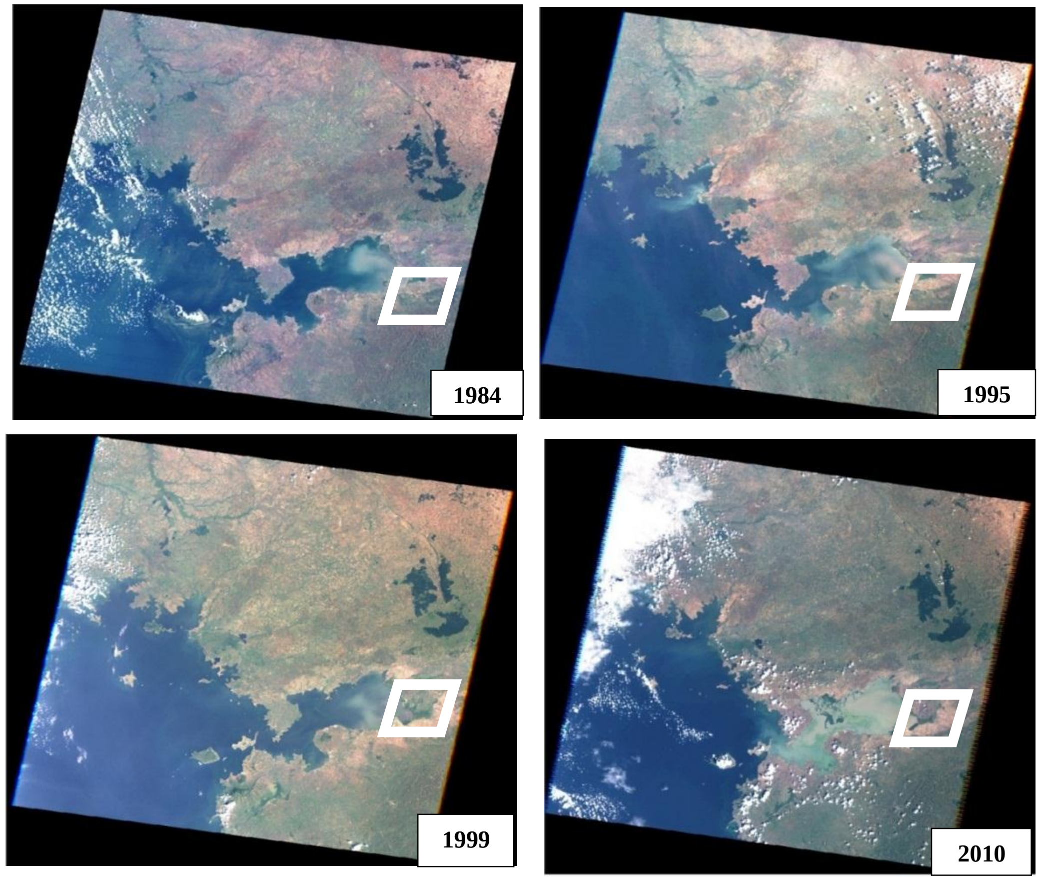

Figure 3.2: **Characteristics of the 1984, 1995, 1999 and 2010 before Sub-setting to Clip out the Study Area during the Study Period**
(**Source:** Adapted from www/http/landsat.usgs.gov and RCSSMRS, 2010).

Note: The white rectangle drawn in white on the images represents the study area which was clipped out of the image scene to exclude pixels that were outside the Area of Interest (AOI) and optimize computer memory resources to increase processing speed in further analysis.

In addition, the image providers had done the systematic mapping of the images onto a standard UTM cartographic map projection on a WGS84 ellipsoid based on the prediction of where the satellite was when the images were acquired. The images were obtained as single bands to enable customized manipulations to suit the needs of the study. Even though the scenes had some cloud cover, the Area of Interest (AOI) to the study was a small proportion of some twenty five thousands six hundreds and ninety seven (25,697) hectares located in the eastern parts of the selected scenes (the white rectangle on the Image in Figure 3.2). The area was 100% cloud free and had images of excellent quality suitable for the study.

3.4.4 Data Merging and Layer Stacking

For visual analysis, colour composites make fullest use of the capabilities of the human eye and this was achieved by the merging of the single bands to produce one image for each time step. This was achieved using the "Layer Stack" algorithm, in the ERDAS IMAGINE 9.2 to create a false colour composite (FCC) image for each time step. The bands were added to each other in the order they were to be in the final image (Figure 3.2).

3.4.5 Geo-referencing and Re-sampling of the Images

Although these images were already geometrically corrected, the geometric accuracy of the systematically corrected products at source was estimated to be within 250 meters (1 sigma) for low-relief areas such as the Kano plains (USGS, 2013); but this is largely valid for sea level locations with low relief. However, the study area is not at sea level and this could introduce geometric inaccuracies. Such geometric inaccuracy could easily combine with other radiometric errors to degrade the quality of spatial data for the study. A 2nd order polynomial image transformation approach which applies a single equation for the "X" and one for the "Y" coordinate values (Equations 1 and 2) across the whole image to adjust pixel locations was applied to the images in ERDAS IMAGINE 9.2. The equation solved was of the form in equation one (1) and two (2).

$$X_{new} = a_x + (c_{x1}*x_{old}) + (c_{x2}*y_{old}) + (c_{x3}*x_{old}*y_{old}) + (c_{x4}*x_{old}^2) + (c_{x5}*y_{old}^2) \quad \ldots\ldots\ldots\ldots (1)$$

$$Y_{new} = a_x + (c_{x1}*x_{old}) + (c_{x2}*y_{old}) + (c_{x3}*x_{old}*y_{old}) + (c_{x4}*x_{old}^2) + (c_{x5}*y_{old}^2) \quad \ldots\ldots\ldots\ldots (2)$$

Where "a" and "c" are constants and "X" and "Y" are Co-ordinates.

The purpose was to improve accuracy, re-register the images on to the Universal Transverse Mercator (UTM) projection Zone 36 South on the World Geodetic System (WGS) 84 Datum and correct for image displacements that could distort results of spatial measurements. The software uses a systematic rubber sheet transformation process that gently warps each of the images (using polynomial equations as in equation 1 and 2) based on the known positions of a set of widely dispersed and evenly distributed Ground Control Points (GCPs). This was achieved using the procedure adapted from that developed by Pala and Pons (1995) and ERDAS Field Guide (1999).

A mean of 20 Ground Control Points (GCPs) was used per image in the process. The GCPs were selected from easily distinguishable and relatively permanent features in the image, such as road intersections or junctions or bridges. The “X” and “Y” input co-ordinates of these points were acquired using the zoom capability in the ERDAS IMAGINE 9.2. The zoom facility allowed zooming in on the area of the rectified image containing the GCPs, clicking on the location to acquire the “X” and “Y” input co-ordinates and then assigning the appropriate reference information to the identical location on the image being rectified. Efforts were made to ensure a relatively even distribution of the GCPs over the entire image.

Once all the refined GCPs were input, the ERDAS IMAGINE 9.2 then automatically solved a geometric model to compute the error for each GCP. The GCPs were refined by maximizing the zoom facility to ensure precision in iteratively matching the positions on both images until the best Root Mean Square Error (RMSE) was attained for each. The GCPs whose RMSEs remained unreasonably high were eliminated from the calculation as necessary so as to reduce the total RMSE and improve the accuracy of the transformation. The RMSE was used to assess the accuracy of the geo-referencing process through the location of independent test GCPs which yielded an error of about 0.7687 (an error of less than 1.0 is considered good). These were used to geo-reference the images. The success of the image rectification process was confirmed by linking two separate images, in two viewers, and then the displays were linked as illustrated in Figure 3.3.

The degree of adjustment that this geo-referencing transformation subjected the images to had the effects of shifting pixel locations, sometimes, quite drastically from one part of the image to the next. When such a shift occurred, scales and co-ordinates were also slightly altered. Once all GCPs were refined and an acceptable RMSE attained and the images geo-referenced, the process of calculating the file values for the rectified images and creating the new files for each of the images (re-sampling) was performed.

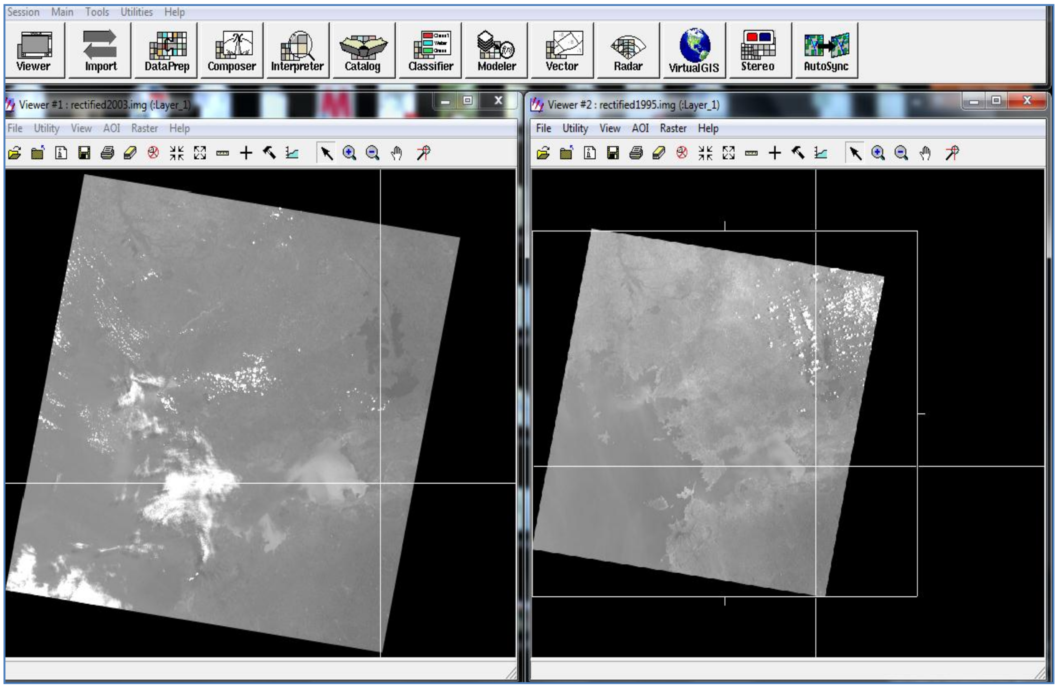

Figure 3.3: **A Screen Shot of Two Separate Images, Displayed in Two Viewers in ERDAS IMAGINE 9.2 During the Rectification Process.**

(**Source:** Modified from www/http/*landsat.usgs.gov and RCSSMRS*, 2010).

Each image was re-sampled using bilinear interpolation algorithm to 30m × 30m, which is the nominal resolution for TM images. Bilinear-interpolation re-sampling operated by finding the 4 pixels in the original image closest to each of the object pixel in the new image, and assigning that pixel in the new image with the average value of the 4 pixels in the original image. The method was chosen to ensure that the original image radiometry was as much as possible preserved.

3.4.6 Image Sub-setting

The new layer-stacked and rectified images were huge files and varied in sizes. For instance, the 1999 image was 6,932 by 6,316 pixels per line per file while the 1984 and 1995 ones were 6,979 by 6,299 and 6,973 by 6,299 pixels per line per file, respectively. In order to have images that covered only the study area and same in size, a shape file (map coordinate-based vectors-Figure 3.4) was generated from ArcGIS 10.1 covering the Area of interest (AOI) (Nyando Wetland shape file). The reason for using a shape file was based on its portability between images and between image processing packages.

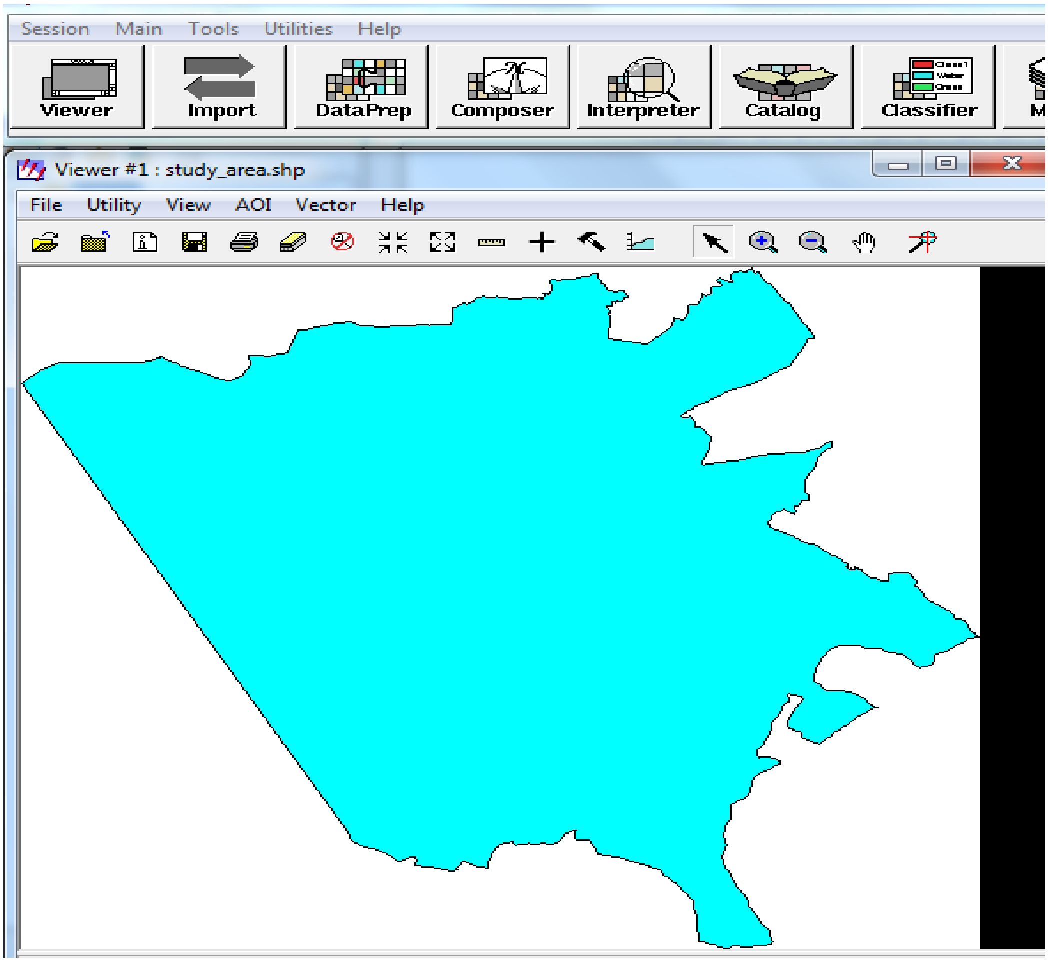

Figure 3.4: A Screen Shot of the Shape File for Sub-Setting the Area of Interest (AOI) in ERDAS IMAGINE 9.2 during the Study Period

The shape file was then imported into ERDAS IMAGINE 9.2 and used as a mask in the sub-setting process. The subset was generated by matching part of the input image name with attributes of the AOI or shape file and then clipping out the AOI. This reduces production time by excluding unneeded pixels from processing. Input files in the process were the geo-referenced, layer-stacked files built above and the output files were the Images covering the AOI. All Zero values were ignored in output statistics. The resultant images are displayed in Figure 3.5.

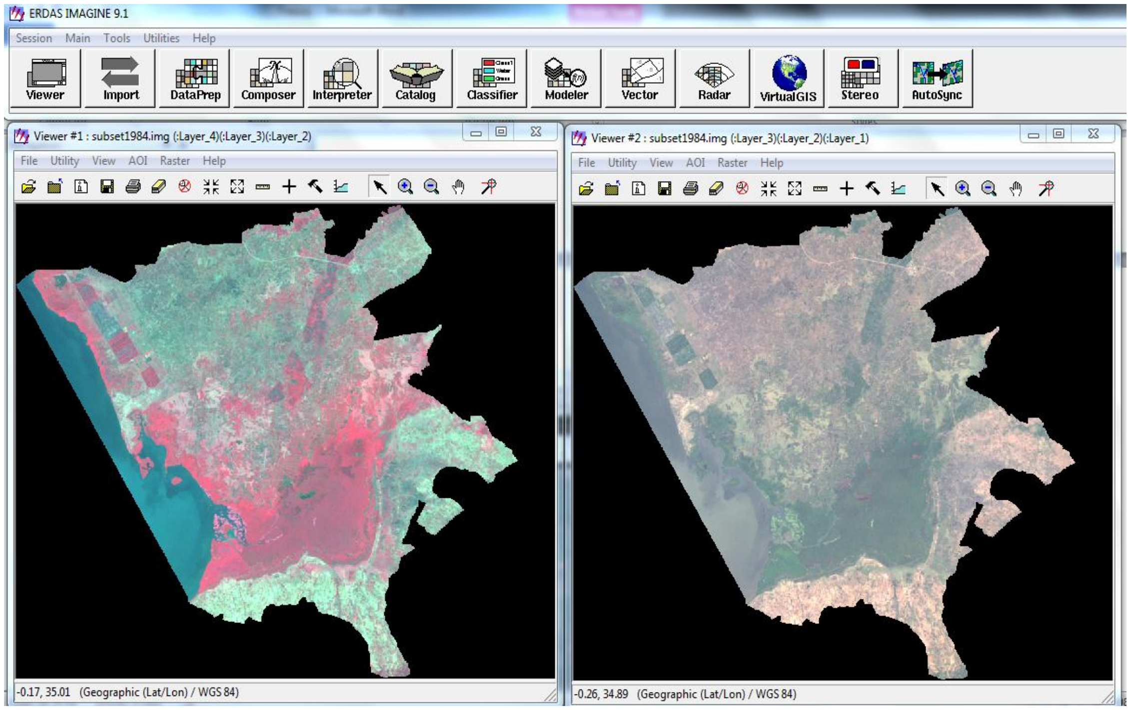

Figure 3.5: Band Combination to a False (Bands 4, 3, 2) and True (Bands 3, 2, 1) Colour Images of the Subset Images during the Study Period

3.4.7 Spectral Enhancements

The images were inspected for clarity and interpretability both visually and digitally (identifying similar spectral signatures i.e. photomorphic regions). This was done by a visual inspection of the false colour images on the display to determine if certain known features such as roads could be identified and measured with certainty and accuracy. It was noted that the images were dull and needed further processing to bring out the features more clearly. This was further confirmed by calculating and displaying the histogram values for each of the original bands and displaying the histogram graphs of the images. The graphs exhibited a Gaussian distribution which did not however, occupy all the values in the display range of the system, which is normally 0-255 leading to the dullness and slight blurriness of the images.

A piecewise linear stretch using a polyline function to increase contrast over different ranges of the image data was applied in the ERDAS IMAGINE 9.2. In this method, the percentages of pixels in particular ranges were manipulated without eliminating the range of data file values of the original images. Lookup Tables (LUT) were created that were stored with the images and loaded each time the image is loaded. The LUTs were plotted on a graph. The graph shored a linear rise with break points dividing the ranges of data into three sections: low, medium and high. The break points created segments on the graph that were interactively manipulated to increase or reduce contrast of particular ranges of data. The LUT graph line with the steepest (highest) slope brings out the most contrast by stretching output values farther apart in the display range. The basic strategy used was that if the grey values of the images were logically spread to utilize the full range possible on the display device (0-255 brightness values), then the quality of imagery and interpretation would be enhanced. Finally, a crisp filter was applied to the images to sharpen the overall scene luminance and feature edges without distorting the inter-band content variance of the images.

3.4.8 Image Classification

The next step was to convert spectral raster data of the imagery into a finite set of classes that represent the surface cover types in the area of study. There are traditionally two broad categories of image classification: unsupervised and supervised. The study first employed an unsupervised classification algorithm on the images. This was in an attempt to identify spectrally homogenous (photomorphic) groups within the image that were later assigned to informational categories as suggested by Richards (1993). The product of this process yielded nine categories. Due to the small farm sizes leading to a "*mixel*" concept situation and resolution constraints (Foody and Mathur, 2006a); the nine categories could not be consistently applied throughout the time steps of the study period without signature confusion. The product was, therefore, manually refined in a supervised classification process into five broad classes by merging classes, which had strong signature similarities with potential for confusion. Such strong signature similarities generally define patterns of land uses/cover types that could be grouped together into various category with minimum effects on the classification accuracy.

During this process, known surface features within the imagery were manually identified and a statistical module in the ERDAS IMAGINE 9.2 used to determine the spectral signatures of the identified features or group of features. The spectral signature files were then used as a basis for the definition of representative training areas for each of the classes on the images. The rules of correspondence between the spectral and the land use-land cover categories were then established. These were generated from fieldwork or ancillary information (ground data). Four main operational strategies for the rules were as follows:

1. Spatial correspondence between the spectral class and the training areas.
2. The spectral class is mainly inside a particular class.
3. The spectral class is not an insignificant part of the class.
4. Pixel remained unclassified if it belonged to a class that is split too much between two or more classes.

Using a maximum likelihood classifier, the "spectral signatures" of the identified features or groups of features were then used to classify the rest of the image with an underlying assumption of a normal (Gaussian) distribution within each class. The probability of a pixel value occurring in each class was computed and pixels were assigned to the class with the highest probability or likelihood of it being a member. The outputs were classified images with numbered labels that were then assigned to the various land use/cover categories for each of the time steps (1984, 1995, 1999 and 2010).

This combination of methods was important because the multi-modal nature of the features in the study area made a single method approach relatively inadequate (Anderson, *et al.*, 1976; Richards, 1993). The statistic of crops such as cereals or groups of cereals obtained in the area rarely followed normal distributions due to the different stages of growth and "*mixel*" characteristics of the pixels in the different fields covered by the training areas. Rice farms were, for instance, difficult to distinguish from turbid water surfaces on the satellite imagery as the farming practices observed in and outside the wetland were based on flooded basins or paddocks. Consequently, only open turbid water surfaces contained in rectangular, regularly shaped features were grouped together with the rice farms even if they were not planted with rice as one category known as Rice Farms and Turbid paddy Water Surfaces (RFTw). This was based on basic principles of image interpretation and ground-truthing outcomes to assure consistency in measurement. Small plot sizes of individual cover types relative to pixels size also further complicated the situation making it necessary to seek photomorphism as a basis for grouping of the categories. This hybrid approach was adapted from Estes, *et al.*, (1983) and Fung (1992).

3.4.9 Post Classification

The classified images were imported into ENVI 5.0 for post-classification comparative analysis. This involved the determination of the level of disagreements (land cover wise) between images taken on varying dates i.e. 1984, 1995, 1999 and 2010. These independently classified images were compared and their accuracy assessed. The classified images were exported to ArcGIS 10.1 after accuracy assessment.

3.4.10 Accuracy Assessment

The error matrix calculation that is a commonly used method of assessing accuracy of a classification was applied in the study. The method compared the agreement between classes predicted through image processing procedures to those observed independently of the classification on the ground (Gidley, 2009). 256 random points were generated using a random generator. The pixels falling on the points, which were randomly distributed throughout the image, were selected for the exercise. Each of the pixel sites formed the basis of sample site definition and each of the sample sites was redefined and identified as a field plot of approximately 2 x 2 pixels in size as modified from the recommendations of Biging, *et al.,* (1999) and Foody, Mathur, Sanchez-Hernandez and Boyd (2006b). These considerations were also informed by the number of points and area sizes normally chosen to assess accuracy in literature which range from 50 to 200 points per study site (Foody, 2002; Sawaya, *et al.,* 2003; Everitt, *et al.,* 2005; Wolter, *et al.,* 2005; Baker, Lawrence, Montagne and Patten, 2007; Everitt, *et al.,* 2008; Laba, *et al.,* 2008). Sample sites which fell on inaccessible locations, especially in the boggy wetland locations were systematically dropped and replaced by points of similar classes that fall in accessible locations within the wetland.

The coordinates of these sample sites were fed into a *Garmin 12* GPS as waypoints and the GPS was used to navigate to ground locations of the sites. Recordings of observations at these ground locations were made independently (Congalton and Green 1999). The original images along with direct field observations were then used to determine the true land cover represented by each random pixel site. These groundtruth data were compared with the classification maps. If the ground truth data and classification data matched, then the classification of that pixel was considered as accurate. The desired measures of association among the map overlays and accuracy elements such as the Kappa Index of Agreement, overall accuracy, producer's accuracy and user's accuracy (Lu, Mausel, Brondizio and Moran, 2004; Maheu-Giroux and de Blois, 2005; Maxa and Bolstad, 2009) were all evaluated and determined in ENVI 5.0.

The Kappa was evaluated as an index for the agreement between the images, thus giving an indication of the overall amount of change that has taken place over the study period. The index was also evaluated according to Monserud (1990) and Rosenfield and Fitzpatrick-Lins (1986), on a per-category basis. In this case, it was used to express the degree to which a particular category agrees between two dates (Eastman, MacKendry and Fulk, 1995, Congalton and Green, 1999). Per-category Kappa was determined using the following equation three (3).

$$K_i = \frac{P_{ii} - P_{i\bullet}P_{\bullet i}}{P_{i\bullet} - P_{i\bullet}P_{\bullet i}} \quad \text{.. (3)}$$

Where;

P_{ii}	The proportion of the entire map layer in which category *i* agree for both dates.
$P_{i\bullet}$	The proportion of the entire map layer in *i* in the reference map layer
$P_{\bullet i}$	The proportion of the entire map layer in class *i* in the non-reference map layer

The per-category Kappa data were tabulated and used to quickly gain an appreciation of which categories are the major ones affected by the changes in land cover, and the nature of the changes. The overall classification accuracy was calculated as the average of the individual class accuracies expressed in terms of percentages in ENVI 5.0.

3.5. Measurement of Changes in Population Growth in the Study Area

3.5.1. Human Population Data

The human population data were collected from the Kenya National Bureau of Statistics (KNBS) for 1989, 1999 and 2009 population censuses (Table 3.2). The data included population sizes for each census year over the study period for all the administrative units at the sub-location level. The population size figures were tabulated in Excel 2007 worksheets for further processing and analysis.

Table 3.2: Population Data for the Administrative Units Covering the Study Area

Location	Sub-location	1979	1989	1999	2009
Kawino South	Nduru				836
	Kadhiambo	4068	4,415	3,116	1,916
	Kwakungu			1,957	232
	Ugwe				1,567
Bwanda	Upper Bwanda	5334	2,817	3,312	3,606
	Central Bwanda			1,610	2,304
Kakola	Kakola Ahero			8,826	9,766
	Kakola Tura	7797	12,987	6,962	8,543
	Kakola Ombaka			2,846	3,370
Kochogo	Kochogo North		3,150	3,703	4,365
	Kochogo Central	4707		1,202	1,534
	Kochogo South		3,525	2,965	3,862
N. Nyakach	Gem-Rae	3637	4,650	3,329	4,204
	Gem-nam			1,764	2,001
Nyalunya	West Kabodho	7971	6,596	4,049	5,039
	North Kabodho			2,378	2,807
Pap Onditi	Kabodho East	10193	9,741	5,697	6,009
	Moro			2,561	3,208
Kombura	Masogo	4410	6803	2,897	3,253
	Lela			4,031	4,863
TOTAL					

Source: Republic of Kenya, (1979, 1989, 2001,); Kenya National Bureau of Statistics 2010

Already digitized administrative unit maps related to these population figures were also collected from KNBS. The maps covered the whole of Kenya at sub-location levels. Consequently, the area covering the study area was clipped off to exclude irrelevant areas using a mask defined by the study area boundary. Topographical maps at scales of 1:50,000 were collected as hardcopy sheets for the entire study area to be used for further processing of the population data. Further information about the population was collected from the socio-economic survey questionnaires and also tabulated into Excel 2007 worksheet.

3.6. Measurement of Socio-ecological Data

3.6.1. Socio-ecological Data

As an initial step, an exploratory survey of the study area was done to familiarize with the local representatives of the county administration, village elders and various geographic features of interest. These included visual distribution of homesteads, cover types such as macrophytes or plant community associations and human activities in the wetland. A canoe was used to access various points and areas of interest in the swampy and flooded or water filled parts of the wetland. Subsequently, a questionnaire was designed and pretested on a small sample population of 40 people drawn from Masogo, Lela and Katho Sub-locations in Kombura Location and Irrigation sub-location in Kawino location. The pre-test population sample size was dictated by the minimum number of data points which is 30 (Fabrigar, Wegener, MacCallum and Strahan, 1999) required by SPSS package to perform a valid analysis. They were randomly selected from among respondents within the study area with characteristics similar to those that were targeted for the actual detailed survey. Those who participated in the pre-test were excluded from the detailed actual survey.

The data resulting from the pre-test were analyzed and results used to refine the questionnaires by incorporating additional information, removing irrelevant questions and restructuring questions that were deemed ambiguous to the respondents. Actual field work was carried out in the later parts of the month of January and in February and March, 2010 to collect the primary data. Data collection involved questionnaire administration and observations. The household surveys using questionnaires covered 200 households. (A sample questionnaire is included in Appendix 1). Focus group discussions and key informants interviews were also carried out to obtain views from stakeholders such as farmers and fishermen. These were used to triangulate information, for instance, exploring the reasoning behind some observed unusual phenomena such as a negative population growth during particular periods. Secondary data from both published and unpublished sources were collected to provide background information about the study area including physical and socio-economic aspects. The questionnaires were also used to collect factual and perception data on the ecological aspects of the study according to Piran, Vaughan, Renwick and Barker (2005). Independent verifications of the ecological facts were carried out using participant observation.

3.6.2. The Study Population

The population of households that surround the Nyando Wetland, was estimated at 13,817 households distributed in 23 sub-locations within 9 locations (Republic of Kenya, 1979).

3.6.3 Sampling Design, Frame and Size

The sampling frame was considered as a list of all the households in the study area. It was assumed that most of the households were engaged in one form of land use or the other affecting the wetland presupposing a relatively homogeneous normally distributed population in terms of the purpose of the study. Purposive sampling was used to select the locations and sub-locations for the study to include those that are riparian to the wetland. The distance decay principle underpinning the study was used to select the 9 administrative locations and the 23 sub-locations that are adjunct to the wetland and whose residents were likely to interact with and influence the state of wetland. The sampling units were defined as the 23 Sub locations.

The sample size was determined according to the method proposed by Watson (2001). The method used a formula based on the relationship between the required sample sizes, number of people in the study population, estimated variance in the population, level of precision, desired confidence level and estimated response rate to generate a standard table (Appendix 2). The table could be used to easily determined sample sizes for populations of between 100 and 100,000. Since the study population of 13,817 lies between 10,000 and 15,000, the sample size was selected from the predetermined values in the table generated for a desired confidence interval of 95%. From the table, for a variability of 30% which tends towards homogeneity, the ideal sample size would be 170 respondents for a population of 15,000 against 390 respondents for an assumed variability of 50%. Since the study population fell between 10,000 and 15,000, it was assumed that any number between 170 and 390 could suffice. Numbers between 170 and 390 were therefore generated and randomly selected. The number 200 was selected as the overall sample size for the study.

Since the enumeration unit for human populations is the sub-location, the study sample unit was adopted as the 23 sub-locations units in the study area. The estimated sample size of 200 was then distributed for each sub-location according to its population and proximity to the wetland. Using equation 7 as shown in Table 3.3.

$$n_i = N\left(\frac{h_i}{n}\right) \qquad (4)$$

Where:

N	the population size
h_i	the distance of the sub location from the wetland (in km)
n	the overall sample size (200 households)
n_i	the sample size for the sub-locations

Systematic random sampling was used to select the 200 households. In each of the sub-locations, a sample interval, which is the ratio of the required sample size to the population total, was calculated (Table 3.3). This was expressed as in equation 5;

$$i = N/n. \ (k = N_i/n_i) \qquad (5)$$

A random number between 1 and "i" was then generated, called the seed number, representing the unique identifier of the first population unit to be included in the sample. The sampling interval, "i", was summed with the random number between 1 and "i" and this was taken as the second unit in the sample. The process was continued until the end of the sampling frame was reached and the desired sample size achieved. For instance, if the sampling interval was 4, all the numbers between 1 and 4 had equal chance of being selected as starting point of the transect.

Table 3.3: Sample Sizes for Each Sample Unit Based on Distance from the Wetland Measured from the Centre of the Wetland Polygon

Location	Sub-location	No. Households (N_i)	Average Distance from the Wetland (Km)	Sample Size per Sub-location (n_i)	Appropriate Sample Interval (k)
Kawino	1. Nduru	300	0.74	5	60
South	2. Kadhiambo	352	0.37	10	35
	3. Kwakungu	262	1.23	3	87
	4. Ugwe	220	0.73	5	44
Bwanda	5. Upper Bwanda	703	0.26	14	50
	6. Central bwanda	381	0.61	6	63
.Kanyagwal	7. Ogenya	349	0.38	10	34
	8. Anyuro	300	1.22	3	100
.Kakola	9. Kakola Ahero	2,174	0.33	12	181
	10. Kakola Tura	1,457	0.47	8	182
	11. Kakola Ombaka	642	0.25	14	45
Kochogo	12. Kochogo North	735	0.62	6	122
	13. Kochogo Central	265	0.58	7	37
	14. Kochogo South	636	0.31	12	53
Wawidhi	15. Ayueyo	893	0.50	9	99
	16. Magina	444	0.24	13	34
	17. Nyakongo	321	0.92	4	80
North	18. Gem-Rae	756	0.32	12	63
Nyakach	19. Gem-nam	391	0.63	6	65
Rang'ul	20. Jimmo Middle	626	0.23	16	39
	21. Kasaye	158	0.75	5	31
Nyalunya	22. West Kabodho	930	0.24	14	66
	23. North Kabodho	522	0.60	6	87
TOTAL		**13,817**		**200**	

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The numbers were randomly drawn to remove bias. Consequently, if the number drawn was 2, then the starting point was the 2nd household from the edge of the wetland walking along the length of the sub-location away from the wetland. From that seed point, every "kth" household would be sampled where "*k"* is the sampling interval for each sub-location.

For purposes of reaching the households to be interviewed, techniques adapted from Teff, Weber and Staatz (1990) were used. The sampling transects were purposively started from the edge of the wetland in each of the sub locations and moved along a zig-zag linear bearing away from the wetland in the direction of the length of the sample unit. The aim was to administer questionnaire to the head of the household in each household. However, there are instances when the targeted respondent was missed in the first instant. This made it necessary to use call back mechanisms to ensure that the process is concluded successfully and as many as possible targeted respondents were reached and interviewed. However, where such callbacks were unsuccessful, use was made of a simple "YES" and "NO" randomization technique to select a neighbouring household.

3.6.4 Questionnaire Administration

A questionnaire (Appendix 1) was administered to the selected respondents to elicit the desired information. Each of the respondents' household location was also geo-referenced using a *Garmin12* Global Positioning System (GPS) with a ±3 metres accuracy level. The purpose of geo-referencing was to make the data spatially analyzable and linked to data from other spatial data sources. This was in view of the fact that distances to a resource such as the wetland was assumed to play a signification role in human population interaction as explained in the distance decay concept (Tobler, 1970; Miller, 2004).

Once a target respondent was identified and secured, an amicable environment for a comfortable engagement with the respondent was set. This was done by making the appropriate introductions including the purpose of the visit, the study and a request for the respondent's permission to engage in the study. The researcher then administered the questionnaire personally during the survey in a language in which the respondent was comfortable and concurrently recorded the answers. The use of this approach ensured direct contact between the researcher and the respondent, a factor which facilitated elaboration of aspects that may not have been easily understood by the respondent. The contact was therefore, important for probity and personality assurance to enhance credibility of responses. The procedure also enabled the researcher to ensure that the questionnaire was completed before leaving the respondent to minimize distortion of questions and cases of incomplete questionnaires.

If the household head was literate and desired to fill the questionnaires him/herself, it was allowed. However, availability of the researcher to explain or clarify any question that is not clear to the respondent was always ensured. On completion of such a questionnaire, it was collected and rechecked. Further clarification in places not properly filled was secured and recorded by the researcher on the relevant sections in the questionnaire. All the completed questionnaires were serialized, stacked together and stored to await processing and analysis.

3.6.5 Key Informant Interviews

Structured interviews were held with people defined as having specialized knowledge about the issues being investigated on the wetland. The respondents for this process were identified and selected in the field in consultation with the local administration (Appendix 3). They were interviewed intensively over an extensive period for the purpose of providing a relatively complete historical and ethnographical description of the social, and cultural patterns and the technical issues facing the Nyando Wetland. The interrogation process was subjected to open-ended questions probing the various objectives of the study. This was guided by a protocol designed for this purpose (Appendix 4). The information generated from this process was used to triangulate primary data obtained through the other sources stated above. They also proved corroboratory in nature to authenticate the quality of information generated from other sources. These were useful for understanding the dynamics of the issues being studied. The approach provided respondents with an opportunity to go beyond simple responses.

3.6.7 Focus Group Discussions

The purpose of the Focus Group Discussions for this research was set and designed to further probe, discuss and help explain the preliminary findings from remote sensing based land-use/cover mapping, socio-ecological survey, population and lake level data analyses. Ten sets of questions were developed to address the key issues, which emerged from the above research stages. The questions covered the uses of the land in the wetland, the history of the uses, the changes that had taken place over time, effects on the riparian communities, the dangers of continued degradation of the wetland and other key research themes such as population growth and lake level recession (Appendix 7).

Ethnographically, the study area is occupied by two broad sub-groupings of the human populations belonging to the Luo community known as the Kano people (“Jokano”) and the Nyakach people (“Jonyakach). Each sub-group is composed of various clans and sub-clans linked together by a common ancestral history and they are known to interact with the wetland as a source of livelihood. The River Nyando traverses the wetland and forms a common border which has been a frequent source of conflict between the two sub-groups, often over the rights of access to the resources of the wetland. Consequently, in order to hold successful Focus Group Discussions (FGDs) in a free, accessible and non-threatening environment, a total of 2

FGDs were held in the study area; one for the Kano people at Ahero Multipurpose Centre on 5th May, 2010 and the other for the Nyakach people at Pap Onditi Market Centre in Nyakach on the 12th May, 2010 (Appendix 5).

For each of the two groups, 9 participants were identified and selected based on age, gender, knowledge based on their previous experiences with the subject matter, willingness to participate, practicability and feasibility. The group's composition was carefully planned to create a non-threatening environment that promotes freedom of expression of opinions and to assure gender, youth and vulnerable groups' inclusivity in the exercises. The date and venue of the FGDs were then identified. Invitations were sent out to participants two weeks in advance (Appendix 6) and a personal contact was made with each one of the identified participants to fully brief them on the purpose and expectations of FGDs and to confirm their participation.

In order to stimulate enthusiastic participation, the location of the venue was carefully selected and set. Selection of the venue was based on accessibility, non-interruptiveness, non-disruptiveness, comfortability and pleasantness for the two groups. Once the group reported at each of the venues, the researcher conducted an introductory session, explained the purpose of the FGD again and the expected operational steps during the meeting. Participants were assured that individual responses would be anonymized before being reported. Ground rules for the FGDs were developed in a participatory and all inclusive way and set in place to guide the process. The rules were designed to ensure that people of all genders and age groups represented in each of the groups were free to actively talk, express their opinions and also respond to other members' opinions, as well as questions posed by the researcher. During the four-hour activity, discussions were most often started by questions put from an open perspective for each key issue area, and then narrowed to specific probing questions, finishing up with suggestions for actions and any questions that needed further clarification.

The spoken, open-ended, relatively broad, and qualitative information upwelling from the discussions were recorded both manually on flip charts and note books as well as digitally using voice recorders. Perception ranking exercises were carried out to validate responses of questionnaires to triangulate and establish the reasons for the observed trend of the expansion of agricultural activities towards the edges of the wetland. Immediately after the FGDs were completed, summaries were made of the notes and the recordings transcribed for analysis.

3.6.8 Ethical Considerations

As an integral part of everyday life, ethics, which is basically an informed consent of the participants in the research, assured the rights, privacy and welfare of the people and communities (Fontana and Frey, 2000; Berg, 2001). In order to ensure that the study, especially the socio-economic surveys, was conducted in the most ethical manner, no respondents were interviewed before their consent to participate was secured. The consents were always secured after the seeking of mandates to carry out the study, clarification regarding the nature of the research, clarification on how confidentiality/anonymity would be assured/protected and provision of the copy of the interview questions. Respect for indigenous intellectual property rights, culture and local community decisions were as much as possible observed so that the study would be seen as adding value to their activities in and around Nyando Wetland. All respondents were offered the right of veto and censure for any material they were associated with, for example, knowledge about those carrying out illegal activities in the wetland. An additional safeguard was that no material in any way could be attributed to the individual participant. Compliance with the set of ethical standards by the National Council for Science and Technology for all research conducted in Kenya was also ensured during the study.

3.7. Data for Lake Levels

Changes in Lake levels were estimated from data generated by the existing lake level gauging station (1HBO4) installed at the shores of Lake Victoria by the Ministry of Water, Environment and Natural Resources. The Water Resources Management Authority (WARMA), which is a parastatal under the Ministry, through the regional office of the Lake Victoria South Catchment Area (LVSCA) – Kisumu, rehabilitated the gauging station recently in 2006. This station provided a good database with the historical sequence of data for the study (Appendix 8). WARMA maintains the database in their regional offices in Kisumu. The Lake levels have been measured by the then Ministry of Water (MOW) and WARMA since the 1950s. The institutions have been using a manual gauge (1HB04) situated at the shores of Lake Victoria in Kisumu, which is about 30 km from the study area; but which is also within the same gulf shoreline as the study area. The data were collected to cover the period slightly beyond that of interest to the study covering from 1970 to 2010. This was approximately more than a decade before the base year for the land use/cover change measurements. The aim was to cater for an anticipated time lag before a response is experienced in the wetland, if lake level decline persisted.

The data were collected from source in Excel 2007 spread sheet formats as pre-processed data in a two columned table of a continuous thread of daily gauge height records spanning some 14,517 records of data over the 39 year period. The Lake level data was based on a local datum at the Kisumu pier constrained to the zero gauge at Jinja in Uganda and reduced to 1122.8 m metres above sea level (m.a.s.l), which is an orthometric height referred to an equipotential gravity plane. These were converted to metres above sea level to reflect the lake levels and re-tabulated in a matrix of years and months (Appendix 8). Data for a period of some 2 years (1st of January, 2005 and 3rd of February 2007) were however missing due to a collapse of the pier pillar on which the gauge was installed. The data gap was however continuous and with the length of the data period spanning more than three decades, the gap was considered inconsequential for long-term trend analysis since the study was interested in the trends and broad relationships. Monthly mean water levels were calculated and tabulated and missing data values were treated according to Garsison (2015). To check the effects of the changes in Lake level on the shoreline, spatial shoreline changes were estimated from overlays generated from interpretation of satellite images. Perception responses on shoreline recession by communities were measured using questionnaires in the household survey.

3.8 Field Observations and Documentation

3.8.1 Visual Observations

Visual observation was used as an important method for gathering data. Hardcopy satellite images were carried along to the field and used to compare and associate observed ground land use patterns with spectral formations visually observable on the images. The purpose of this was to gather data and ancillary information for the development of a classification system, image interpretation, classification and post-classification procedures. Observations were also carried out at sampling sites to collect data that helped in the verification of whether the information given by the respondents are in any way related to the observable features in the sample unit. This method was also applied during FGDs to gauge behavioural dispositions that could be useful in interpreting certain pertinent opinions. Non-verbal communications and group interactions were observed to give insights into feelings on particular issues.

3.8.2 Photographic Documentation

Horizontal photography was used to record observable features that helped in explaining various issues addressed by the objectives of the study. Data collected using this method accurately and reliably reflected the actual situation on the ground and helped in the description of class characteristics. Photographs were also used to validate results from other data collection procedures, for instance, showing the vegetation destruction going on in the wetland, the form and type of land use activities and the extent of recession of the shoreline.

3.9 Analysis of Land Cover, Population, Lake Level and Socio-ecological Data

3.9.1. Data Processing and Analysis for Land Cover/Use Change

Simple differencing change detection procedures were run on the classified images to quantify and produce maps for each land use/cover category in each time-step. A table of extracted classified pixel data was created in ENVI 5.0. The classified pixel data table was imported into ArcGIS 10.1. Feature classes for all the classified areas represented by the pixel groups were created in a geo-database to enable spatial and temporal visualization as well as for further analysis. The geo-database created incorporated land-use categories from the classified images and the quantifiable socio-economic data sets. The attribute table associated with these pixel categories was extracted and imported into an Excel 2007 worksheet and converted to hactarage. Various measures of land use change were then calculated for each time step using descriptive statistics such as percentages and graphs.

3.9.2. Population Data Processing and Analysis

Population data were imported both into ArcGIS 10.1 and Excel 2007 worksheets. Calculations were then carried out in Excel 2007 to project the population data at location levels to the land use/cover change detection time steps and seek for relationships. Taking into account the inconsistencies in change patterns of some of the administrative units, two locations of Kakola and Kochogo which exhibited a near normal change pattern were used to typify population growth in the study area. The compounded rate of growth method was used for estimation of population projections. The compounded rate of population growth was calculated using equation six (6).

$$R = [(P_n / P_o)^{1/n} - 1] \times 100 \quad (6)$$

Where;

R = Compounded rate of growth

P_n = Population in the current year

P_o = Population in the base year

n = Number of intermediary years.

Once this rate was estimated, it was then applied to equation seven (7) to determine the population figures in any given year during the study period (Appendix 9).

$$P_n = P_o (1+R/100)^n \quad (7)$$

The administrative unit maps sheets earlier collected from KNBS were subjected to further geo-rectification processes to introduce them into the analysis process. They were geometrically rectified and registered on to the UTM map coordinate system UTM zone 36 South, Spheroid Clarke 1880, Datum Arc 1960.This was done in order to register them on to the coordinate system of the existing 1:50,000 topographic maps and the collected Landsat TM images as well as to make them amenable to manipulation, analysis and change detection in the GIS environment. The 1979 population map units were geo-rectified first and used as a base map for this process.

Later, administrative subdivisions were aggregated and dissolved back in the 1979 location boundaries status for each time step of 1979, 1989, 1999 and 2009 to make them comparable. All the data were then aggregated to this level. This was because the only areal units that were comparable with some level of consistency over the study period were the location feature classes. The creation of the sub-locations as an administrative unit commonly used as a basic census unit was too dynamic and variations occurred, inhibiting change analysis processes and the units were avoided as much as possible. The population statistics were then associated with their respective location units in an ArcGIS 10.1 database to prepare and visualize the spatial dimensions of each time-step. The population size was then used to represent the labels in the various spatial units for each time step so that they could be used to generate maps and also generate the graphs for the time step years. This enabled determination of areas of population concentrations and whether the population size was increasing or decreasing within the study period.

In keeping with the "*ecumene*" principle, the wetland feature class was erased from the spatial data set using the erase tool to mask out the wetland areas and only deal with spatial administrative units' areas that were outside the wetland. The erase tool created a feature class by overlaying the input features with the polygons of the erase features. Only those portions of the locations falling outside the wetland feature class boundaries were copied to the output feature class that represented the new feature class. The population data representing the locations were then changed to point data by the use of a feature to point data tool in ArcGIS 10.1. A feature class containing points generated from the representative locations of input features was created.

After the point data was created where the population in any given location or sub-location was represented by a point in the middle of the feature class polygon acting as a height, the point data was interpolated using the Spline with Barriers tool in the Spatial Analyst module in ArcGIS 10.1. This is a tool that interpolates a raster surface, using barriers from points using a minimum curvature spline technique. The barriers were entered as the polygon representing the area of study to limit the generated raster to that area.

The population surface maps were generated to indicate areas of population pressure for the wetland. Due to the coarseness of the spatial units of data that could be comparable (administrative locations) over the time series, the population surface maps were only used as a background to population graphs. This was to give a visual comparison between the surface map and the bar graphs showing the time series change in the size and distribution of population of the study area. The 2009 situation was refined using the sub-location data to improve the resolution of the surface map which was finally used in this process.

3.9.3. Socio-economic Data Processing and Analysis

The questionnaires were rechecked for completeness, serialized for identification and linkage. During this process, 4 questionnaires were dropped from the pack due to inadequacy of the responses leaving 196 questionnaires for further analysis. The linkages were achieved through a coding procedure in which each of the questionnaires was given a serial code from the first to the last and all the questions and responses were given numerical value codes to enable linkages from the data to the idea and from the idea to all the data pertaining to that idea in the database. Values of either 1 or 0 were given to the dichotomous (yes or no) responses and values of 1, 2, three onwards were given to ordinal (low, medium, high) and explanatory response data. The data were then entered into an Excel 2007 worksheet.

Data cleaning was carried out to improve the quality of data and make them "fit for use" in the research by identifying and reducing errors in the data and improving their documentation and presentation. The strategy used was to check each of the data values in the database to ensure that they were correct and at the very least, conformed to known set of rules, applicable standards and conventions. The process involved format checks, completeness checks, reasonableness checks, limit checks, review of the data to identify outliers or other errors, duplicate records, spelling errors and assessment of data to ensure validity. Within Excel 2007, several worksheets were created one for each logical step. The first worksheet contained the original data as they were entered. Several subsequent sheets were dedicated to the interim data processing phases each sheet representing a particular check step. The final worksheet was dedicated to the final cleaned data ready for further analysis. In each of the check steps, suspect records and data values were flagged up and rechecked by making comparisons with the original data in the questionnaires and making appropriate corrections.

To refine the data for eventual statistical analysis, the cleaned data was further processed by parsing the data using Excel 2007 built-in parsing wizard. The wizard splits cell data at specified delimiters, such as commas, tabs, or spaces, and puts the output into separate cells. The data were re-coded and a "comma-separated values" (**.csv**) data file was prepared. The **.csv** data file was imported into the SPSS version 11.5 and preliminary data analysis carried out using descriptive statistics in both Excel 2007 and the SPSS to exploit analytical and visualization strengths of each software. The level of significance for the analysis was fixed at 95% confidence interval. Inferential statistics were also used during the analysis. The chi-square (χ^2) test of goodness of fit, sample t-test and percentage distribution techniques were used to further test and analyze the data. Percentage rank scores were calculated for likert-scale ranked data. All the relative scores were then multiplied by the counts (no. of respondents) for each category, to produce indices for each variable, and then standardized to a maximum of 100%. The data were then imported into MINITAB 16 for further analysis. Standard logistic regression approaches using the model in equations 8, 9 and 10 were used for analysis of dichotomous and ordinal data sets.

$$\log \frac{\widehat{p_i}}{1-\widehat{p_i}} = \beta_o + \beta_1 x_{i1} + \beta_o + \beta_2 x_{i2} + \cdots + \beta_p x_{ip} \quad \text{……………………} (8)$$

Then,

$$\frac{\widehat{p_i}}{1-\widehat{p_i}} = e^{\beta_0} e^{\beta_1 x_i 1} e^{\beta_2 x_i 2} \ldots e^{\beta_p x_{ip}} \quad \text{……………………………………} (9)$$

Consequently, the odds ratio was calculated using equation eleven (10) below;

$$\psi = e^{\beta 1} - 1 \quad \text{………………………………………………………...} (10)$$

Where;Ψ(Psi)	the Odds Ratio
e	the exponential constant
β1	the coefficient of the variables
p	the probability of occurrence.
1-*p*	probability of non-occurrence

This was especially carried out for variables selected for modelling parameters that influenced wetland degradation and perceptions of the local population.

In ArcGIS 10.1, more data on the administrative boundaries (locations and sub-locations) used in previous censuses as enumeration units were imported into the geo-database. The attribute tables representing sub-locations and the locations were expanded to include other columns on the population and household data for more analysis and visualization.

Information from FGDs summaries were reviewed and analyzed in one sitting for each of the FGD sessions. Comments that appeared repeatedly as well as those which appeared unexpectedly eliciting emotional responses were checked out and noted. This was to identify trends that could be useful in explaining certain observed trends and issues in the previous stages of the research.

3.9.4. Lake Level Data Processing and Analysis

Since the Lake level data were only associable with the polygon named "Lake" and not the administrative unit polygons, analysis in GIS was found to be impractical and of little use. Analysis and manipulation for results was therefore carried out in the Excel 2007 and MINITAB 16. Monthly means of the daily lake level data were calculated and tabulated. Extreme environmental pulses such as "*Lamina"* or "*El nino*" that could influence the distribution were identified and either excluded from the analysis or normalized. The data was transposed and then classified by year and by month to enable frequency analysis. This exercise was carried out in Excel 2007 using a filter function to arrange the data into a format that was used to interrogate for homogeneity (Appendix 10). The data were then imported into MINITAB 16 for further analysis, which included statistical comparisons and trend analysis.

A sequence plot, which is a graph of the data series values on the vertical axis against time on the horizontal axis, was made. The purpose of the sequence plot was to give a visual impression of the nature of the time series and suggest if there are any behavioural patterns in the time series to inform model selection. A general linear trend model was then selected and fitted to the time series data to estimate trends. However, due to the potentially additive or multiplicative seasonality that were noted to be present in the trends, the data were further subjected to exponential smoothing using Holt-Winters method (Goodwin, 2010). The method calculated the dynamic estimates for three components which included the levels, trends, and seasonality. Shoreline shifts signifying lake level changes were measured from satellite images using overlay procedures in ArcGIS 10.1.

3.9.5. Analysis of Relationships between Predictor Variables and Wetland Area

A wetland polygon was generated with a centroid. Respondents' spatial locations were then plotted on the map from the X and Y co-ordinates files that were generated from the GPS waypoint data and incorporated in the database. Distances of respondents from the nearest wetland boundary point and centroid were generated and added into the database. Six most frequent perception responses were then selected as parameters for further analysis. These included distances of respondents from the wetland, fertility of the soil in the wetland as an incentive to work in the wetland, good soil moisture content in the wetland soils as an incentive to circumvent frequent droughts in the area, animal destruction of crops in the wetland as a disincentive to cultivate the wetland and flood frequency also as a disincentive to work in the wetland due to its attendant destructive events.

The proportional odds and logistic regression models were applied and fitted to the data for the selected parameters to investigate the relationships between the categorical outcomes and the explanatory variables according to Brant (1990), Agresti (2002) and Thompson (2009). In order to understand how the variables have related to each other over time, a correlation analysis was carried out to determine the nature of the relationship between the dependent variable (wetland) and the explanatory variables (land use, population and lake levels). Land use was measured through its elemental indicators such as areas covered by small-scale agriculture, rice farms and turbid water surfaces; open grasslands, bushes and water area. Figure 3.7 presents a generalized summary of the study process.

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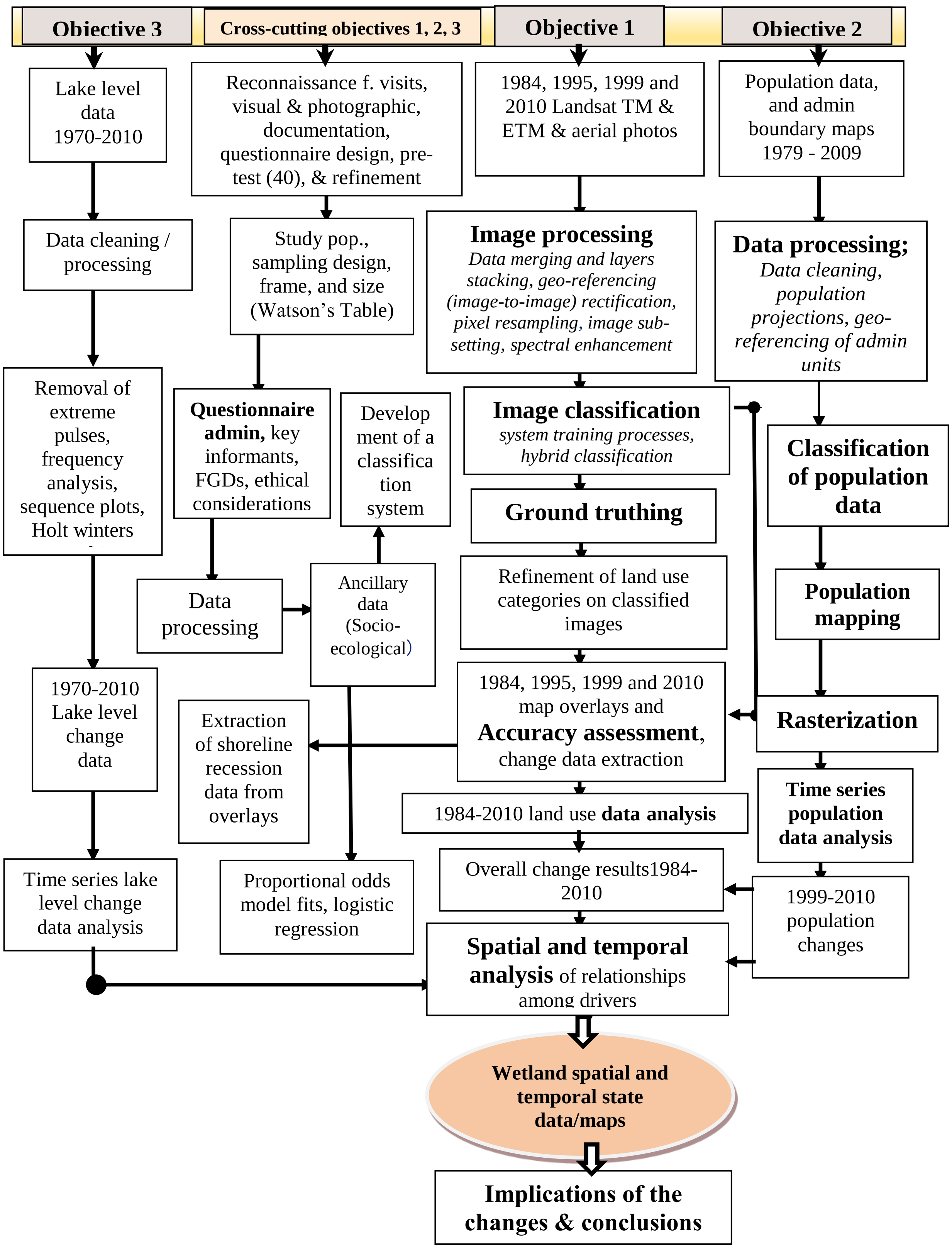


Figure 3.6: Summary of the Entire Study Process during the Study Period in the Nyando Wetland Study.

CHAPTER FOUR

4.0 RESULTS

4.1. Image Classification and Land Use/Land Cover Mapping

Five land use categories were identified and used as a basis for class definitions and assignment for the land cover and use mapping exercise. These categories were:

1. Water area (WATr)
2. Wetland area (WTLa)
3. Rice farms and turbid paddy water surfaces (RFTw)
4. Small-scale agriculture (SSAg), (predominantly subsistence)
5. Open grassland, mixed bushes with exposed bare ground (OPGb)
6. Unclassified (U0)

These five land use/cover categories were used to run a change detection procedure on the various satellite images to produce 4 map overlays presented in Figure 4.1"a" and "b" and Figure 4.2 "a" and "b". Each land use/cover category was quantified in each time-step. These were first quantified as the number of pixels belonging to each category presented in Table 4.1 and then expressed as ground surface areas depicting spatial extents in hectares (ha) as presented in Table 4.2 and Figure 4.3.

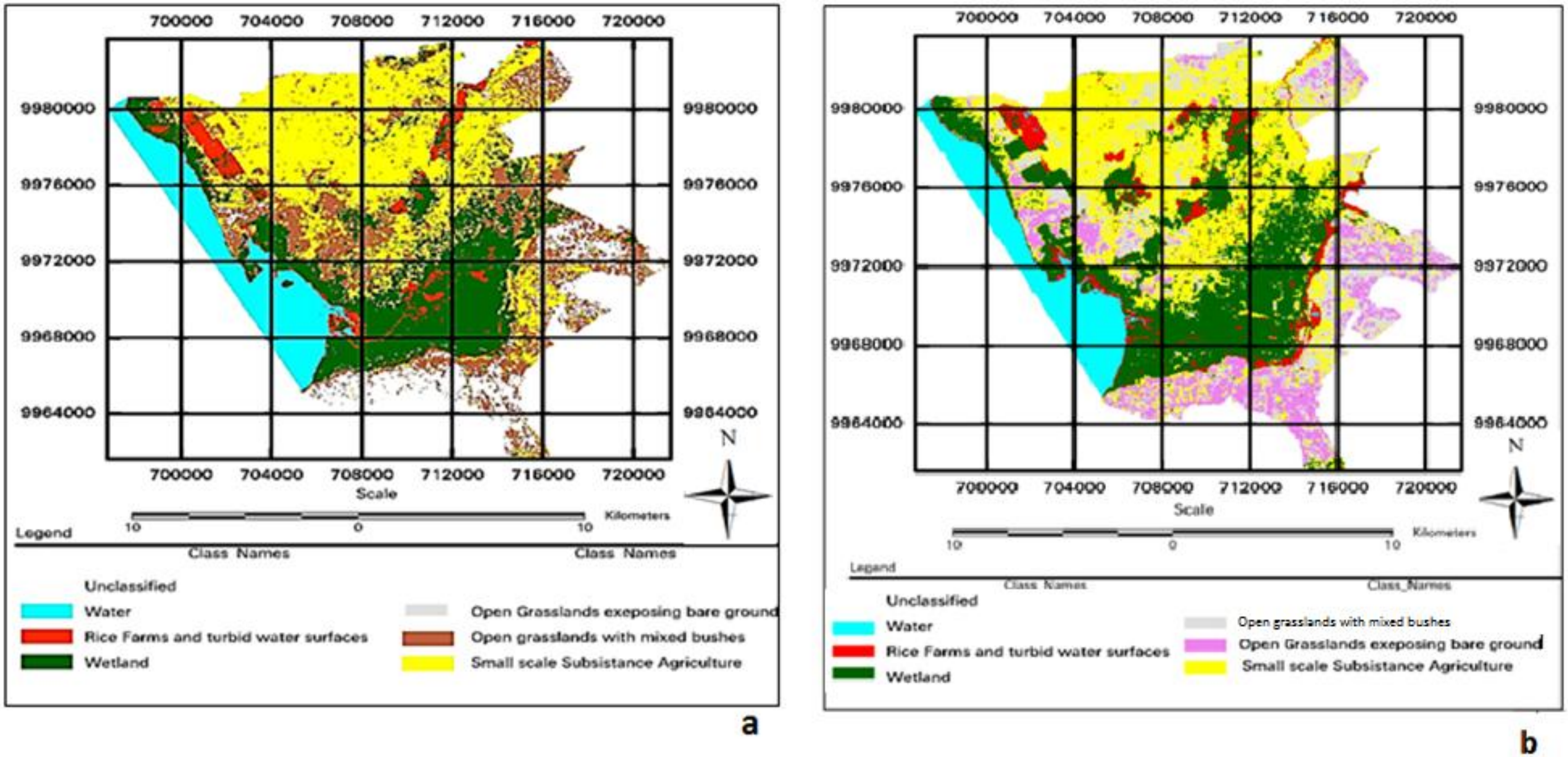


Figure 4.1: (a, b) Spatial Rendition of Land Use/Cover as at (a) 1984, (b) 1995 in Nyando Wetland

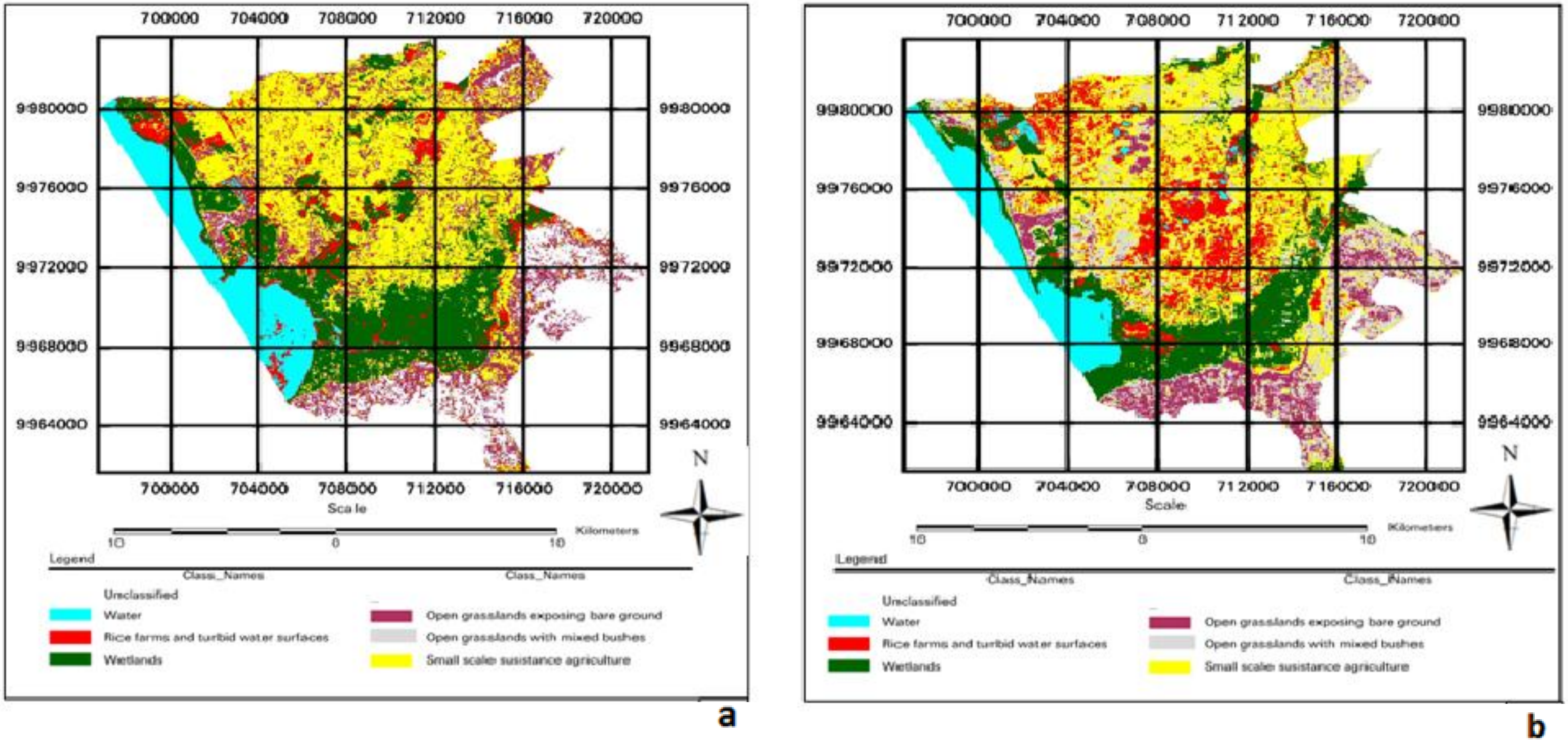


Figure 4.2: (a, b) Spatial Rendition of Land Use/Cover as at (c) 1999 and (d) 2010 in Nyando Wetland

4.2. Changes in Land Cover/Use in Nyando Wetland

The results of pixel count groupings summarized in Table 4.1 show that the number of pixels grouped as belonging to each of the categories in each of the time-steps are not equal to each other indicating a spatial and temporal change.

Table 4.1 The Spatial Change Detection Statistics (No. of Pixels) after Classification of the Images of 1984, 1995, 1999 and 2010

Cover Type	No. of pixels in 1984	No. of pixels in 1995	No. of pixels in 1999	No. of pixels in 2010
WTLa	72,380	65,360	60,125	49,880
SSAg	94,000	103,420	106,125	110,840
WATr	30,510	27,200	24,140	22,160
RFTw	14,770	14,050	16,865	20,190
OPGb	73,860	75,490	78,265	82,450
Class Total (no. of pixels)	**285,520**	**285,520**	**285,520**	**285,520**

Key: **WTLa =** Wetland area**,** **SSAg =** Small-scale agriculture**, WATr =** Water area**,**
RFTw = Rice farms and turbid paddy water surfaces,
OPGb = Open grassland, mixed bushes with exposed bare ground

The measures of change in ha have been presented in Table 4.2. There were increasing trends in size of small-scale agricultural farms (8,460 ha to 9,976 ha), rice farms and turbid water surfaces mainly in paddy fields (1,329 ha to 1,817 ha) and open grassland, mixed bushes with exposed bare ground (6,647 ha to 7,421 ha) with time over the study period. There were also observed declining trends in the area under water (WATr) especially the area covered by Lake Victoria within the study area (2,746 ha to 1,994 ha) and the area covered by the wetland cover type (6,514 ha to 4,489 ha) from 1984 to 2010, respectively.

Table 4.2 **Measures of Land Use Change in Nyando Wetland between 1984 and 2010 in Hectares**

Cover Type	Size in ha in 1984	84-95 (11 yrs) Change in ha	Annual rate of change (ha/yr)	Size in ha in 1995	95-99 Change in ha (4yrs)	Annual rate of change (ha/yr)	Size in ha in 1999	99-10 Change in ha (11 yrs)	Annual rate of change (ha/yr)	Size in ha in 2010	84-10 Change in ha	Annual rate of change (ha/yr)
WTLa	6514	-632	-57	5882	-471	-118	5411	-922	-84	4489	-2025	-78
SSAg	8460	848	77	9308	243	61	9551	424	39	9976	1516	58
WATr	2746	-298	-27	2448	-275	-69	2173	-178	-16	1994	-752	-29
RFTw	1329	-65	-6	1265	253	63	1518	299	27	1817	488	19
OPGb	6647	147	13	6794	250	62	7044	377	34	7421	773	30
TOTALS	**25697**			**25697**			**25697**			**25697**		

Key: **WTLa =** Wetland area**, SSAg =** Small-scale agriculture**, WATr =** Water area**, RFTw =** Rice farms and turbid paddy water surfaces, **OPGb** = Open grassland, mixed bushes with exposed bare ground

The Figure 4.3 illustrates the magnitudes and trends of changes in the various land use categories.

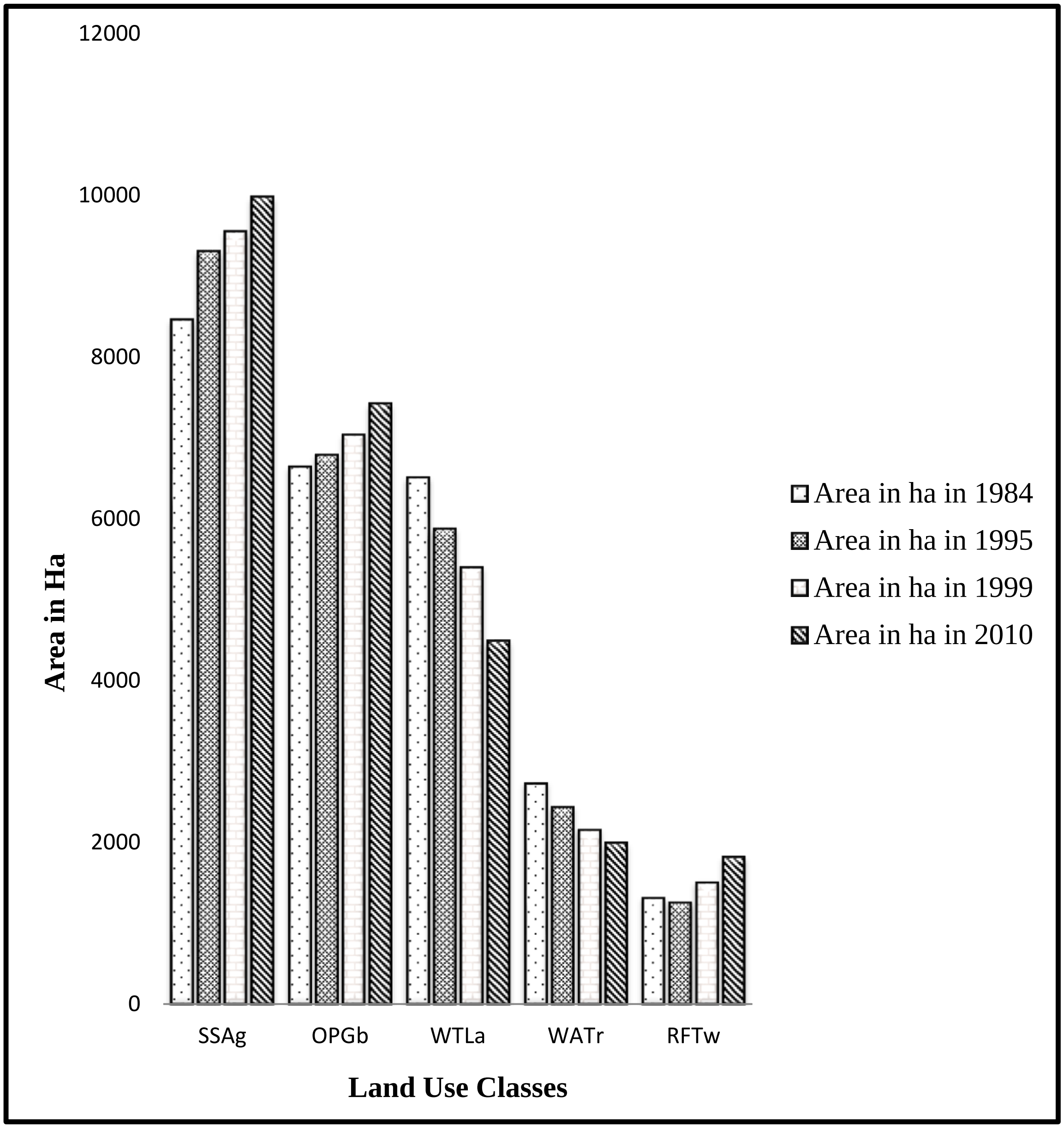


Figure 4.3: Quantitative Illustration of Changes in Area of Land Use Classes Measured Over Time from Satellite Images

Key: **SSAg =** Small-scale agriculture **WTLa =** Wetland Area**,** **WATr =** Water area**,**

OPGb = Open grassland, mixed bushes with exposed bare ground

RFTw = Rice farms and turbid paddy water surfaces, Accuracy analysis of the maps yielded an overall classification accuracy of 87%. The lowest accuracies were recorded in the category of Water Area (WATr). The overall kappa statistic of the maps was 86% (Table 4.3).

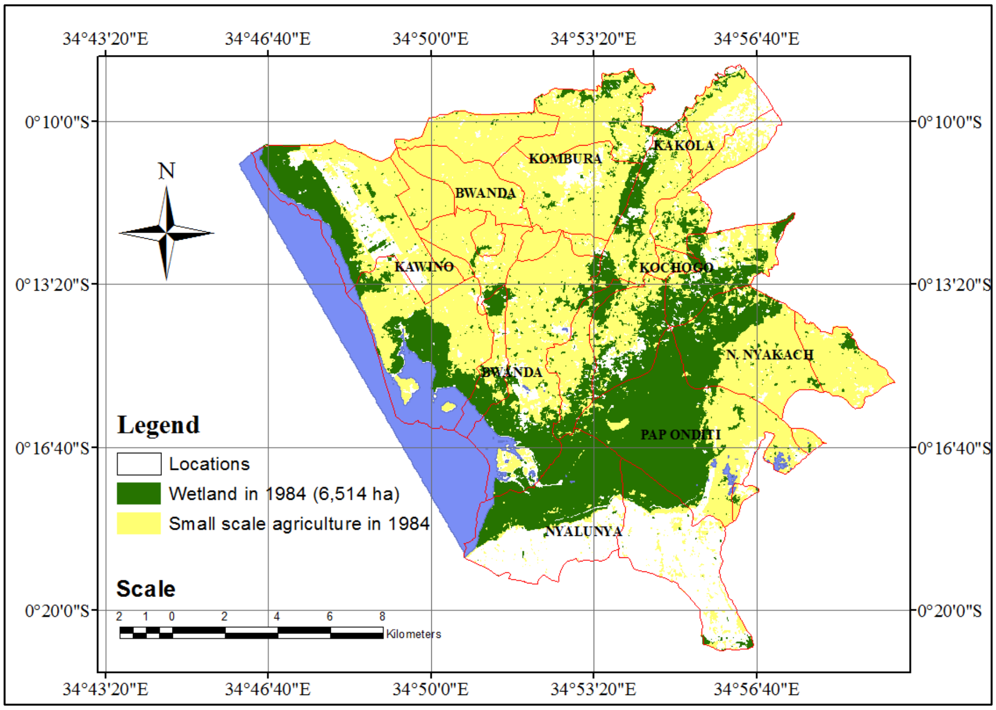
Table 4.3 Image Classification Accuracy Assessment for Nyando Wetland during the Study Period

Accuracy Totals						
Class Name	***No of Reference Pixels sites***	***Classified***	***Classified Correct***	***Producers* Accuracy**	***Users* Accuracy**	**Conditional Kappa per Category (K^)**
WTLa	88	81	73	90 %	83%	0.88
WATr	40	35	31	89%	78%	0.67
RFTw	36	36	32	89%	89 %	0.82
SSAg	200	201	182	90%	91%	0.87
OPGb	148	140	136	97%	92%	0.91
Unclassified	0	19	0			0
Totals	**512**	**512**	**454**			
Overall Classification Accuracy				**87%**		
Overall Kappa Statistic						**0.86**

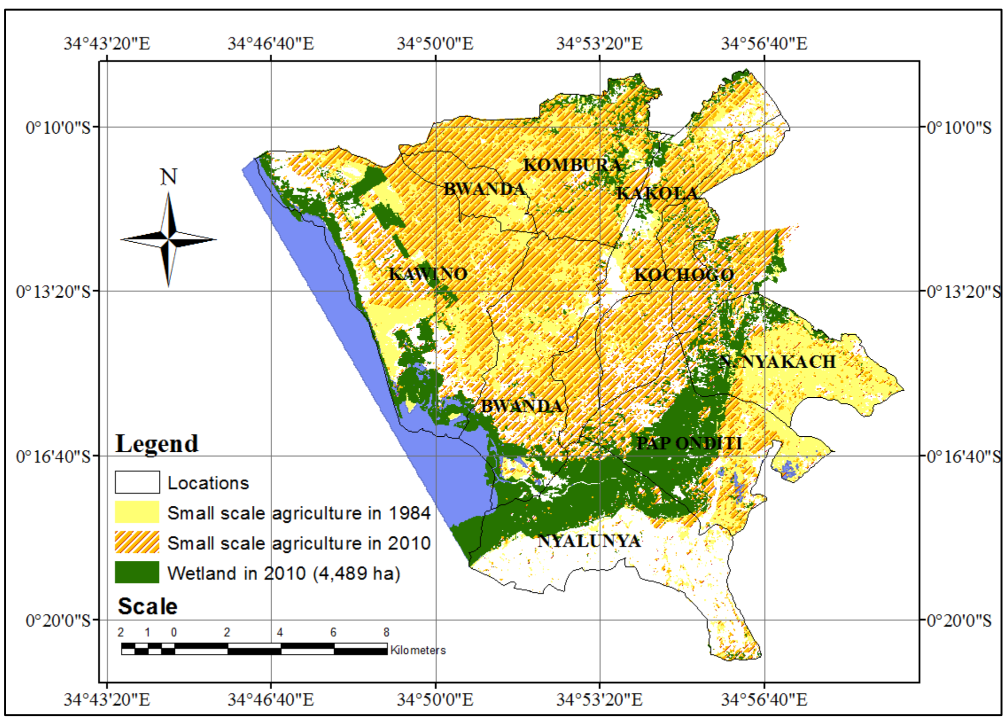
Key: **WTLa =** Wetland area**,** **SSAg =** Small-scale agriculture**, WATr =** Water area**,**
RFTw = Rice farms and turbid paddy water surfaces,
OPGb = Open grassland, mixed bushes with exposed bare ground

4.2.1 Changes in Small-scale Agriculture (SSAg)

The Small-Scale Agriculture (SSAg) cover type was found to have a temporal and spatial variability (Figure 4.4). In 1984, this category covered 8,460 ha which was about 32.9% of the study area, but increased by 10% (848 ha.) to 9,308 ha in 1995. During this period, the SSAg, cover type increased at an annual rate of 77 ha per year compared to 61 ha between 1995 and 1999.



a) Small-Scale Agriculture 1984



b) Small-Scale Agriculture 1984 and 2010

Figure 4.4: (a, b) Changes in Small-Scale Agricultural Land Use in Nyando Wetland 1984-2010

The latter case gave a variable value of 9,551 ha in 1999. However, there was a decline to 39 ha/annum in the rate of change in the subsequent years. The measured variable value of the cover type was recorded as 9,976 ha by the end of the study period in 2010.

Most changes in the SSAg cover type were intense in southern locations bordering the wetland of Kochogo South, Kakola Ombaka, Bwanda/Kanyagwal, Kawino South and Magina in Wawidhi in Nyando sub-county and Kadibo divisions of Kisumu sub-county. In Nyakach sub-county the most impacted locations were found to be Nyalunya North, Pap Onditi and North Nyakach in the north-eastern side of the Nyando Wetland, where part of the conversions were from agriculture to more open grasslands and bare ground; but which were compensated in the wetland areas. These changes occurred in a south-easterly direction during the period between 1984 and 2010. By 2010 the edges of the wetland cover type were already converted to small-scale farmland cover type giving the wetland category polygon a highly serrated indentation (Figure 4.4 and Plate 4.1). A variety of methods used for these conversions included burning, slashing or uprooting often worsened by excessive livestock grazing in the dry seasons (Figure 4.9 and Plate 4.1).

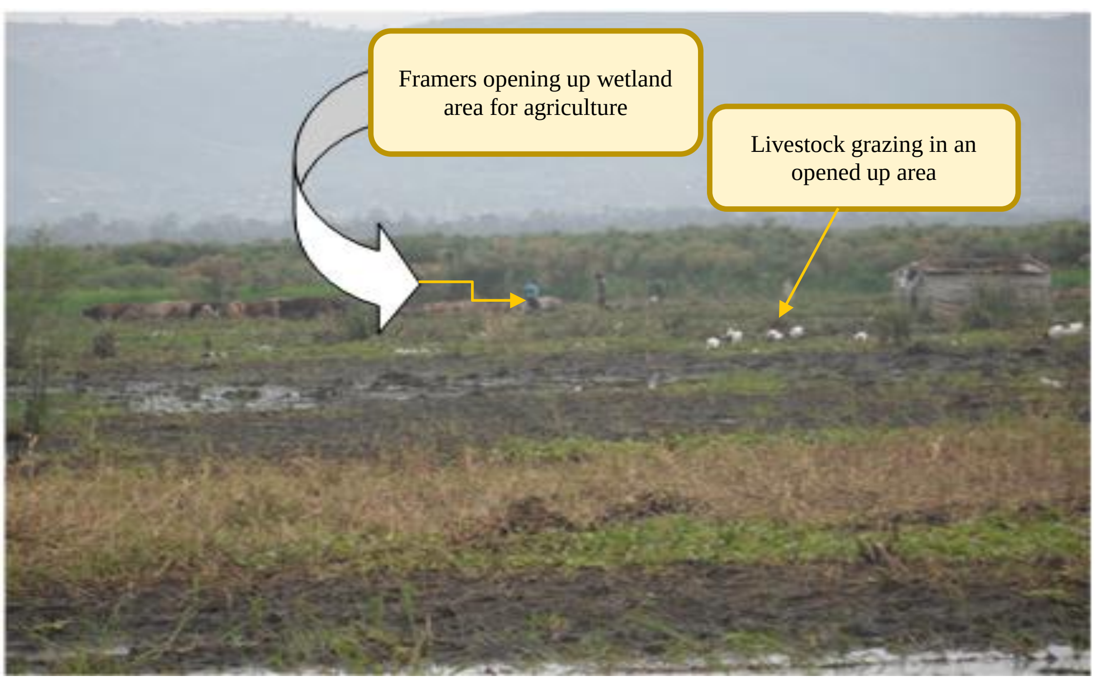
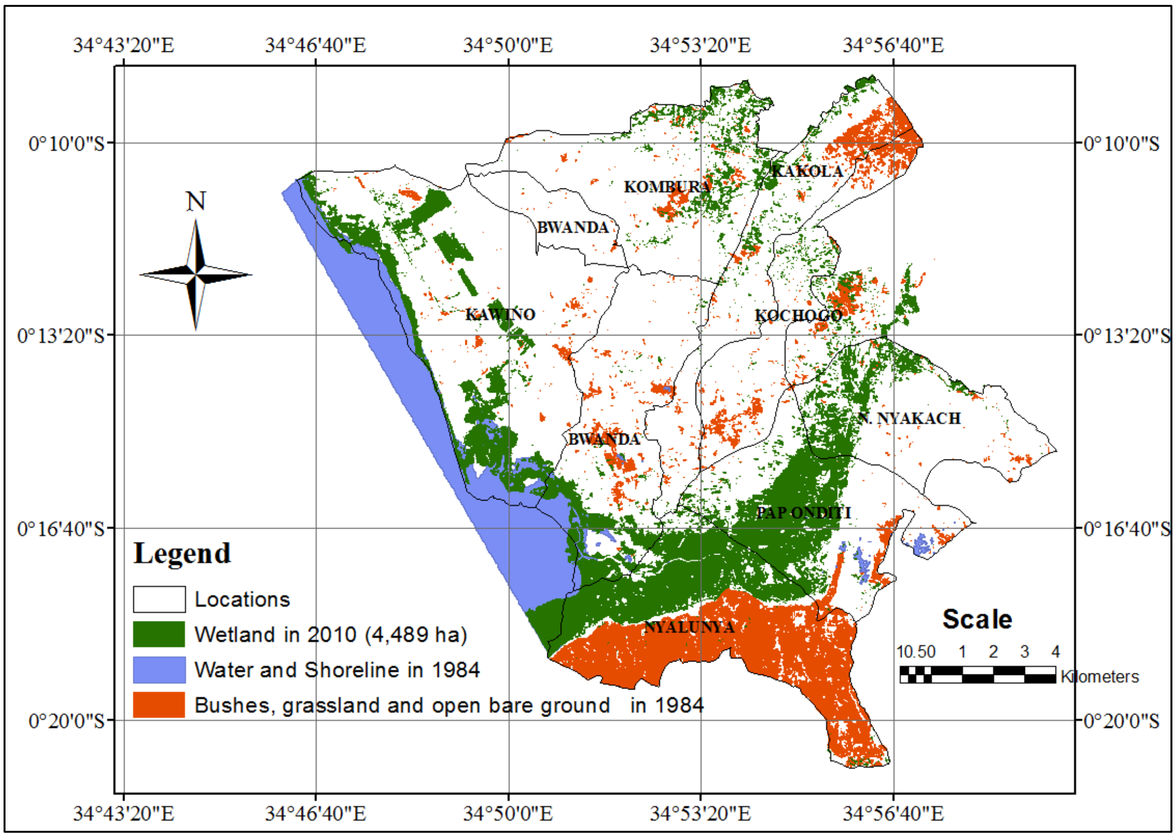


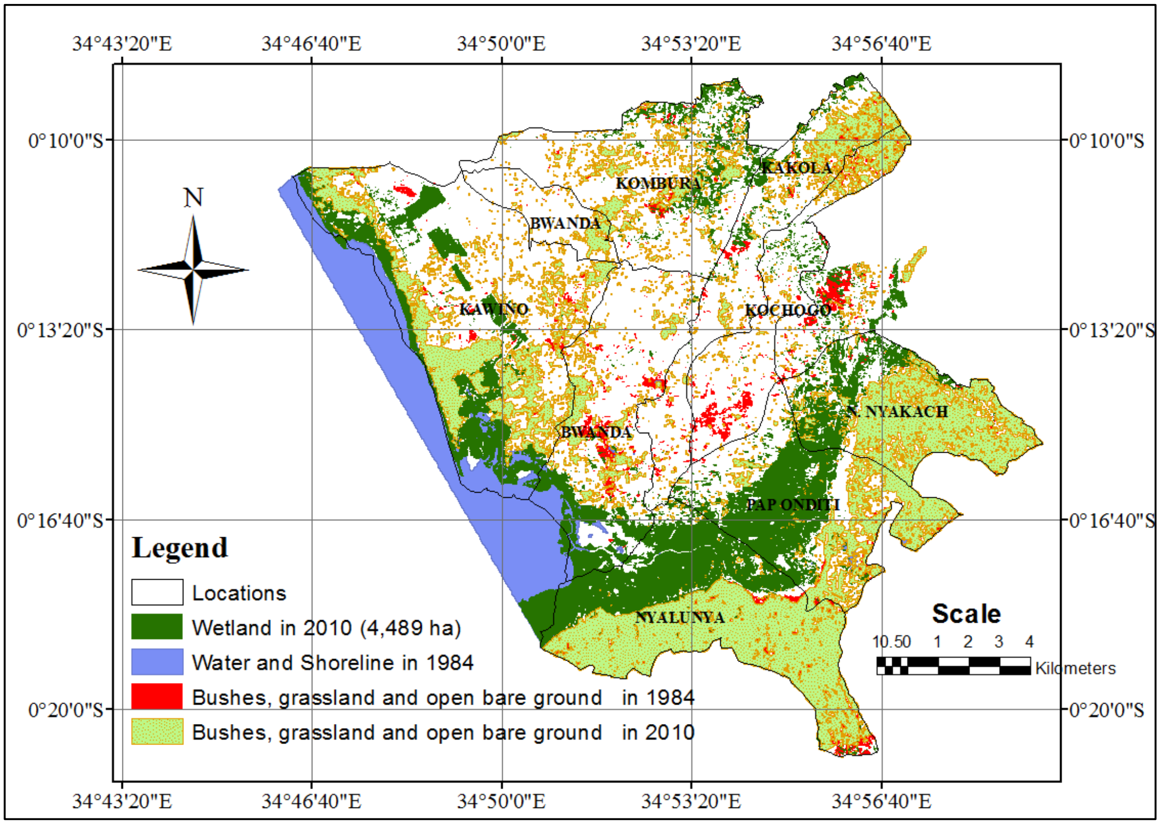
Plate 4.1 Livestock Foraging in a Burned Area of the Wetland Being Prepared for Agriculture at the Edges of the Remaining Wetland during the Study Period

4.2.2 Changes in Mixed Bushes Open Grassland, with Exposed Bare Ground (OPGb)

In 1984 the OPGb category covered some 6,647 ha which was about 25.9% of the study area. The area increased to 6,794 ha in 1995 and to 7,044 ha in 1999. By 2010 the category had expanded to 7,421 ha which was about 28.9% of the study area with some 3% overall increase during the study period. As presented in Figure 4.5 "a" and "b", the spatial predominance of this category was observed in the southern parts of the study area in Nyalunya Location and parts of Wawidhi sub-location in 1984 (the orange patches in the maps in Figure 4.5 "a" and "b"). Minimal patches were also observed in the southern parts of Kochogo and Bwanda Locations.



a) OPGb in Nyando Wetland Study Area in 1984.



b) OPGb in Nyando Wetland Study Area in 1984 and 2010

Figure 4.5: (a, b) Changes in OPGb in Nyando Wetland for the Period between 1984 and 2010

Areas in the wetland that had this category were observed in very minimal patches in North-eastern parts of north Nyakach and a bit of Wawidhi sub-location. By 2010, the spread of OPGb category was noted to have intensified in the same areas and spread to new areas in North Nyakach, Pap Onditi, northern parts of Kakola, Kawino (particularly in areas bordering the wetland) and Kombura Locations (the light green patches in maps in figures 4.5 "a" and "b"). The wetland areas in south-western Kochogo and north-western Pap Onditi were also noted to have parches of this category. The most affected wetland areas were observed in the south-eastern parts of Kawino, a bit of southern Bwanda and north Nyakach locations signify bush encroachment in the wetland area and in lands which were under other categories at the beginning of the study period.

4.2.3 Rice Farms and Turbid Paddy Water Surfaces (RFTw)

The spatial extent of RFTw is presented in Figure 4.6 and Figure 4.7. Regular flooded rectangular paddy fields are used as rice farms in the study area (Plate 4.2).

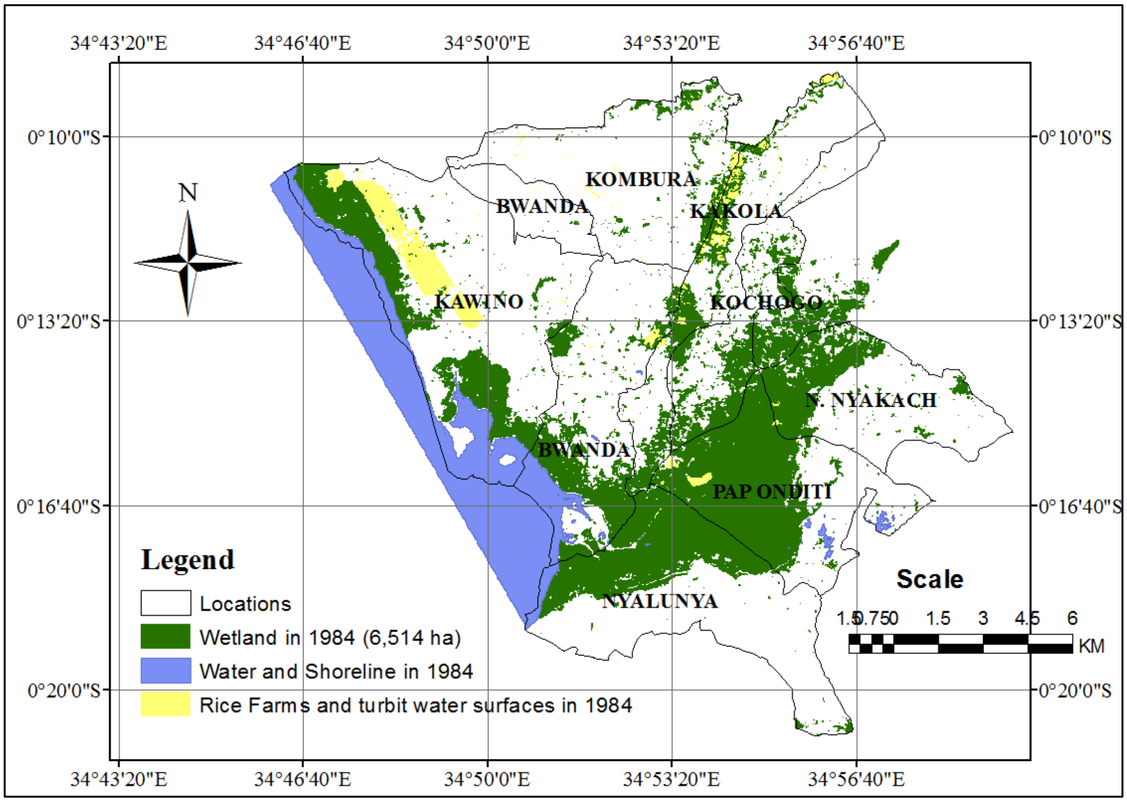


Figure 4.6: Spatial Rendition of Area of RFTw in 1984 in Nyando Wetland

The RFTw cover type declined in area by 5%, from 1,329 ha in 1984 to 1,265 ha in 1995. Estimates show that between the years 1995 and 2010, the area under this category progressively reclaimed at least 19 ha. (2%) annually. In 1995, the area under the category began to expand such that by 1999 it was 1,518 ha and then increased to 1,817 ha in 2010. Many more patches of this category occurred within the wetland in 2010 compared to 1984.

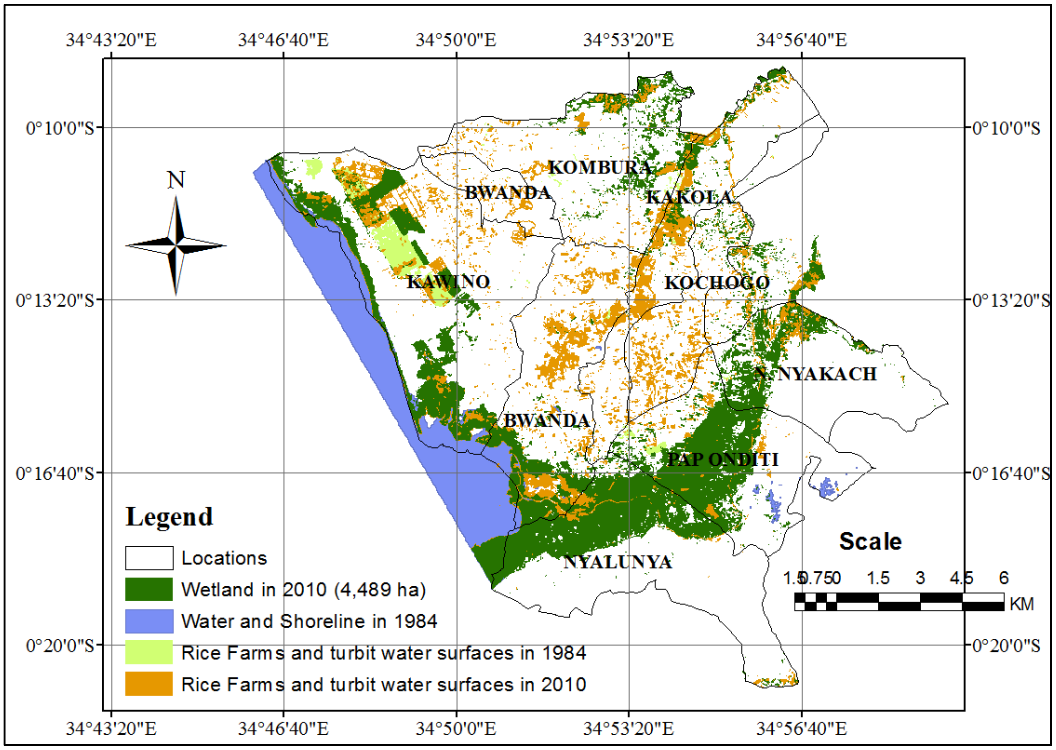


Figure 4.7: Spatial Rendition of Changes in Area of RFTw between 1984 and 2010 in Nyando Wetland

Plate 4.2 Rice Farming and Flooded Paddy Water Surfaces in the Wetland

(Evidence of multiple agricultural activities and grain eating (Granovores) bird nuisance (the scarecrows) are clearly seen in the fore and mid grounds)

Wetland areas in the study area such as lower parts of Nyatini, Kamayoga, Nyakalewa, Dakrawo, Ondila, Siany and West Kano, now under irrigated rice crop, were observed to have contributed much of the increase in the size of this category. Magina, and Awach patches in the north-eastern, eastern and the south-eastern parts of the wetland, were however observed to have contributed marginally to the increase in land coverage within the RFTw category.

Results in Table 4.4 derived from perception measures investigated as part of the DPISR framework further show that land used for crops increased significantly over the years from 1980 to 2010.

Table 4. 4: Changes in the Land Used for Crops in Nyando Wetland for the Period Starting 1980 - 2010

	% of respondents *Cropland Land inside wetland*			
Period (Years)	***Decreased***	***Remained same***	***Increased***	***Statistics***
1980-1990	14	34	54	χ^2 = 26.25, df = 2, p <.0 00
1991-2000	17	30	53	χ^2 = 27.86, df = 2, p < 0 00
2001-2010	33	16	52	χ^2 = 30.36, df =2, p < 0.00

n=196

Sixty three per cent (63%) of the households reported using combination of methods to clear the wetland and expand their agricultural activities in the wetland (Fig. 4.8). These included burning, slashing and uprooting. Cutting or slashing and burning as individual methods of opening up the wetland for cultivation were also reported as important at 24% and 17%.

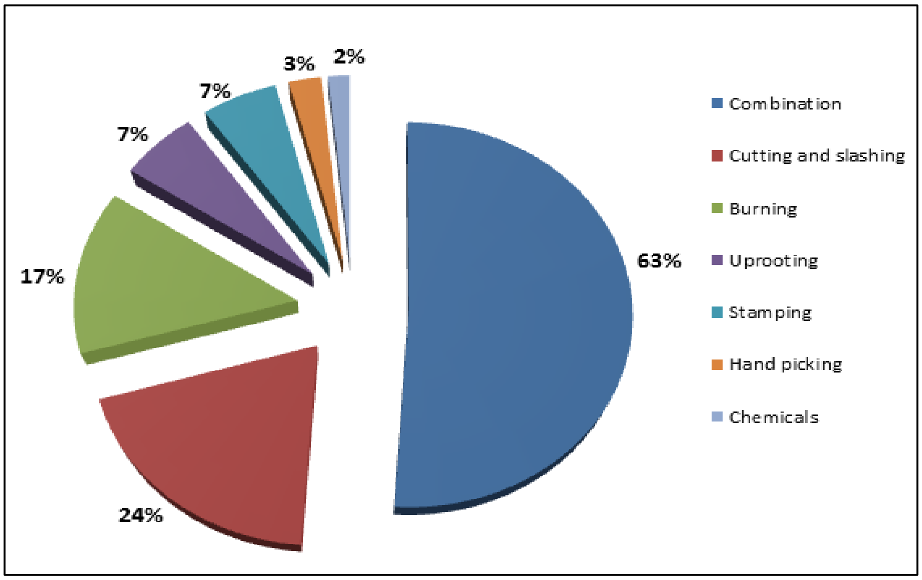


Figure 4.8: **The Methods Used to Clear the Wetland Area for SSAg in Nyando Wetland during the Study Period**

There were several patches of the small scale agriculture (SSAg) cover type right inside the Nyando Wetland (Plate 4.3) especially on the northern, north western, north eastern and eastern frontiers of the wetland. This phenomenon is reflected by the intensity of the reddish colour renditions for the 2010 SSAg cover type on the maps in Figure 4.4.

Plate 4.3: **Patches of Mixed Agricultural Activities Noted Right in the Middle of Nyando Wetland (shown by the arrow) on the North Eastern Part of the Photograph**

(**Photo courtesy;** MEMR, 2012)

Perception ranking results are presented in Figure 4.9. They indicated that a total of 16 factors influence crop production or agricultural expansion within the area. Out of the 16 factors, five are considered major as the majority of respondents (62%) cited them as important in influencing rapid expansion of this land use category into the wetland area. These include damage by insects, diseases or both wild and domestic animals (18%), lack of water/drought (16%), shortage of working capital (12%), lack of reliable markets and high cost of inputs (8%) and non-farm income (8%). The rest of the other 9 factors investigated each contributed below 10% and in total accounted for 38% making them relatively insignificant in the decisions of respondents to expand agricultural activities into the wetland area.

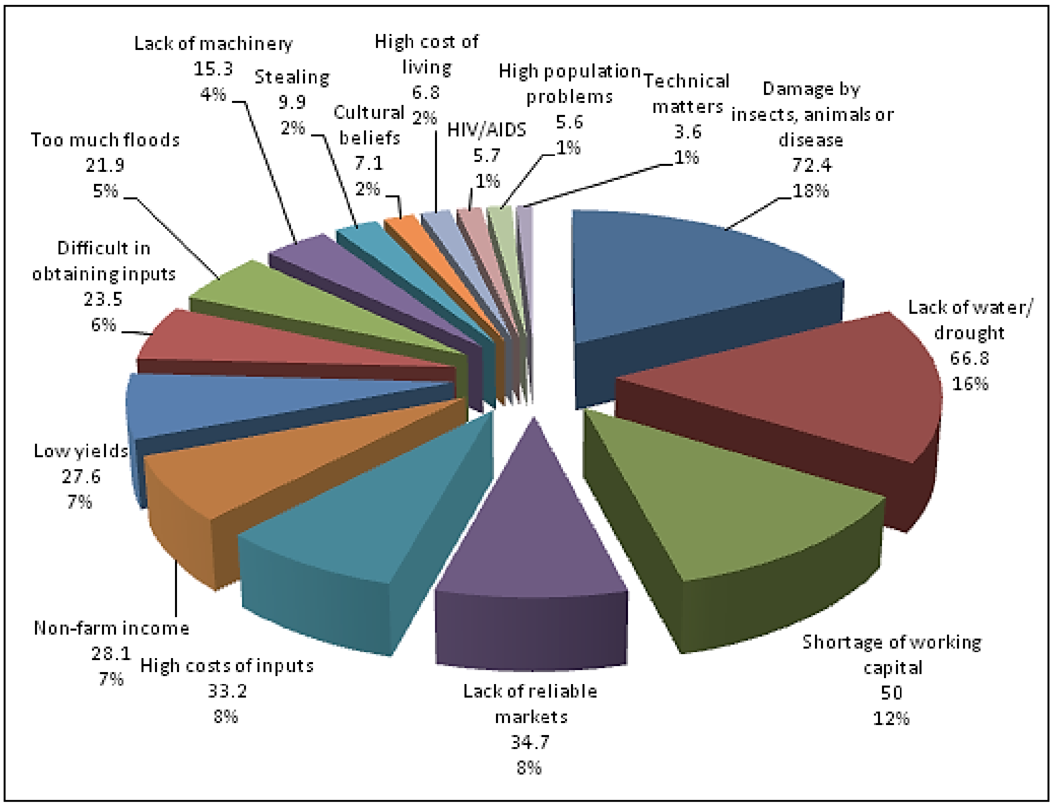


Figure 4.9: Respondents Ranking of Reasons for Expansion of Smallscale Agricultural Activities into Wetland Areas during the Study Period

4.2.3 Implications and Impacts of Land Use/Cover Changes in Nyando Wetland

Results of analysis of questionnaire data show that, 12 different crops are grown. The farmers grow 1 to six 6 different types of crops in their relatively small plots both inside and outside of the wetland area. Sixty eight (68%) of the households grow more than one type of crop inside the wetland area; while sixteen (16%) planted at least one crop and fifteen (15%) had no crop in the wetland plots. In order of area under coverage and preference, the crops grown in the area were maize, rice, sugarcane, sorghum, water melon, beans, cowpea for seed, cow pea for vegetable, and butter nut. Others were sweet potatoes, arrow root, kale, tomatoes, finger millet, spider plant (*Cleome gynandra*) often referred to as "dek" in local dialect, onion, cassava, pepper (*Capsicum*), black nightshade (*Solanum*) often referred to as "Osuga" in local dialect and Banana.

The crops with the highest financial returns were maize, rice, sugarcane and sorghum. Sorghum's returns were shown to be more for farming outside than was for farming inside the wetland (Figure 4.10).

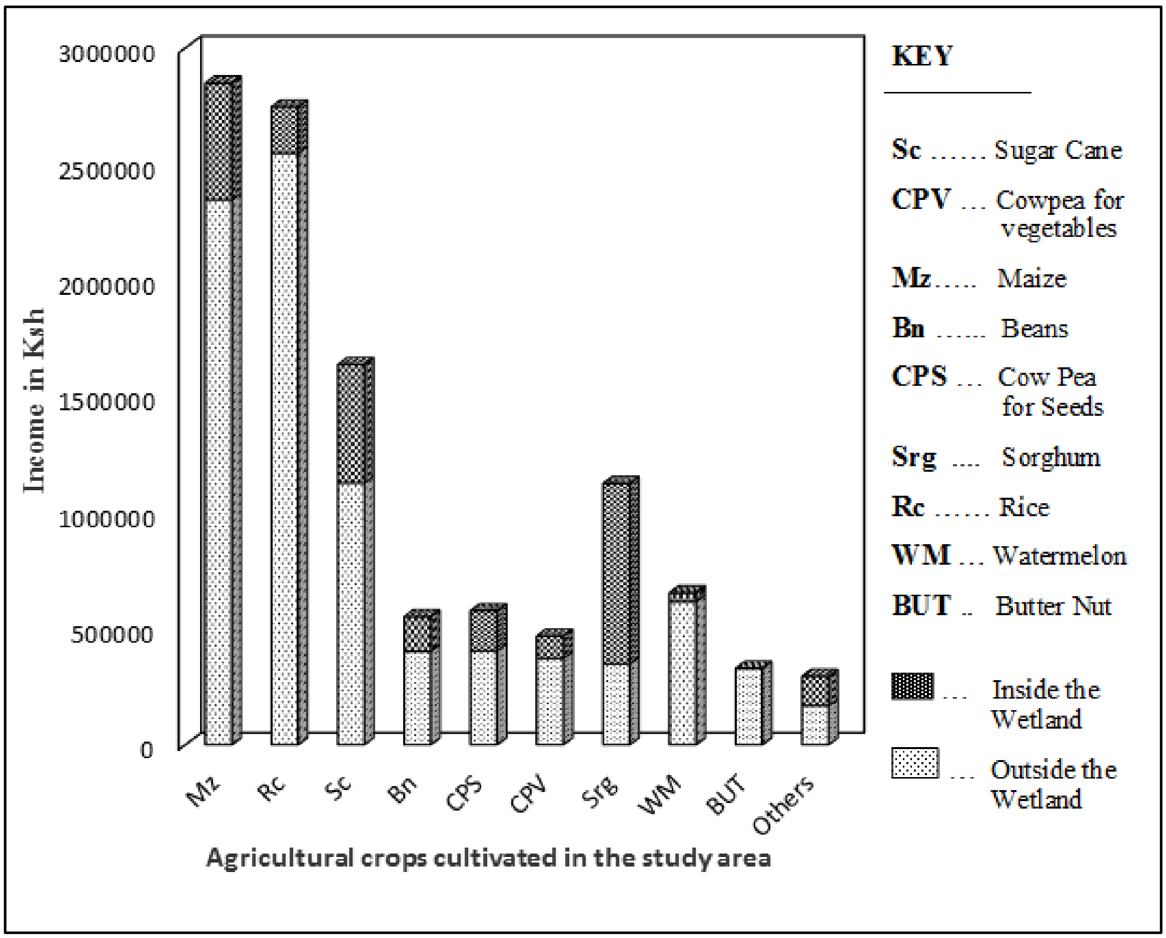


Figure 4.10: Agricultural Activities, Economic Returns from Farming Inside and Outside Nyando Wetland during the Study Period

Of the annual income of more than Kshs. 11,226,560 obtained by the respondents in Nyando Wetland area, 77% originated from farming activities inside the wetland while only 23% are proceeds from farming activities outside the wetland. It may then be that this difference arose from the fact that there are normally higher yields in terms of quantity per unit area than can be obtained from farming outside the wetland.

However, sample t-test values (Appendix 11) associated with corresponding p-values for the same crops indicated that crops such as maize (t-stat = 0.59, p = 0.56), rice (t-stat = 0.45, p = 0.65), sugar cane (t-stat = 0.06, p = 0.95), sorghum (t-stat = -1.23, p = 0.23), cow peas for seeds (t-stat = 0.47, p = 0.63) and beans (t-stat = 0.81, p = 0.42) have p-values greater than the common alpha level of 0.05 at 95% confidence level. This suggests that there is no evidence for a significant difference in financial returns for these crops whether cultivated inside or outside the wetland. This means that perhaps there are other factors other than financial profitability driving the communities to open up wetland areas for farming of these crops in the wetland. The only crops that showed evidence of a difference in economic returns, with p- values less than or equal to 0.05 were cow peas for vegetables (t-stat = 2.23, p = 0.02) and water melon (t-stat = 2.47, p = 0.03) meaning that they are actually profitable.

The number of years the households have been farming in the wetland is given in Table 4.5. The various respondents claim that they have practiced agriculture in the Nyando Wetlands for periods ranging from 2-58 years. This time variation between categories was found to be statistically significant at 95% confidence level (χ^2 = 90.78, df = 5, p < 0.00). The modal categories of 1-10 yrs and 11-20 yrs which constitute more than 62.2% of the land users have actually been practicing agriculture in the wetland for the last 20 years.

Table 4. 5 **The Period Respondents have Been Carrying out Farming Activities in Nyando Wetland**

Years (categories)	Frequency	Per cent
1-10	61	31.1
11-20	61	31.1
21-30	36	18.4
31-40	22	11.2
41-50	11	5.6
above 51	5	2.6
Total	196	100.0

($\bar{X}$=18.52, median = 15, mode = 7, σ - 12.67, minimum = 2, maximum = 58, (χ^2 = 90.78, df = 5, $p < 0.00$)

Perception of habitat/biodiversity change due to the observed conversions, using *granoivores* such as the *Ploceidae* family of birds e.g. *Ploceus spekei and Quilea quilea*, as indicators of change and as part of the DPSIR framework are presented in Figure 4.11.

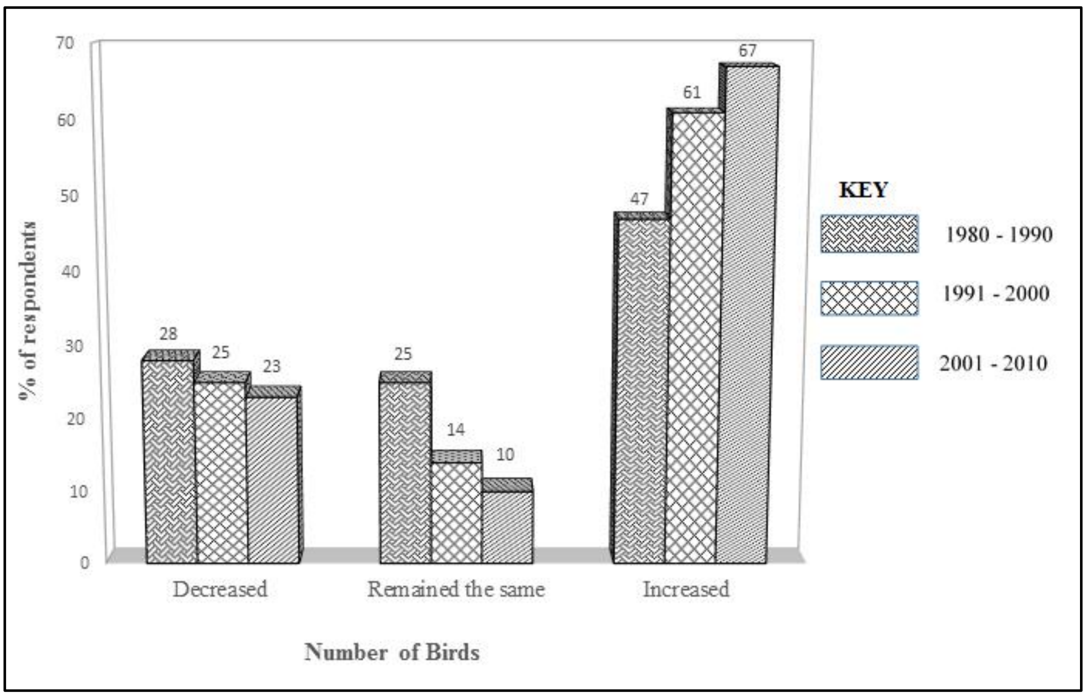


Figure 4.11: Perceived Impact of Wetland Cultivation using Granivores (*Quelea quelea*) as an Indicator of Biodiversity Changes in Nyando Wetland during the Study Period

The results show that between 1980 and 1990, 47% of the respondents indicated that grain eating birds had increased in the wetland as compared to 28% and 25% who thought, the birds had decreased and remained the same respectively. This is significant ($\chi^2 - 9.01$, df 2, $p<0.05$). Similarly, between 1991-2000 and 2001-2010, more people, 61% and 67% respectively reported increases in grain eating birds than in previous periods in which 14% and 10% were reported respectively. The analysis shows that the difference is significant ($\chi^2 = 44.68$, df = 2, $p < 0.00$) and ($\chi^2 = 71.15$, df = 2, $p < 0.00$).

4.2.4 Hypothesis testing for Objective one

Stating the first hypothesis to address objective one of the study;

H_{01}: There are no significant spatio-temporal changes in land use/cover types that can be attributed to changes in the size of Nyando Wetland

Or the Alternative;

The regression analysis output in Table 4.6 shows that out of the four land use variables considered in the study (WATr (x_1), SSAg (x_2), OPGb (x_3) and RFTw (x_4)), only three have significant effects on the changes in wetland area. The open grasslands and mixed bushes (OPGb) (x_3) was excluded from the model because the regression output showed that it was not a significant addition to the model possibly due to collinearity at a tolerance level of $7.03*10^{-7}$ (Table 4.7). This can be attributed to the fact that when the wetland area is negatively affected by the anthropogenic land use variables (SSAg (x_2), RFTw (x_4)), the open grasslands and mixed bushes (OPGb) tends to increase possibly due to other non-agricultural areas such as fallow areas in the wetland. It therefore changes with respect to impacts of the anthropogenic factors on the wetland. As for the other land use variables, the adjusted R^2 is positive (0.998) therefore suggesting that the model is significant since all the three explanatory variables in the model have significant effect on the dependent variable (wetland area - WTLa).

Table 4. 6 **Regression Analysis Output of the Model Showing the Effects of Land Cover/Use Variables on WTLa in Nyando Wetland during the Study Period**

Model	Coefficients: Unstandardized B	Coefficients: Unstandardized Std. Error	Coefficients: Standardized Beta	t- Stat	p-Value	*H_0*
(Constant)	27599.16	2717.07		10.15	0.01	NO
WATr(x_1)	-1.54	0.16	-1.09	-9.49	0.01	NO
SSAg (x_2)	-2.20	0.27	-.88	-8.08	0.01	NO
RFTw (x_4)	-1.85	0.40	-.87	-4.58	0.04	NO

Key: **WTLa =** Wetland Area, **WATr =** Water area**, SSAg =** Small-Scale Agriculture**,**
RFTw = Rice farms and Turbid Paddy Water Surfaces

Table 4.7 **Regression Analysis Output of Model Showing the Effects of OPGb Variable as Excluded from the Model**

Model	Beta In	t-stat	Sig. (p)	Partial Correlation	Collinearity Statistics Tolerance
OPGb (x_3)	35.54	0.78	0.57	0.61	$7.03*10^{-7}$

Key: **OPGb (x_3) =** Open Grasslands and Mixed Bushes with exposed bare ground

Since the probability statistic (p-values) of the three predictors of the explanatory variables WATr ($p = 0.01$), SSAg ($p = 0.02$) and RFTw ($p = 0.04$) are less than the common alpha level ($p < 0.05$), the study fails to accept the null hypothesis at 95% confidence level.

4.3 Population Size, Growth and Land Use Conversions in the Wetland

4.3.1 Characteristics of Human Population

The study interviewed 65% male and 30% female headed households. The category of households that were headed by men but run by women accounted for only 5%. It was also found that the majority of the heads of the households were married (66%), while 32% were widowed and 2% were single. The majority of respondents had between 3 and 10 children and the mean household size was 6 (household size range from 1 to 13). Majority (82.1%) of the respondents were aged between 21 and 60 years (Table 4.8).

Table 4. 8 Age Categories of the Household Heads in Nyando Wetland Area during the Study Period

Age categories	Frequency	Per cent
Below 20 years	6	3.1
21 - 40 years	92	46.9
41 - 60 years	69	35.2
61 - 80 years	28	14.3
over 81	1	.5
Total	196	100.0

$\overline{X}$ *= 43.66, se = 1.06, median = 41, mode = 35, Std. dev. = 14.88, minimum = 16 maximum = 82*

It was also found that 14.3% of the respondents had no formal education. Over 76% were in the lowest categories of formal education, which is upper primary, lower primary and no formal education. About 14% had reached secondary education and 7.7% post primary level of training. The respondents who had received post-secondary training, middle level college and university were 2.5% (Figure 4.12).

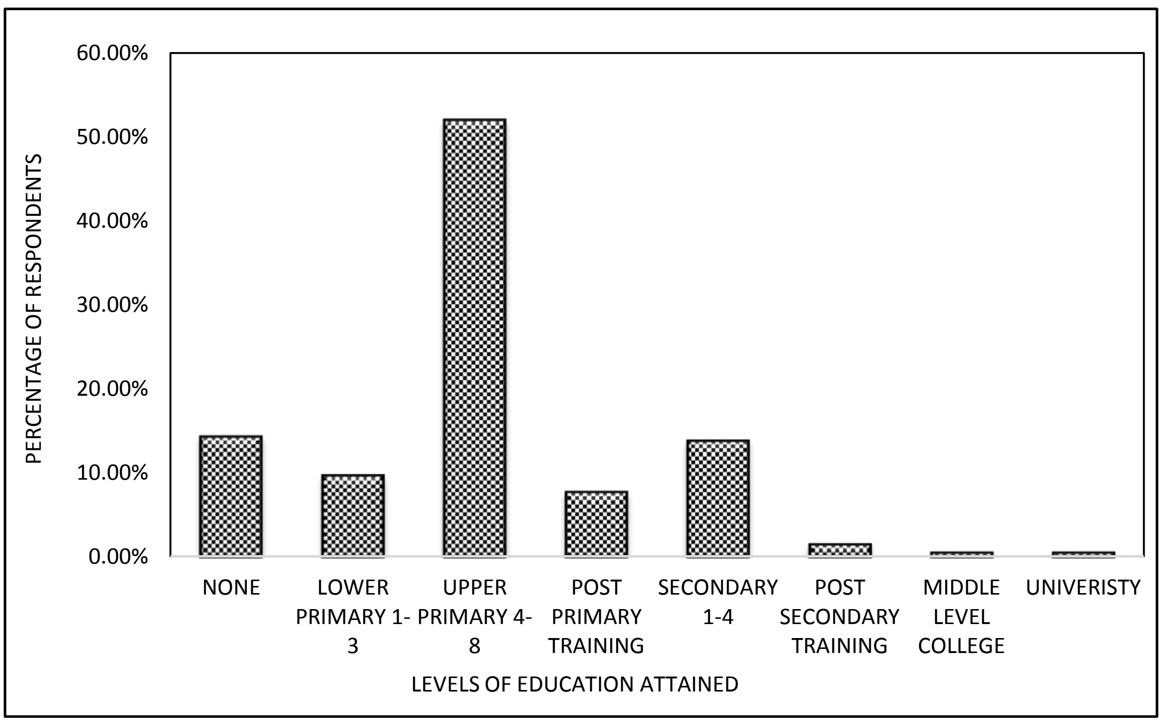


Figure 4.12: Education Attainment Levels of the Household Head in Nyando Wetland

4.3.2 Human Population Growth Patterns

The average human population growth rate per annum in the nine (9) locations over the thirty year period (1979 – 2009) was estimated as 1.63% using the compounded growth rate formula as follows:

$$\text{Population Growth Rate} = \left\langle \left(\frac{78{,}057}{48{,}117}\right)^{\frac{1}{30}} - 1 \right\rangle \times 100 = 1.63\%$$

Growth Rate = 1.63%

The inter-censoral human population growth rate between 1979 and 1989 was 2.14% per year calculated as follows:

$$\text{Population Growth Rate} = \frac{(58{,}451 - 48{,}117)}{48{,}117} \times {}^{1}/_{10} \times 100 = 2.14\%$$

Between 1989 and 1999 the human populations grew at 1.44% per year as calculated below:

$$\text{Population Growth Rate} = \frac{(66{,}850 - 58{,}451)}{58{,}451} \times {}^{1}/_{10} \times 100 = 1.44\%$$

The human population growth rate between 1999 and 2009 was estimated as 1.7% per year in these locations also calculated as follows;

$$\text{Population Growth Rate} = \frac{(78{,}057 - 66{,}850)}{66{,}850} \times {}^{1}/_{10} \times 100 = 1.68\% = 1.7\%$$

Generally however, the human population of Kakola location was found to have risen from 7,797 in 1979 to 21,967 persons in 2009 - an increase of about 178% thus exhibiting a compounded growth rate of 3.5% per annum over the thirty year period. This was followed by Kochogo which increased from 4,707 in 1979 to 9,761 persons in 2009, an increase of about 107% exhibiting a growth rate of 2.5%. The other locations that are shown to have registered consistent positive increases were, Kombura from 4,410 to 8,116 (84% rise and 2.1% population growth rate), North Nyakach from 3,637 to 6,205 (70% increase and 1.8% growth rate), Rang'ul from 3,767 in 1989 to 4,772 in 2009 (27% and a growth rate of 1.2%). Bwanda and Kawino south locations had a slight population increment over the 30 year period of around 0.3% while Pap Onditi's and Nyalunya's human population sizes slightly reduced at a rate of -0.3 and -0.1 respectively (Figure 4.13).

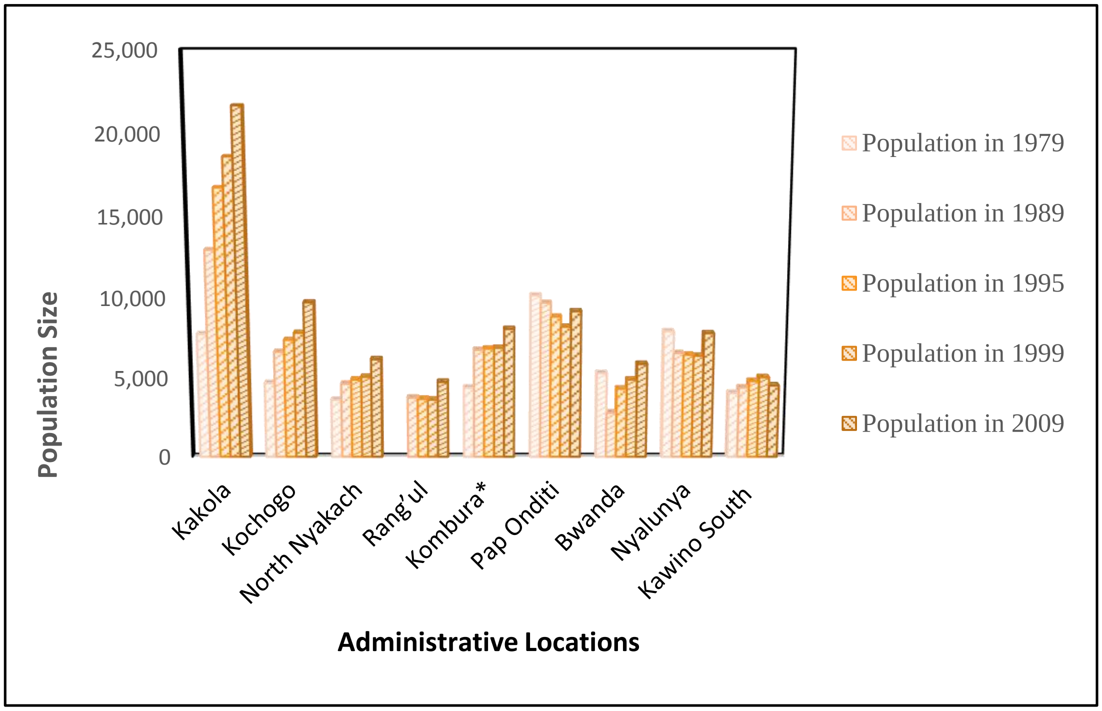


Figure 4.13: **Human Population of the Study Area between 1989 and 2009**
(Source: KNBS 1989, 1999 and 2009)

The overall growth rates for the study area were also compared to the mean national growth rate of Kenya as a country (Figure 4.14). It was found that the population growth rate increased rapidly between 1979 and 1989 against a dropping national population growth rate; but then flattened off and then began to slightly reduce in the period approaching 2010. In order to understand the relationships between population growth and Nyando Wetland resource use, data from two locations of Kochogo and Kakola were further analyzed since they best represent the characteristics of a typical developing country such as Kenya. It was found that if these two locations were to be used as a representation of the study area, then

Nyando Wetland area registered the highest compounded growth rates at 4.63% between 1979 and 1989, 2.1% between 1989 and 1999 and finally settling at a growth rate of 2.7% (Figure 4.15).

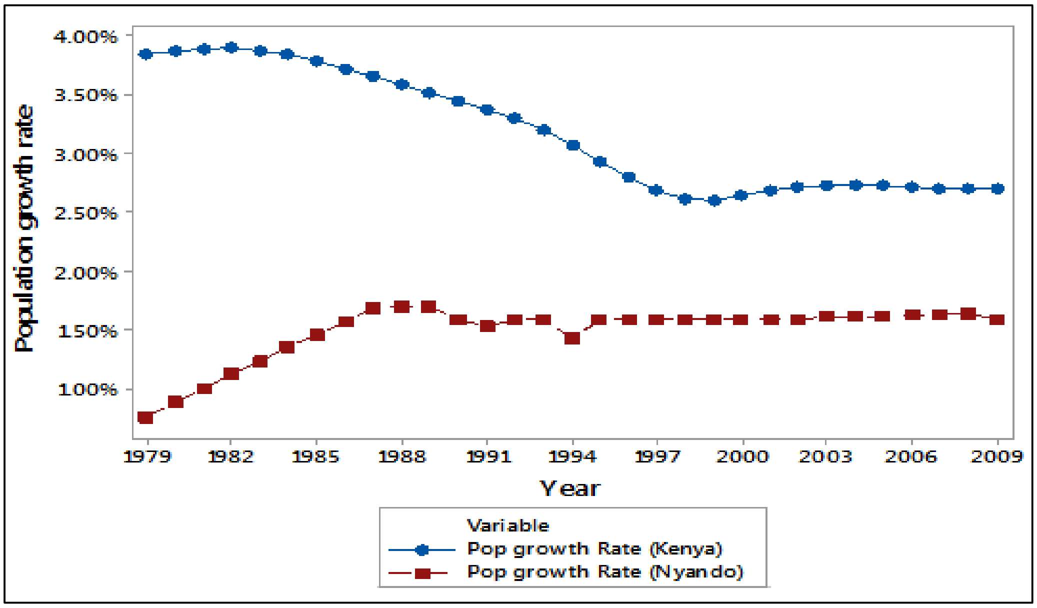


Figure 4.14: Population Growth Rates of the Study Area as Compared to Mean National Growth Rates

(**Source:** KNBS 1989, 1999 and 2009).

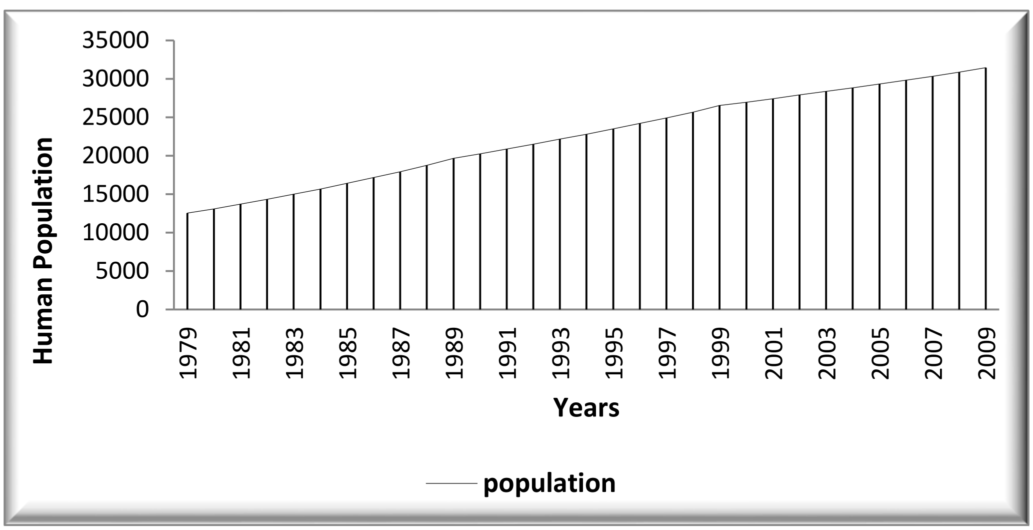


Figure 4.15: Population Growth Curve of the Study Area as Represented by the Two Locations of Kochogo and Kakola during the Study Period

(**Source:** KNBS 1989, 1999 and 2009).

Figure 4.16 presents the spatial distribution of population densities (the yellow to deep orange colours), while the bar graphs shows the spatial distribution of population growth patterns in the study area. The Figure indicates that slow and inconsistent population growth patterns are typified by locations that are spatially close to the wetland except for the case of Pap Onditi. It also shows that population concentrations and steepest growth rates, as evidenced by the population size bars, were further away from the wetland. These areas were in the proximity of urban and market areas such as Ahero (deep orange colours).

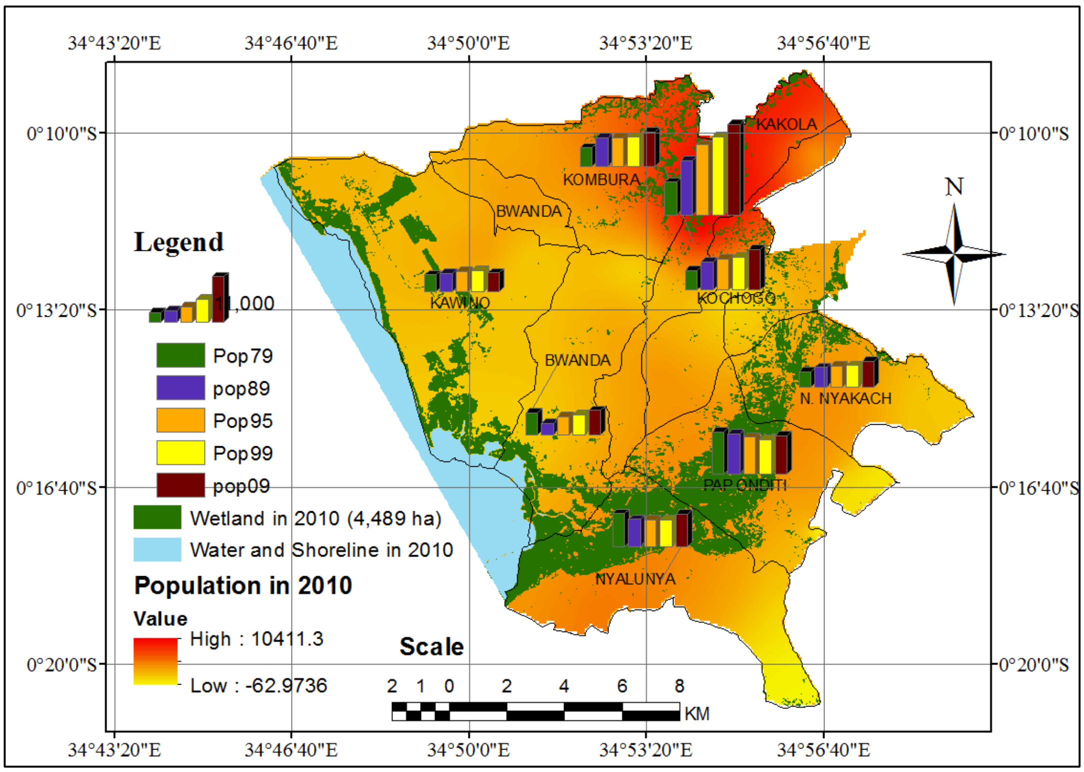


Figure 4.16: Spatial Representation of Population Changes in the Study Area between 1979 and 2010

(Source: KNBS 1979, 1989, 1999 and 2009, Field Data, 2010**)**

4.3.3 Household Spatiotemporal Interactions with Nyando Wetland

The spatial distribution of the sampled households to determine how the local communities perceive and interact with the resources of Nyando Wetland as part of the DPSIR framework is presented in figure 4.17. The linear zig-zag patterns of the dots show transects taken across each of the sampled sublocations in the study area.

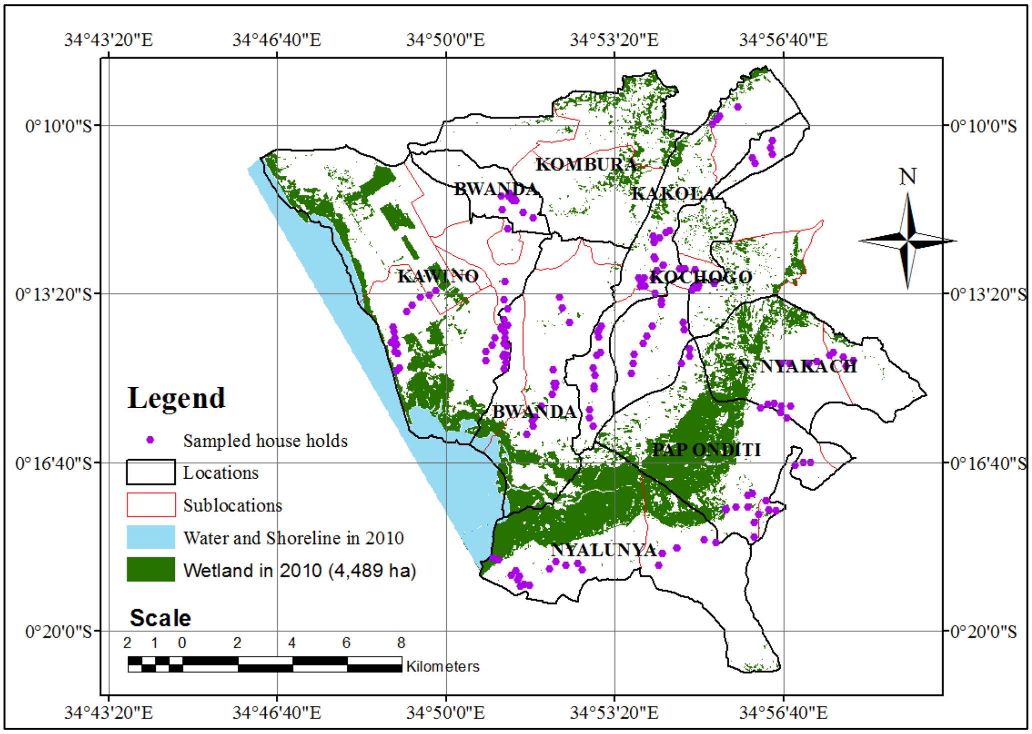


Figure 4.17: Spatial Distribution of Sampled Households in the Study Area

The results indicate that land ownership is a critical issue and is considered as a major capital by the riparian community in the Nyando Wetland study area, especially when it is available inside the wetland area. It was found that only 15% (30/196) of the respondents did not own any piece of land inside the wetland while 68% (133/196) owned at most 3 acres of land there, while 13% (25/196) owned land of between 3 to 5 acres inside the wetland. Some 8% of the respondents, however, said that they own more than 5 acres of land. Most of the land was found in areas which were once covered by the wetland especially in those areas which were either temporarily inundated or exposed by the lake-water recession and people were able to access them for farming.

A logistic regression model (equation 11) to investigate some of the socio-economic characteristics of the population that had significant influence on the decisions of the households to open up wetland areas for agricultural activities was run on the data. The response value that was designated as the reference event in the model was wetland farming. The six risk factors mentioned most frequently in the household survey included; distance, fertility change, soil moisture (water constraint), animal destruction, flood frequency and maize returns (representing other crops often cultivated inside the wetland area). Results of the model are as shown in Figures 4.18, 4.19 and 4.20 and Tables 4.7 and 4.8.

Figure 4.18 shows the distribution of the household survey data and how well they fitted the model. In the charts, about 6% of the total respondents in the survey were not well fitted by the model because they have high delta Chi (χ^2).

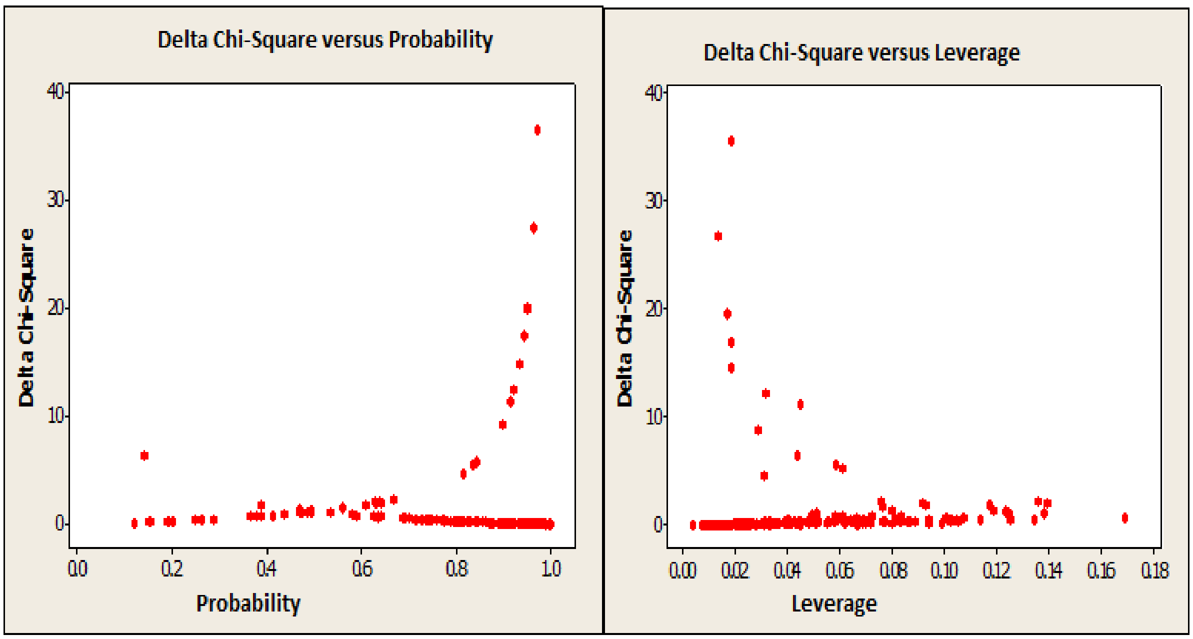


Figure 4.18: The Distribution of the Household Survey Data and Model Fit for Nyando Wetland during the Study Period

The measures of association in Table 4.9 give results of three different measures of rank correlation computed for the quantities. The various measures of rank correlations are good ranging from 0.19 to 0.62. The logistic regression (Table 4.10) presents the estimated coefficients, standard error of the coefficients, z-values, p-values, and the odds ratio at a 95% confidence interval. It was found that, out of the six variables investigated, only four had significant influence on the decisions of communities to reclaim wetland areas for farming activities. These include: Distance ($z = -2.63$, $p = 0.01$), Soil moisture ($z = 2.04$, $p = 0.04$), Animal destruction ($z = 3.44$, $p = 0.00$) and Maize returns ($z = 1.18$, $p = 0.05$). This resulted in binary logistic model expressed as follows:

$$\text{Logit}, \mathbf{Wc} = -0.10975 - 0.32802_{\mathbf{x1}} + 1.03128_{\mathbf{x2}} + 1.58611_{\mathbf{x3}} + 0.00014_{\mathbf{x4}} \ldots\ldots\ldots\ldots\ldots (11)$$

Where:

Wc= Decisions of respondents to farm inside (yes) or outside (no) the wetland

$\mathbf{x_1}$=Distance

$\mathbf{x_2}$=Soil moisture

$\mathbf{x_3}$=Animal destruction

$\mathbf{x_4}$=Maize returns

It was also found that soil moisture was the single most important factor providing incentives for conversion of wetland areas into agricultural activities since; for every unit increase in soil moisture whose odds ratio was 2.80, the odds of wetland farming increased by 180% all other factors held constant. This was as compared to the odds ratio for maize returns, which was signifying fertility or productivity of wetland soils that was found to be 1.0. Thus for each unit increase in maize returns, while the other variables were held constant, the odds of wetland farming did not change at all. On the other hand, animal destruction was found to be significant in this particular model and is reported by 88% of the respondents but the other benefits of wetland farming alleviate the effects of this variable in the model. Other variables such as fertility change (z = -0.14, p = 0.89) (z = 0.23, p = 0.82) and flood frequency (z = 0.14, p = 0.89), (z = 0.10, p = 0.27) have p-values greater than 0.05 and therefore not statistically significant. The odds ratio for distance was estimated as $e^{-0.328019}$ (0.72); and e^{B1-1}(-0.28). For each additional unit increase in distance from the wetland, the odds of wetland farming decreased by 28%, all other factors held constant.

Table 4. 9 **Measures of Association between the Response Variable and Predicted Probabilities in Nyando Wetland during the Study Period**

Pairs	Number	Per cent	Summary Measures	p-Value
Concordant	4755	80.8	Somers' D	0.62
Discordant	1104	18.8	Goodman-Kruskal	0.62
Ties	24	0.4	Gamma Kendall's Tau-a	0.19
Total	**5883**	**100.0**		

Table 4. 10 **Logistic Regression of Wetland Farming and Potential Decision Risk Factors in Nyando Wetland during the Study Period**

Potential Decision Risk Factor	Coefficient	SE Coefficient	Z	p-Value	Odds ratio	95% C.I Lower	95% C.I upper
	-0.11	0.59	-0.19	0.85			
Distance	-0.33	0.13	-2.63	0.01	0.72	0.56	0.92
Fertility	-0.10	0.74	-0.14	0.89*	0.90	0.21	3.81
	-0.14	0.63	-0.23	0.82*	0.87	0.25	2.95
Soil moisture	1.03	0.51	2.04	0.041	2.80	1.04	7.55
Animal destruction	1.59	0.46	3.44	0.00	4.88	1.98	12.06
Flood	0.088	0.64	0.14	0.89*	1.09	0.31	3.82
frequency	0.84	0.77	1.10	0.27*	2.33	0.51	10.53
Maize returns	0.00	0.00	1.18	0.05	1.00	1.00	1.00

Figures 4.19 and 4.20 presents the results of a further investigation into the concept of distance decay function using ArcGIS 10.1. It was found that some of respondents closest to the edges of the wetland owned the smallest parcels of land inside the Nyando Wetland than respondents further away contradicting the concept of distance decay principle. Generally however, the majority were found to conform to this principle.

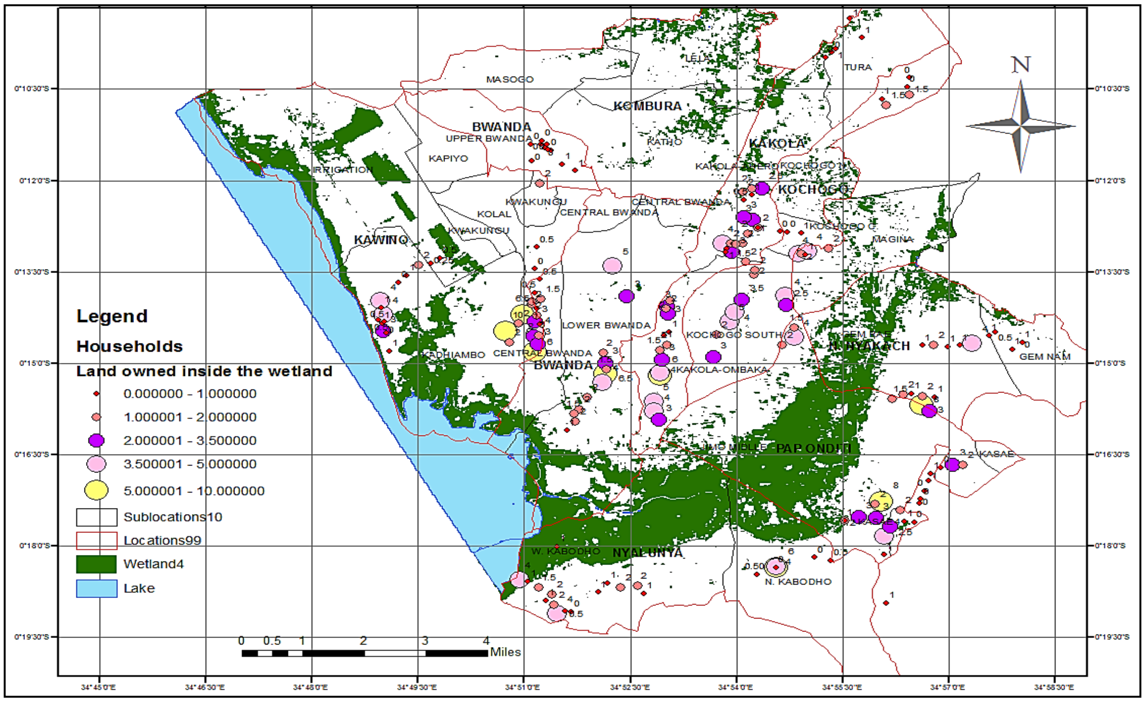


Figure 4.19: **Spatial Renditions between Distance and Land Owned Inside Nyando Wetland**

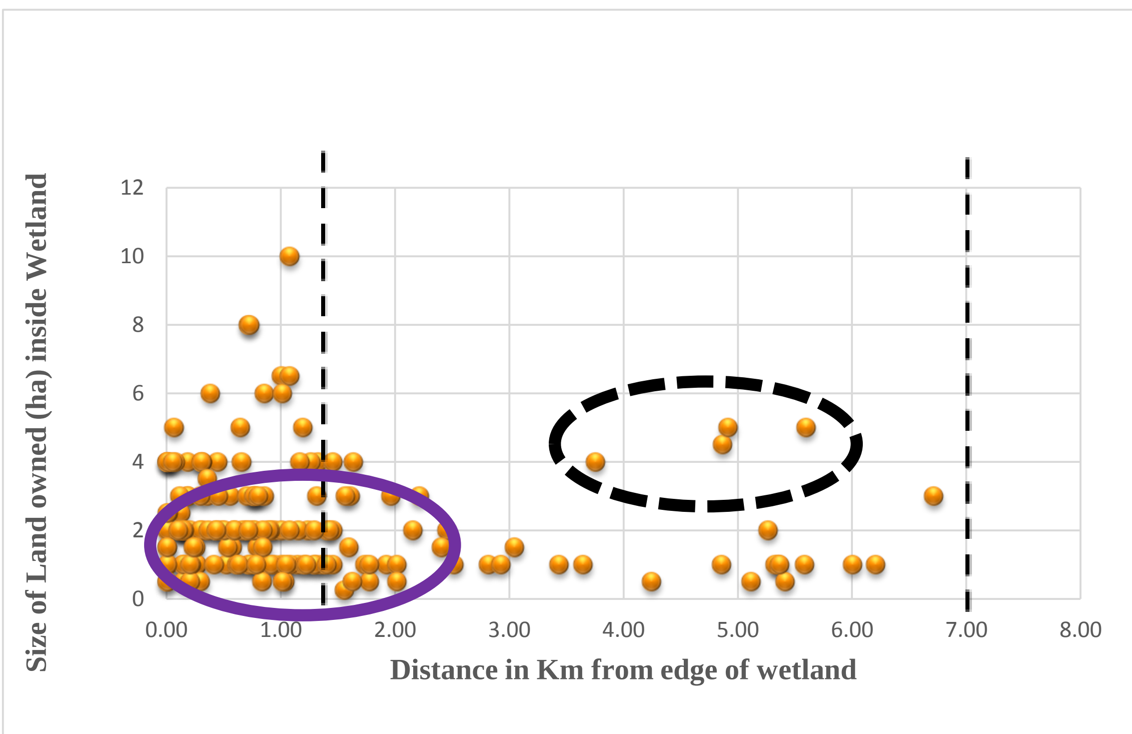


Figure 4.20: **A Scatter Plot of Land Owned Inside Nyando Wetland against Distance of Respondents from Wetland**

4.3.4 Hypothesis Testing for Objective Two

Stating the second hypothesis to address objective two of the study;

H_{02}: There are no significant changes in human population growth that can be attributed to the changes in the size of Nyando Wetland.

Or the Alternative;

In a simple linear correlation matrix (Table 4.11), there is a high negative correlation (-0.97) between the WLTa (wetland area) and population increase as a parameter. Population increase also has a strong positive relationship with SSAg (0.97) and the RFTw (0.85).

Table 4. 11 Simple Correlations between the Dependent and the Independent Variables in the Nyando Wetland study

	WTLa (y)	SSAg (x1)	RFTw (x2)	OPGb (x3)	WATr (x4)	Population (x5)	MLl (x6)
WTLa (y)	1.00						
SSAg (x1)	-0.94	1.00					
RFTw (x2)	-0.89	0.73	1.00				
OPGb (x3)	-0.98	0.88	0.97	1.00			
WATr (x4)	0.94	-0.92	-0.91	-0.97	1.00		
Population (x5)	-0.97	0.97	0.85	0.95	-0.94	1.00	
MLl (x6)	0.45	-0.31	-0.61	-0.55	0.46	-0.53	1.00

Key: **WTLa =** Wetland area, **SSAg =** Small-scale agriculture, **WATr =** Water area,

RFTw = Rice farms and turbid paddy water surfaces, **MLl =** Mean Lake Level,

OPGb = Open grassland, mixed bushes with exposed bare ground

Note: The numeric values denote the extent to which any of the variables are correlated to the wetland area (WTLa) which is the dependent variable.

However, when population was included in a multiple regression mode (Table 4.12), the probability statistic of population (0.14) is higher than the common alpha level of (0.05) at 95% confidence level and is hence not a meaningful addition to the prediction model. Due to collinearity, OPGb was excluded from the model.

Table 4.12: Effect of Population on the Regression Model for All Study Variables on WTLa in Nyando Wetlands during the Study Period

Model	Coefficients			T	P-Value.
	Unstandardized		Standardized		
	B	Std. Error	Beta		
(Constant)	-133479.23	0.00		.	.
SSAg (x_1)	-2.79	0.00	-1.973	-13.97	0.05
RFTw (x_2)	-3.04	0.00	-1.219	-16.14	0.04
WATr (x_4)	-2.54	0.00	-1.194	-11.93	0.05
Population (x_5)	0.06	0.00	0.90	4.40	0.14
Mean Lake Lvl x_6	151.01	0.00	0.11	19.74	0.03

Key: **WTLa =** Wetland area, **SSAg =** Small-scale agriculture, **WATr =** Water area, **RFTw =** Rice farms and turbid paddy water surfaces,

Consequently, population increase has an indirect effect on the wetland area through the two anthropogenic factors (e.g. Small-scale Subsistence Agriculture and Rice Farms and Turbid Water Surfaces). The study therefore rejects the null hypothesis.

4.4 Lake Level Changes

The average lake level (m.a.s.l.) for Lake Victoria over the forty year period was found to be 1135.21 metres above sea level (m.a.s.l.) with the maximum level being 1136.05 m.a.s.l. recorded in the year 1998 and the minimum of 1134.17 m.s.a.l. recorded in the year 2007. Spikes of high peaks occurred at least once in almost every decade covering the period of 1970-1990 (10yrs), 1990-1989 (9yrs) and 1989-999 (10 yrs). This indicates a generally decadal cyclic pattern with a variance of 0.19. The highest variations in the Lake levels were recorded in the year 2000 at 0.063 while lowest variation was recorded in the year 2003 at 0.00. The month with the highest variance was May (0.24) and the least was December (0.14) across this period of time. The most observed lake level during the study period was 1135.5 m.s.a.l. while the least was 1133.5 m.a.s.l.

The highest fluctuation peaks were experienced in the months of May, June and July 1990 and 1998 when the levels rose to 1136.4 m.a.s.l. Such high levels were also observed in the same months in 1999. The lowest levels were recorded in the months of March and October over the 40-year period. It was also observed that the first decade between 1970 and 1979 recorded the highest average Lake level of 1135.48 m.a.s.l. while the least average level was experienced in the final decade of 2000 and 2009 (1134.82 m.a.s.l.). In regard to the daily levels observed, the highest level was 1136.4 metres from 30th May to 1st June, 1998 and the lowest level observed was 1133.78 m.a.s.l. on 29th March, 2007. Consequently, the fluctuations of Lake Victoria levels were observed to have attained negative maximum amplitude of 2.62 m.a.s.l. during the period between 1970 and 2010.

Heterogeneity tests were performed on 7 classes of Lake level data taken on a daily basis over a 40-year period overlapping the study period. It was found that the frequency distribution of the Lake level is heterogeneous. A generally declining trend of the lake levels was observed over the study period with peak levels in June/July of each year. This was found to be significant (χ^2 =19734.12, df =234, p < 0.00). The 3D plot showing the general declining trends of the fluctuation over time is presented in Figure 4.21.

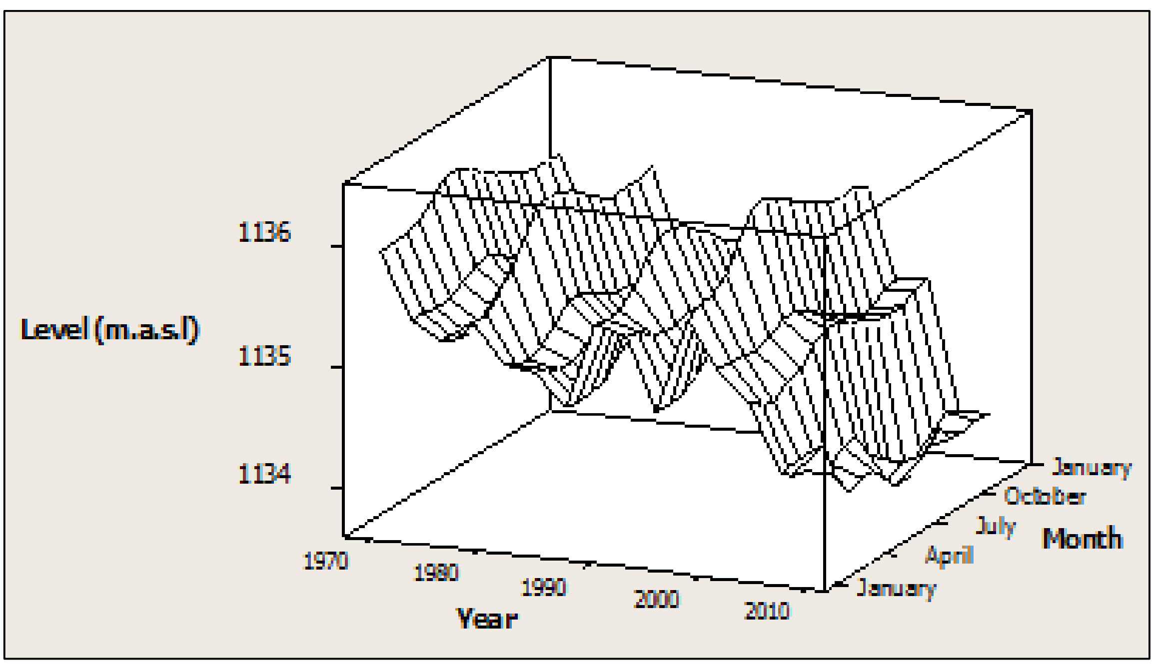


Figure 4.21: A Three Dimensional Plot Showing the Annual versus Monthly Variation in the Lake Victoria Levels at Kisumu Gauging Station from 1970 to 2010

A general linear trend model fitted to the data to perform a trend analysis described a linear relationship as in equation (8) as follows:

Lake Level (m.s.a.l.) = 1135.54 – 0.0000446932*Year……………………………....... (8)

The 39-year time series analysis and three measures of accuracy of the fitted model (Mean Absolute Percentage Error-MAPE, Mean Absolute Deviation-MAD, and Mean Squared Deviation-MSD) calculated gave results presented in Figure 4.22 (a) and (b). An MSD value of 0.16 was obtained. It was observed that the combined fits from the trend analysis and decomposition (Figure 4.22 and 4.23) are close to the actual lake level graphed values except for trends after the year 2005 which was not well fitted. The dynamic estimates for the three components of seasonality, trends and levels were calculated to integrate and smooth their effects on the data using Holt-Winters exponential smoothing approach which gave results presented in Figure 4.23. In the analysis, the difference between observed value (y) and its corresponding fitted value (ŷ) indicate low residual values (Figure 4.24).

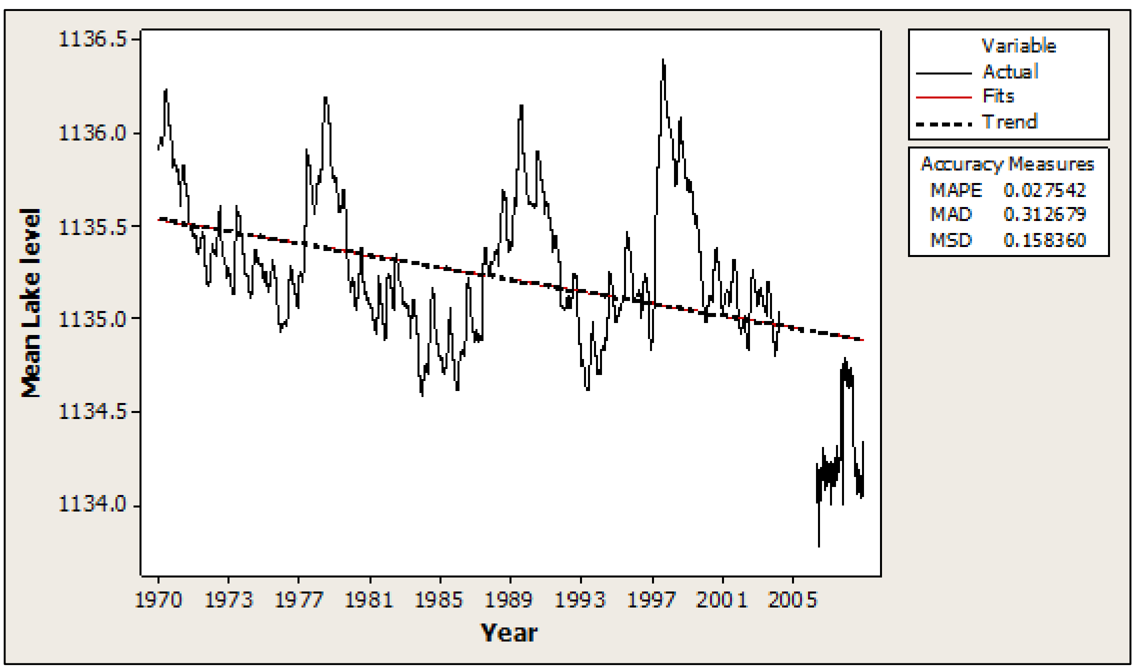


Figure 4.22 a: A 39-Year Time Series Decomposition Plot for Mean Lake Level in the Multiplicative Model

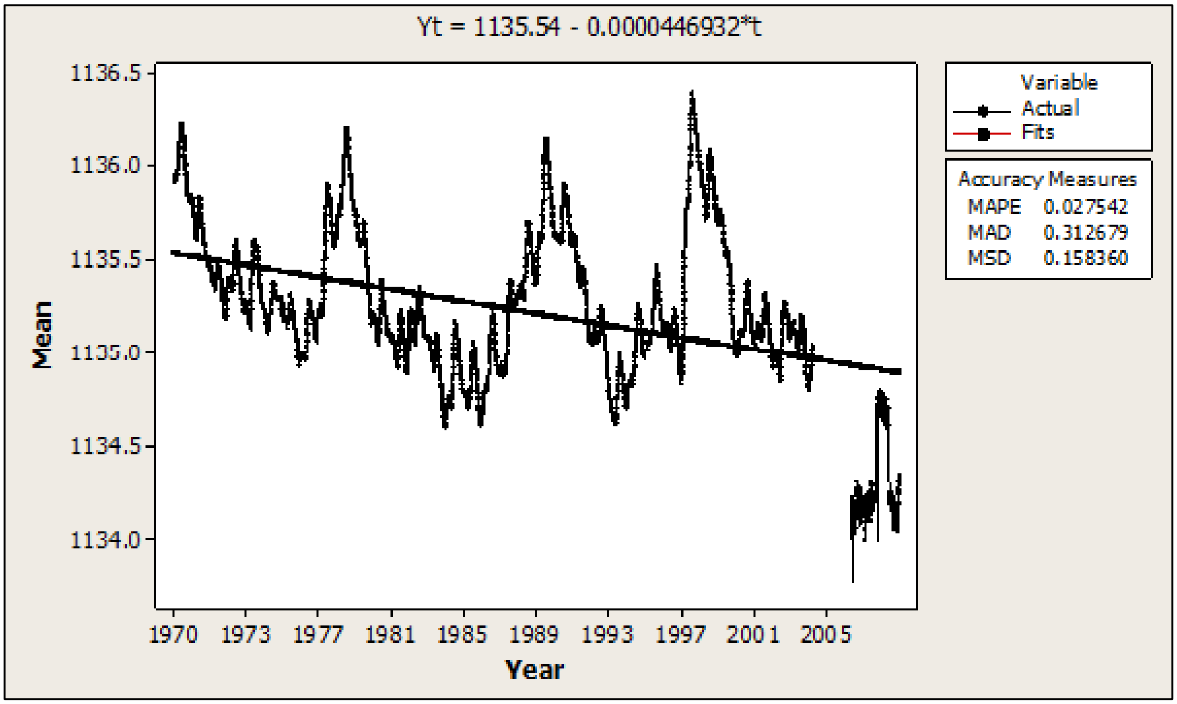


Figure 4.232 b: A Linear Trend Model of Actual Versus Fitted Trend of Lake Victoria Levels at Kisumu Gauging Station from 1970 to 2009

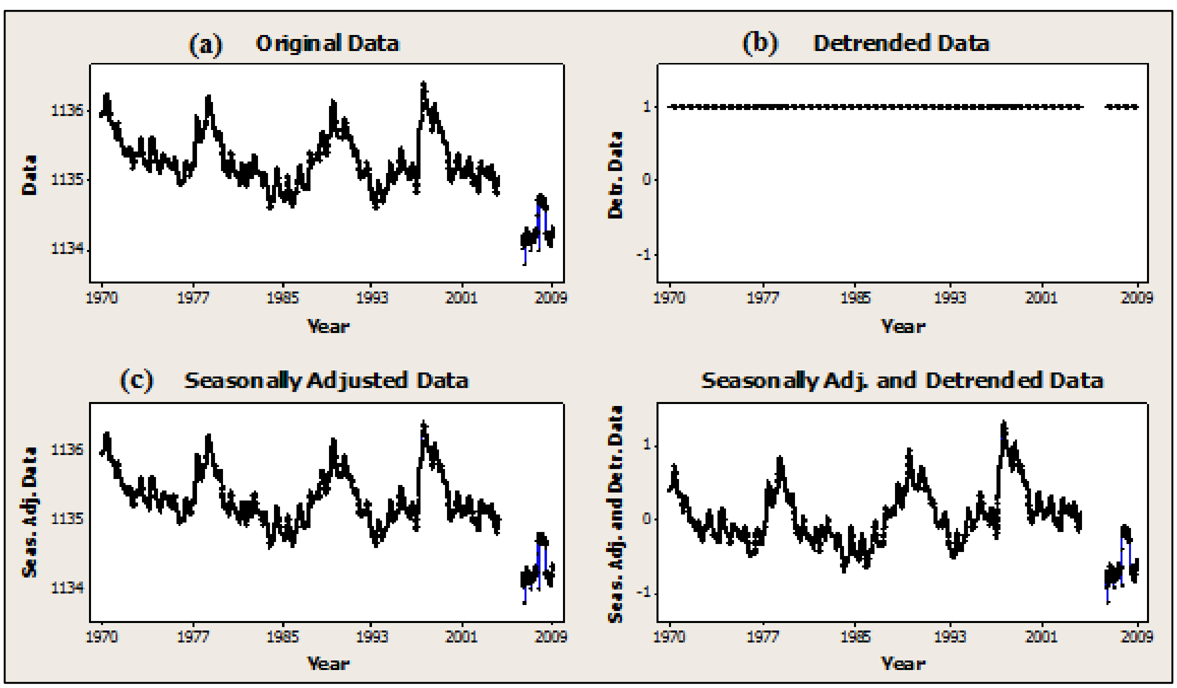


Figure 4.243: Component Analysis of the Lake Victoria Levels (m.a.s.l.) in Terms of ("a" and "b") Trends and ("c" and "d") Seasonality at Kisumu Gauging Station from 1970 to 2009.

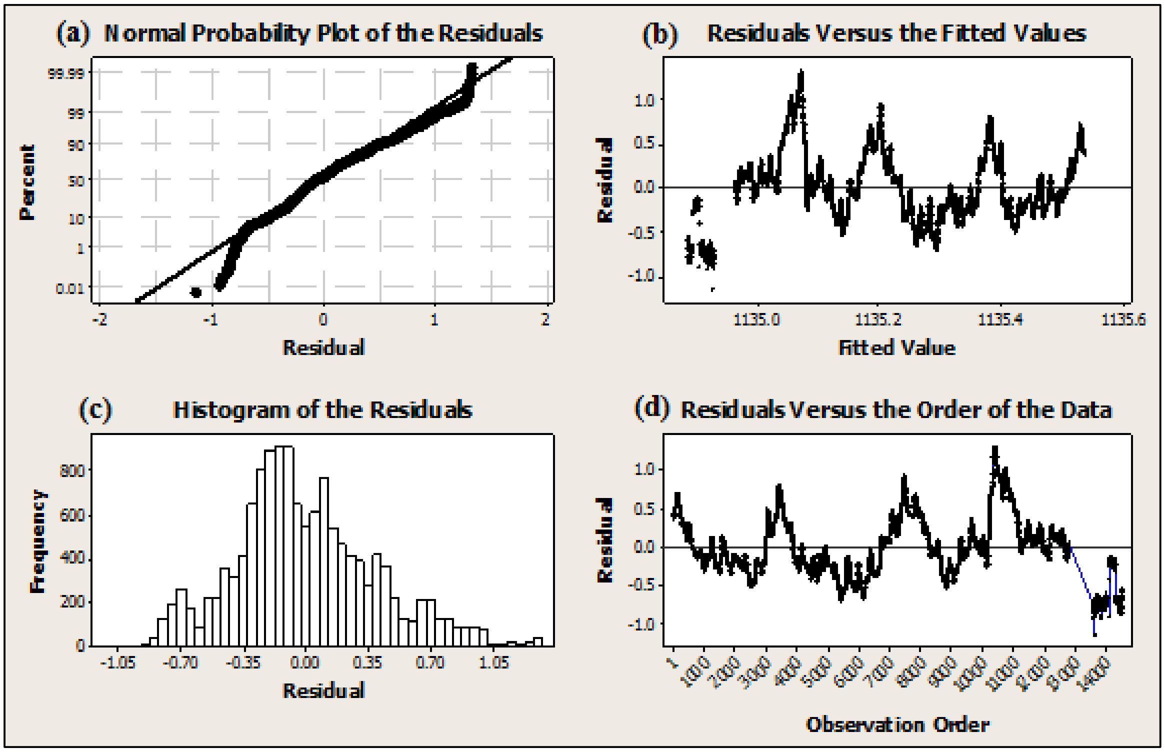


Figure 4.254: **Residual Plots of the Mean Lake Victoria levels (m.a.s.l.) at Kisumu Gauging Station Showing a) the Normal Probability Plot, b) Histogram of Residuals, c) Residuals versus Fitted Values and d) Residuals Versus Order of the Data**

As part of the DPSIR framework, respondents were asked in the socio-economic survey, whether or not they thought that the level of Lake Victoria had reduced over the years. 58% of the respondents responded in the affirmative (Figure 4.25); but they were not able to associate the decline in lake level with the decline in wetland area.

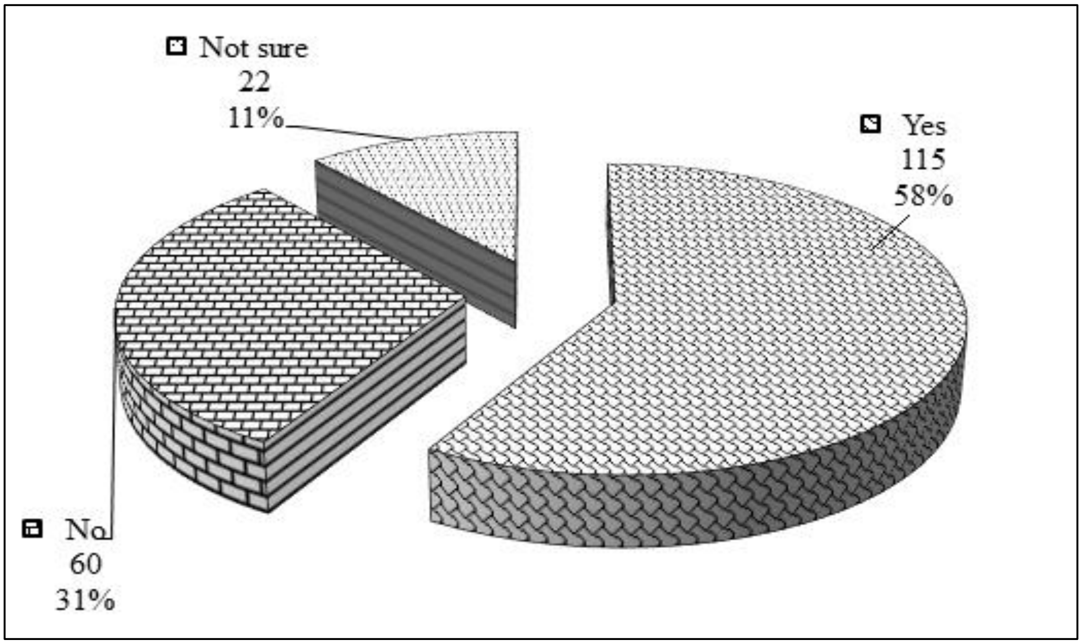


Figure 4.26: Respondents' Perception of Lake Level Recession in Nyando Wetland

About 31% of the respondents indicated that the lake level had not changed but keeps moving back and forth in cyclic patterns – a phenomenon they variously refer to in local dialect as "*Nger", "Nam dar", "Oro"*, *"Pi opong" "Nam dwono", "Nam otwo," "Nam Rumo"* and *"Pi odok"*, (all of which mean the same thing) while approximately 11% of the respondents were not sure.

4.4.1 Lake Victoria Shoreline Recession (WATr)

In Nyando Wetland area, the Lake Victoria shoreline covered about 27 kilometres trending in a south-easterly direction. The study found that vast areas of the Lake's shores were now dry land created by the receding shoreline. This has exposed open land on the Lake-ward side of the wetland that is being invaded by local communities for agricultural and livestock activities. Changes in the area under Lake water was used as a measure of wetland degradation due to Lake level recession. It was found that the area under Lake water within the study area declined by (-)752 ha at the rate of 29 ha per year between 1984 and 2010 (Figure 4.26). The changes occurred consistently from 2,746 ha in 1984 to 2,448 ha in 1995 to 2,173 ha in 1999 and 1,994 ha in 2010. Respondents gave multiple responses about the areas exposed by the receding Lake level (Figure 4.27). The majority (86%) of the respondents indicated that they cultivate the exposed areas after the water had receded and dried up (Plate 4.4), while only 4% of the respondents felt that such areas are ecologically sensitive and should be left fallow.

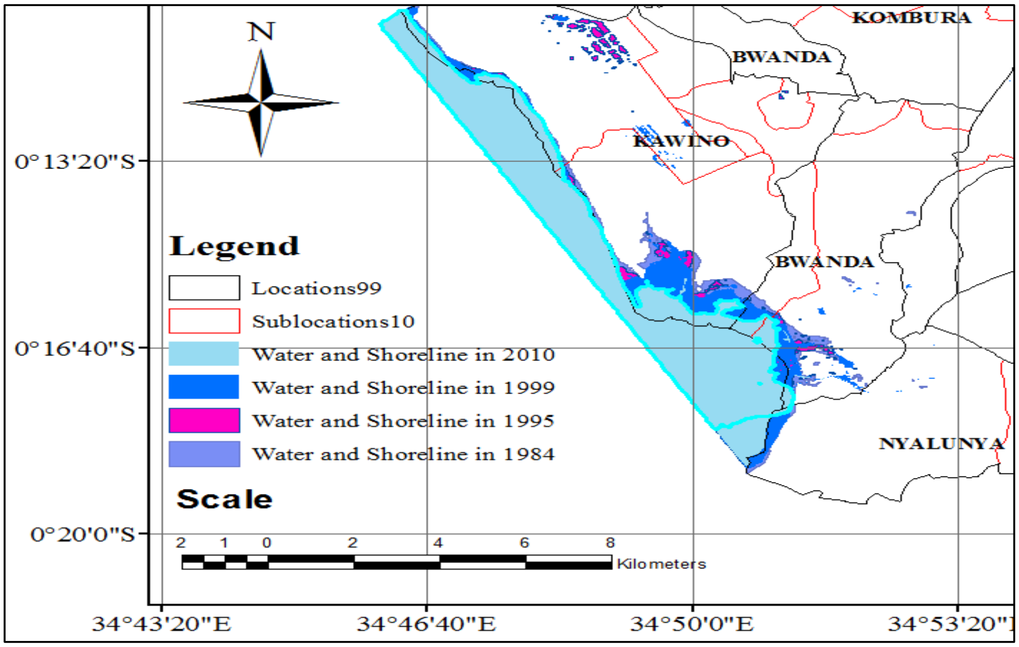


Figure 4.27: Water Area and Shoreline Recession between 1984 and 2010 along Nyando Wetland Area Fringing Lake Victoria

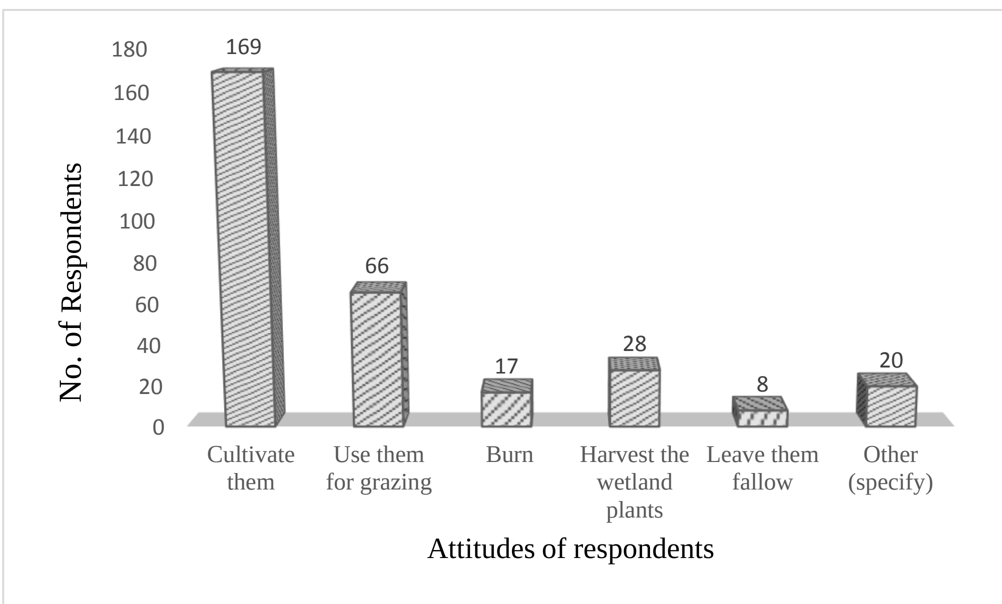


Figure 4.28: Attitudes of Respondent towards Land Exposed by Receding Lake Victoria Waters in the Wetland Area during the Study Period

Plate 4.4 **Area Exposed by Receding Lake Victoria Water Level Currently Under Cultivation on the Lake-Ward Side of Nyando Wetland**

4.4.2 Spatial and Temporal Changes in the Area of Nyando Wetland (WTLa)

The area covered by WTLa category decreased from 6,514 ha in 1984 to 5,582 ha in 1995 especially in areas such as West Kano Irrigation Scheme, Ogenya and Ugwe and minimally at Siginda in Kakola-Ombaka sub-location forming a thin band of WTLa, about 0.2-1.0 km, along the edges of the wetland. In 1995, some incursions were also noted in Wasare and Magina sub-location areas ranging from 0.2 km to 3.3 km into the wetland. The Lake-ward edges of the wetland in nearly all other riparian sublocations were least affected during this period as shown by the bright green renditions on the map in Figure 4.28.

Between 1995 and 1999, Nyando Wetland area further decreased from 5,582 ha to 5,411 ha. The highest decline was (-)118 ha per annum during this period. Figure 4.29 compares the spatial state of the wetland in 1999 compared to the baseline situation of 1984.

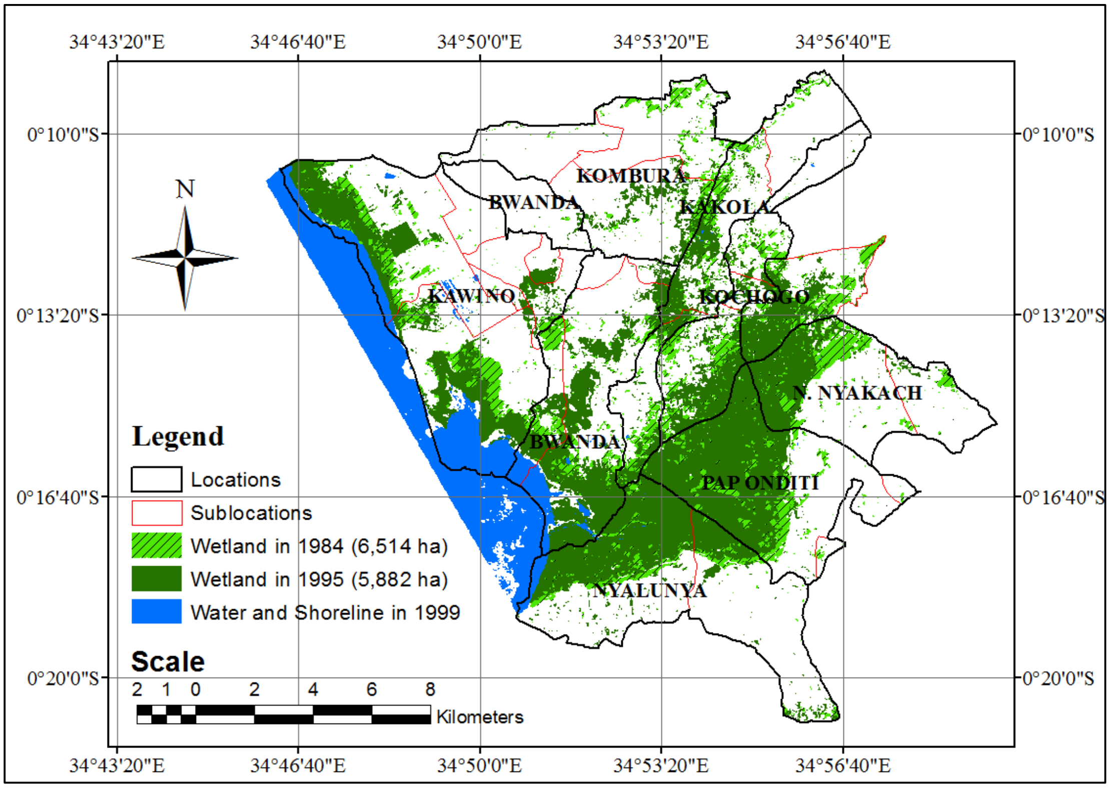


Figure 4.29: **Spatial Rendition of Changes in Area Covered by Nyando Wetland 1984-1995**

Spatial incursions of between 0.2 km to 5.5 km (measured south easterly into the wetland) were observed in Sigida (Kakola), parts of Kochogo, Magina, and Wasare in nothern parts of Jimo middle sublocation. In Magina sub-location area, nearly all the wetland had been cleared by the end of this period. Some wetland along the borders of Kakola Ahero and Kakola Ombaka/Kanyagwal (Lower Bwanda) and Kochogo South sub-locations (an area of approximately 1.2 km^2) were turned into farmland where rice and maize were the main crops.

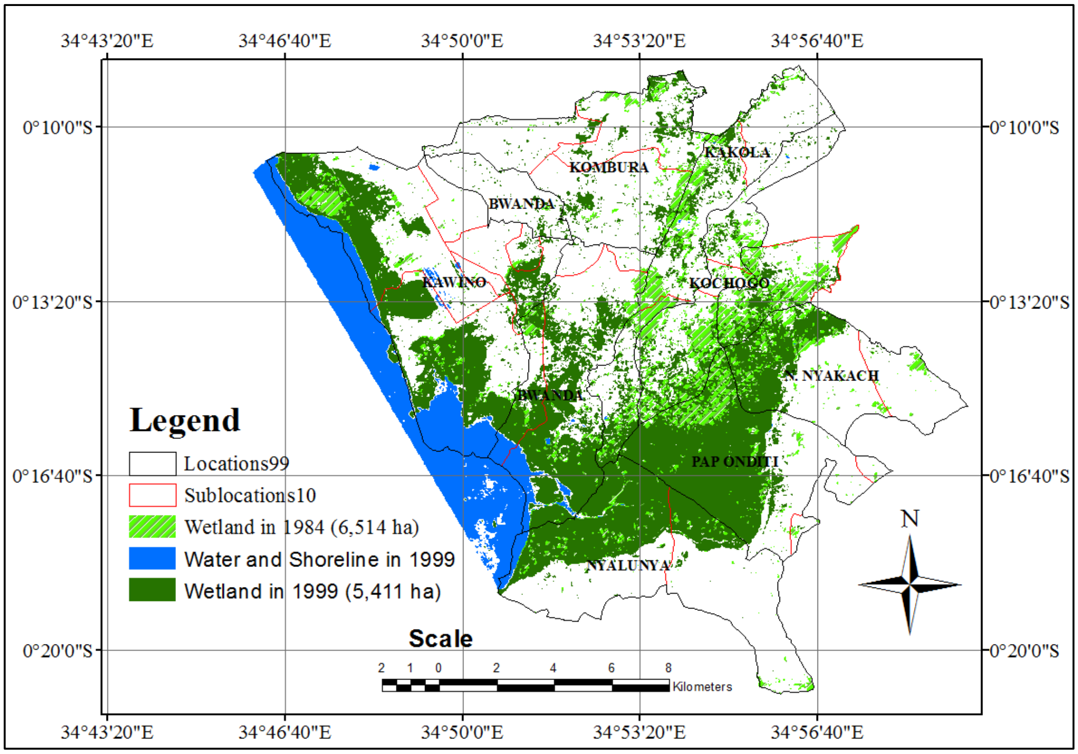


Figure 4.30: Spatial Rendition of Changes in Area Covered by Nyando Wetland1984 - 1999

Between 1999 and 2010, the area covered by the wetland categories declined further from 5,411 ha to 4,489 ha at an annual rate of change of (-)84 ha. Figure 4.30 presents the spatial state of the wetland at the end of the study period in 2010. By the end of the study, Nyando Wetland had lost its pristine cover types by about 2,025 ha which is about 31% of the area that it covered in 1984 (lighter green colour in the map). The belt stretches some 9.2 km by 1.8 km (approximately 1,600 ha) in a south westerly direction from Magina-Wasare area to Siginda. It then extends some 7 km by 0.8 km (about 560 ha), in a north westerly direction from Singida to the end of west Kano irrigation scheme, along the outer edges of the wetland.

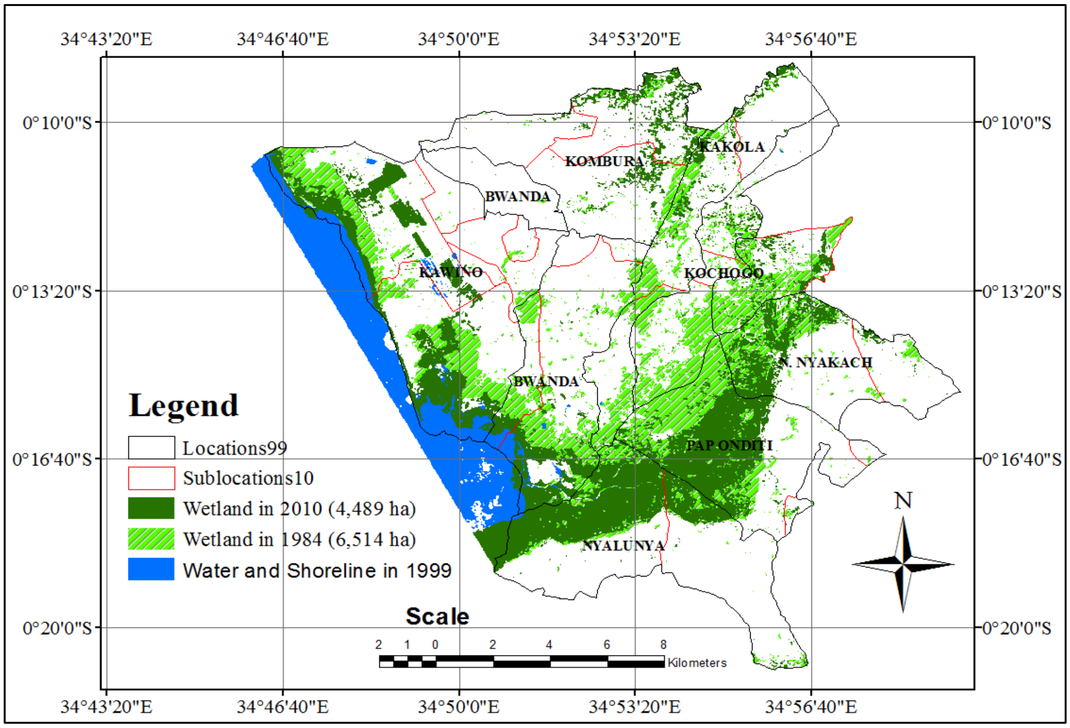


Figure 4.31: Spatial Rendition of Changes in Area Covered by Nyando Wetland (1984 - 2010)

As part of the DPSIR framework, the study went ahead to carry out the household survey. Only 24% of the respondents thought that the wetland had decreased while a majority (76%) reported that it had increased in size between 1980 and 1990. This was found to be significant (χ^2 =13.19, df = 2, p < 0.00) determinant of the ability to respond to the pressures affecting the wetland. Some 33% thought that the wetland had decreased in size in the decade of 1991 to 2000. A majority of 62%, however, thought that the wetland had actually decreased in size in the decade of 2001 to 2010 (Table 4.13).

Table 4. 13 Changes in the Acreage of the Wetland as Perceived by Respondents

Years	% of the households in area			*Statistics*
	Decreased	*Not changed*	*Increased*	
1980-1990	24	28	48	χ^2=13.19, df = 2, p< 0.00
1991-2000	33	25	42	χ^2 = 6.77, df = 2, p < 0.03
2001-2010	62	12	26	χ^2 = 64.11, df = 2, p < 0.00

N = 196

4.4.3 Hypothesis Testing for Objective Three

Stating the third hypothesis to address objective 3 of the study;

H_{03}: Fluctuation in lake levels do not significantly contribute to the decline in the size of Nyando Wetlands leading to human encroachment

Or the Alternative;

Based on the multiple regression analysis in Table 4.14, the fluctuations in the lake level and the Water area exposed by the reducing Lake levels both have a significant ($p = 0.03$ and $p = 0.05$) influence on the wetland area. The probability statistic of the mean lake level is lower than or equal to the common alpha level of 0.05 at 95% confidence. This means that the mean lake level has meaningful contribution to the regression model and therefore the study rejects the null hypothesis.

Table 4. 14 Multiple Regressions of Water Area (WATr) and Mean Lake Level on (WTLa) in Nyando Wetlands during the Study Period

Coefficients

Model	Unstandardized B	Unstandardized Std. Error	Standardized Beta	t	p-Value
(Constant)	-133479.23	0.00		.	.
SSAg (x_1)	-2.79	0.00	-1.97	-13.97	0.05
RFTw (x_2)	-3.04	0.00	-1.23	-16.14	0.04
WATr (x_4)	-2.54	0.00	-1.19	-11.93	0.05
Population (x_5)	0.06	0.00	0.90	4.40	0.14
MLl (x_6)	151.01	0.00	0.11	19.74	0.03

Key: **SSAg =** Small-scale agriculture, **WTLa =** Wetland Area**, WATr =** Water area**,**
RFTw = Rice farms and turbid paddy water surfaces, **ML**l=Mean Lake Level
OPGb = Open grassland, mixed bushes with exposed bare ground,

4.5 Analysis of Results

The values of anthropogenic and hydrodynamic drivers (variables) that were measured in the study indicate spatial and temporal change between 1984 and 2010 with regard to the observed degradation and loss of wetland area. While the wetland area reduced by 31% and the area covered by the waters of Lake Victoria in the wetland decreased by 27%, the combined increase of small-scale subsistence agriculture and area under rice cultivation was 21% as open grasslands increased by 18% and the human population increased by 57% (Table 4.15). The interpretation of this scenario is that agriculture based variables including rice cultivation driven by the needs of the increasing population and water area could be driving wetland loss in the study area as further analyzed in the following paragraphs.

Table 4. 15 **Data Values for the Dependent and Explanatory Variables in Nyando Wetland during the Study Period**

		Land Use Elements/Parameters					
Year	**Wetland Area (y)**	**SSAg (x_1)**	**RFTw (x_2)**	**OPGb (x_3)**	**WATr (x_4)**	**Population(x_5)**	**Mean Lake Level (x_6)**
1984	6514.20	8460.00	1329.30	6647.40	2745.90	53521.50	1134.89
1989	6353.55	9064.35	1011.15	6544.35	2723.40	60440.00	1135.47
1995	5882.40	9307.80	1264.50	6794.10	2448.00	66225.00	1135.03
1999	5411.25	9551.25	1517.85	7043.85	2172.60	68849.00	1135.84
2009	5095.35	9794.70	1771.20	7293.60	1897.20	80066.00	1134.28
2010	4489.20	9975.60	1817.10	7420.50	1994.40	84266.50	1134.50

Key: **SSAg =** Small-scale agriculture **RFTw =** Rice farms and turbid paddy water surfaces **WTLa =** Wetland area**,** **OPGb** = Open grassland, mixed bushes with exposed bare ground, **WATr =** Water area**,**

The simple linear correlation matrix (in Table 4.11) presents how the variables relate with each other. In the table, a negative correlation was found between wetland area (dependent variable) and SSAg, RFTw, OPGb, and population (independent variables). The OPGb had the highest negative correlation coefficient (-0.98) followed by population (-0.97), SSAg (-

0.94) and finally RFTw (-0.89). The wetland area is positively correlated to the water area and the mean lake level. The water area has a higher positive correlation (0.94) as compared to the mean lake level which has low positive correlation (0.45) with the wetland area.

The initial model used to analyze the changes in the wetland area, before regression analysis was expressed as in equation twelve (12).

$$Y = a + b_1(WATr) + b_2(SSAg.) + b_3(RFTw) + b_4(OPGb) + b_5(Pop) + b_6(Mn\ Lk\ level) \ldots (12)$$

After conducting regression analysis on the variables, the most appropriate model that best predicts the changes in the wetland area was established as in (equation 13).

$$Y = a + b_1\ (WATr) + b_2\ (SSAg) + b_3\ (RFTw) \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Population and the mean lake level were removed from the model because the analysis showed that they were not useful direct predictors of the changes in the wetland area. When they are included in the model, regression returns a negative adjusted R^2 value.

This was solved and found to be of the form of equation fourteen (14) as presented below:

$$\boldsymbol{WTLa} = \mathbf{27599.16 - 1.545}\ (WATr) - \mathbf{2.203}\ (SSAg.) - \mathbf{1.852}\ (OPGb) \ldots\ldots\ldots\ldots (14)$$

However, if the intercept was held constant at zero, the analysis of variance output showed that, the four land use change parameters combined have a relatively moderate significant effect on the changes in wetland area (WTLa) with positive adjusted R^2 of 0.50. This means that even the OPGb which was removed from the model could still act as a good predictor if more data points or increased time steps were included in the analysis.

In order to identify the effects of each of the independent variables on the wetland area (WTLa), a multiple regression analysis was carried out and the results are presented in Figure 4.31. The steepest slope was obtained for the human population growth followed by subsistence agriculture whose effects are both negative on the wetland area. The only positive slope was found in water area which was a proxy for lake level.

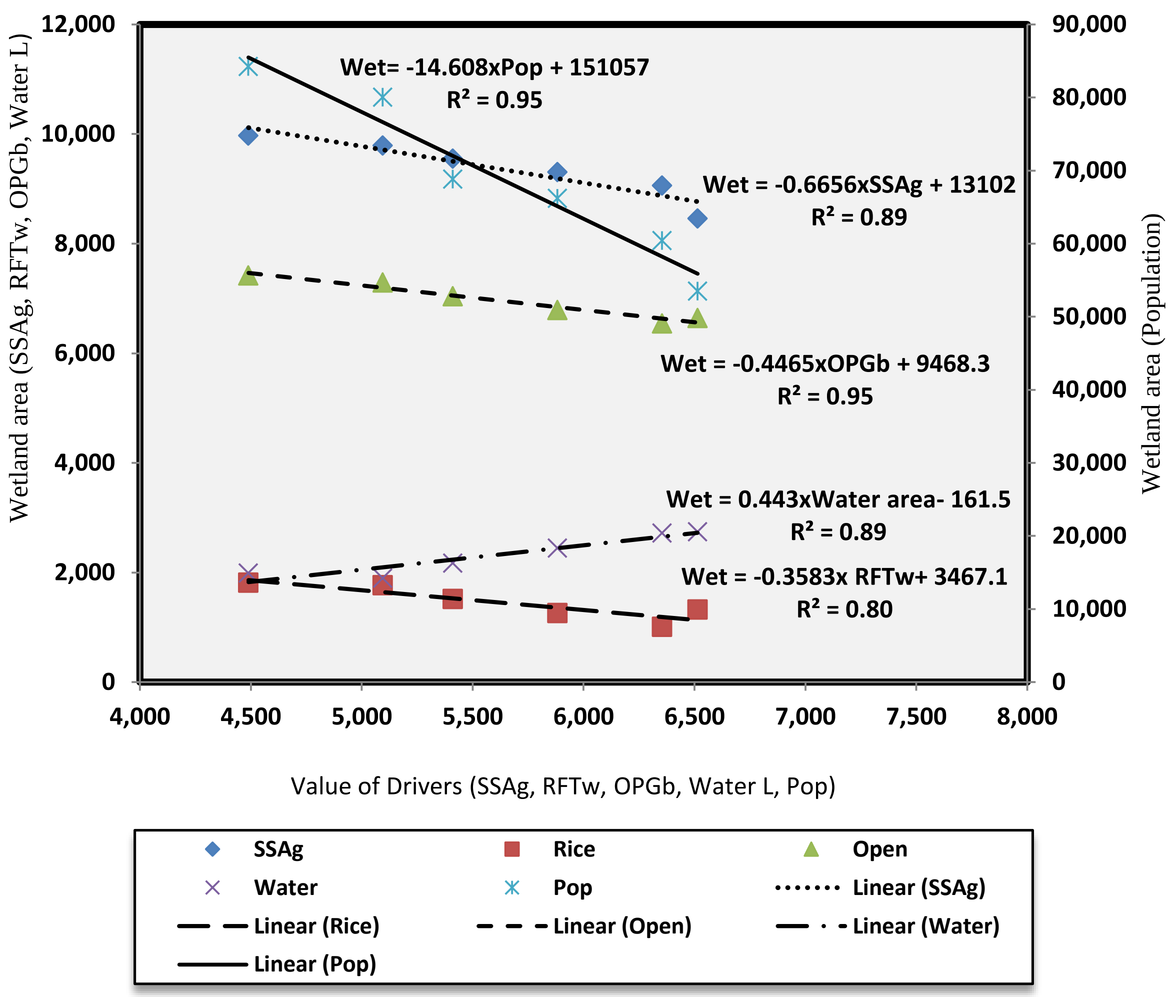


Figure 4.32: **Relationships between Nyando Wetland Area (WTLa) and the Predictor Variables - Smallscale Agriculture (SSAg), Rice Farms and Turbid Paddy Water Surfaces (RFTw), Open Grassland, Mixed Bushes with Exposed Bare Ground (OPGb), Water Area (WATr) Proxy For Lake Water Level and Human Population Growth (Pop)**

CHAPTER FIVE

5.0 DISCUSSION

The findings of the present study are discussed in relation to how the decline in the area covered by the wetland has been influenced by anthropogenic and hydrodynamic drivers operating in the study area during the study period. The drivers include various types of land cover/uses found in the study area such as the small-scale subsistence agriculture; rice farms and turbid paddy water surfaces; open grassland, mixed bushes with exposed bare ground and; area covered by Lake Victoria waters. These were mapped with an overall classification accuracy of 87% and overall kappa statistic of 0.86. The accuracies achieved were typical of those achievable when satellite imagery of the level of resolutions used in this study are used as data sources and therefore acceptable and comparable to those of other studies such as Congalton and Green (1999), Lu, *et al.* (2004), Maheu-Giroux and de Blois (2005), Ozdogan, *et al.* (2006), Maxa and Bolstad (2009) and Beekhuizen and Keith (2010). With these accuracy levels in mind, it is clear that the rapid human population growth and the declining Lake Victoria water level, when combined with the demands for human use, constitute unrelenting negative driving forces of environmental change in Nyando Wetland. The interactions among these factors are leading to an unprecedented decline in the wetland size and degradation of its natural resources (Ogello, Obiero and Munguti, 2013).

The results show that the area under small-scale subsistence agriculture, which is one of the drivers, has expanded from 8,460 ha to 9,976 ha (an increase of 17.95%) while rice farms and turbid paddy water surfaces increased from 1,329 ha to 1,817 ha (an increase of 36.7%) during the period under study. The land cover changes caused by these two agricultural categories recorded an increase of 8% to stand at 46% of the study area by 2010. This observation is comparable to Olang, Kundu, Bauer and Fürst (2011) who recorded a 44.1% agricultural cover for 1986 in the entire Nyando river basin meaning that the general trend of increase in this land use category is similar in most parts of the basin. Between 1984 and 2010, the study found that the small-scale subsistence agriculture category recorded the highest rate of increase of 10% (77 ha per year) in the Nyando Wetland study area. This increase could be attributed to the initiatives of sugar cane out-grower companies to expand cane growing in the Nyando basin. Several out growers companies and societies such as

Onyisa, Janam, Disi Muti-Purpose Out-growers Associations and New Odiembo Farmers' Cooperative Society were formed and these groups operated in the lower Nyando basin (i.e. Ahero, Kimira, Kochogo and Kakola-Ombaka) to promote sugarcane farming for Miwani Sugar Factory. However, between 1995 and 1997 after the factory collapsed there was a corresponding decline in the annual rate of land cover change for this particular category because many farmers abandoned growing sugar cane leaving some farms fallow. Many of these fallows converted to open grassland, mixed bushes with exposed bare ground.

All other factors held constant, it may however, be concluded that about 58 ha of new agricultural areas were on average created each year in the study area over the 26 year period (1984 to 2010). Even though there may be minor differences of findings, especially in magnitude of change reported by this study as compared to other findings such as those of Olang', *et al.,* (2011) and Muiruri, Wenninger, van Griensven, Uhlenbrook and Khisa, (2012), the trends in the results are all consistent that there is an unprecedented increase the Small-scale Agriculture category. Observed variations in magnitude could be attributed to methodological approaches, data sources, resolutions and non-uniformity in class definitions common in most land use studies worldwide (Gils, *et al.,* 1991; Bronsveld, *et al.,* 1994, Liverman and Cuesta, 2008,). However, from a physical scientific view, the import of this observation is that as this category of land use continues to increase, there will be a corresponding decrease in the area covered by Nyando Wetland.

This is even clearer when it is considered that 54%, 53% and 52% of the households significantly increased their cropland between the periods of 1980 to 1990, 1991 to 2000 and 2001 to 2010 respectively. Most of these expansions were reported to occur in and around the wetland with a strong statistically significant level (r^2 = -0.94; R^2 = 0.89) and were also observed in satellite image derived map layers prepared during the study. The observed moon shaped south-easterly rippled progression of conversions from wetland cover type to agricultural categories indicates the expansion of this category in the study area is creating great agricultural pressure that will significantly reduce the size and cause fragmentation of the wetland (Wood and Halsema, 2008; Orwa, *et al.*, 2012). Much as pressure on the wetland driven by the need for more agricultural land was reported in this study, the respondent's also highly ranked damage by animals, insects and disease and human-wildlife (especially the human-hippoptamus) conflict as constraints to cropland expansion into the wetland. Studies carried out by Gerakisa, *et al. (*1998), Svotwa, Ngwenya, Manyanhaire and Jiyane, (2007), Lamarque, *et al.*, (2009) and Pachaur, (2014) elsewhere also attributed this sort of conflict to human population growth creating the need for more agricultural land, which drives expansion of crop farming and industrial activities such as disposal of wastes into fragile ecosystems like Nyando Wetland.

On the other hand, the rice farms and turbid paddy water surfaces, which is an agricultural land use category, experienced a 5% drop in area between 1984 and 1995, followed by a steady increase up to the end of 2010 at an average increase of 19 ha per annum. The drop in area under this category could be attributed to shortage of water in most rice growing areas (Otieno, 1996), especially in the northern parts of the study area. During this period, the study found that there was a shortage of irrigation water, which was partly attributed to interference with farmers' water drawing systems at the time of construction of the irrigation canals and associated infrastructure such as outlet gates for Nyatini and West Kano schemes. This was started in 1991 and ended in 1993. The farmers had difficulty accessing the water from a deepened river Nyatini thus; reducing their area of command. The irrigation infrastructure was commissioned in late 1993 (Leereveld and Otieno, 1995). This combined with drought frequency (Ambeje, Gitonga and Kerkmann, 2009; Omondi, 2010; Muvundja, *et al.*, 2014) that occurred during this period explains the drop in area under this category in the 1980s and part of the 1990s.

Effective utilization of the irrigation infrastructure began in 1994 with farmers progressively expanding the areas under the category at the rate of 19 ha per annum. A proliferation of private millers providing some sort of ready market for the farmers and promotional activities by these millers buttressed the expansion efforts for this category (Otieno, 1996), leading to the observed increases of this cover type in the subsequent periods. This category was observed even in the middle of the wetland and with a strong positive correlation ($r^2 = -0.89$; $R^2 = 0.80$) with the declining wetland area. Its continued expansion could lead to habitat modifications not compatible with normal wetland functions and result in an irreversible change in the ecological character of the wetland (Ramsar Convention Secretariat, 2010).

This notwithstanding, the moderate to severe drought conditions reported in the study area for the period between 1995 and 2000 by Awange, *et al.* (2007) and Huho, Ngaira and Ogindo (2010) is believed to have not only influenced the rice farms and turbid paddy water surfaces category thereby affecting the wetland; but also the dynamics of open grassland, mixed bushes with exposed bare ground in the study area. In these studies, rainfall during the years from 1961 to 1999 was abnormally lower than 25% of the normal average amounts in the study area. They also observed that the number of drought events and severity which are predisposing conditions for the development and expansion of this land cover category were also increasing in the last 3 decades. This could explain the expansion of open grassland, mixed bushes with exposed bare ground. In 1994, this land use category covered 26% of the study area but later increased to about 29% at an annual rate of 30 ha per year especially in the southern parts of the study area. About 10% of the changes were found in areas previously occupied by small-scale agriculture, especially sugarcane, at the edges of the wetland. Consequently, this study attributes the increases in this category to both climate change related changes such as increased drought events (Ambeje, *et al.,* 2009; Omondi, 2010; Obiero, *et al.*, 2012; Muvundja, *et al.*, 2014) and the abandonment of sugarcane fields due to the collapse of Miwani sugar factory during the same period. Many of these sugarcane fields that could not support other agricultural activities such as horticulture and maize or rice farming converted to fallow areas and developed into open grassland, mixed bushes with exposed bare ground.

This is especially clearer when it is noted that the highest increase in open grassland, mixed bushes with exposed bare ground category occurred between 1995 and 1999 and coincided with the period of abandoning of the sugarcane fields. A strong negative correlation (r^2 = -0.98; R^2= -0.95) was found between open grassland, mixed bushes with exposed bare ground and the declining wetland area. This means that as its dominance increases with all other factors held constant, the wetland area will continue to decline especially in areas where grazing and related destructive human activities are dominant. In many instances, even elsewhere, the magnitude of change in response to grazing for most wetland attributes is variable; but responses are often negative, with very occasional exceptions Morris and Reich, (2013). Extensive grazing in Nyando Wetland (Obiero, *et al.,* 2012) has therefore the potential of changing the biophysical characteristics of the wetland ecosystem in ways that could make it suitable for colonization and dominance by open grassland, mixed bushes with exposed bare ground (Reeves and Champion, 2004).

Human population growth is closely (r^2 = -0.97; R^2 = -0.95) associated with the decline of the area of Nyando Wetland. This is especially important when it is considered that more than eighty two per cent (82.1%) of the human population in the study area were in the age group between twenty one (21) and sixty (60) years, which is agriculturally active and rapidly growing. For instance, the populations of Kakola, Kochogo and North Nyakach locations increased by 178%, 107% and 70% respectively as the entire study area's population grew at the highest compounded growth rates of 4.63% between 1979 and 1989. This was above (1.7% more than) the national growth rates of 2.9 % during the same period (KNBS, 1990). The growth rate however dropped to 2.1% between 1989 and 1999 and finally settling at 2.7% in 2009, which was slightly below the national average growth rate of 3% (KNBS, 2010). Results however, showed that this population has a doubling time of fifteen (15) years and if the rates were held constant from 1979, it was expected to hit the doubling mark in 1994; but it doubled in 1997. It was three (3) years lower than the Malthusian generalized proposition of about 25 years doubling times for populations of developing countries such as that of the study area (Haupt and Kane, 2004). This implies that a slowing down but still rapid population growth is experienced in the study area which has implications in the use of the resources of Nyando Wetland. A slowing down rate of growth in human population has also been reported by KNBS (2010) and attributed to population control and management activities in the area and the county at large. The designs and implementation of these population control and management activities such as family planning education and awareness campaigns needs to be enhanced by the county government to integrate population, environment/climate change and development initiative to interest target communities.

The results presented in this study show that the demographic momentum, which has resulted in high human population growth and densities (356.5 persons per km^2), has an indirect influence on the riparian households' drive to extend their croplands into the wetland areas where there is enough soil moisture for all-year-round agricultural activities. The momentum has ensured that each individual's share of arable land outside the wetland has concomitantly continued to decrease with the increasing human population resulting in smaller and overused plots. Consequently, the local people have been compelled to look for alternative land to their formal land holdings elsewhere. In the households' perceptions as measured in the study, such land is available in the wetland because their ancestors once lived there and were displaced by an expanding wetland since the 1950s. This wetland, in their view, is now moving back to where it used to be before the 1950's hence the urge to reclaim their right. In the wetland, their land shortage problems, land quality issues including soil fertility affecting yields and the droughts affecting crops appear to be solved. Increasing human populations living in a limited area often add agricultural and resource use demands leading to the degradation of an ecosysten (Cohen, 1999; Benedick, 2000; Liverman and Cuesta, 2008; Ben-Edigbe, 2009; AFIDEP and PAI, 2012). Similar studies elsewhere, also concur that such degradation worldwide are caused by the mounting utility pressure of a rapidly growing human populations (Benedick, 2000; Owino and Ryan 2007; MEMR, 2012).

In Nyando wetland, there has been widespread resource degradation during the past 26 years. The degradation has taken the form of wetland fragmentation and a reducing wetland area which could compromise its biophysical and socio-ecological functions.

As it emerged from this study, the number of years of human activities in the wetland among the households ranged between 2 and 58 years with a mean of 18.52. This means that some of the local people have been utilizing the wetland for close to 6 decades. It is however, noteworthy that about 31% of the respondents in the study area had owned these parcels inside the wetland area for a period of between 1 and 10 years, 31% between 11 to 20 years, 18% between 21, to 30 years, 6% between 41 to 50 years and only 3% had been utilizing the wetland area for more than 51 years. The differences in the number of years of ownership (activities) between the various categories of land users were found to be statistically significant. This could imply that since wetland ecosystems often attract human populations from far-flung areas with the motivation of farming and grazing, the study area population could be having a segment that is immigrant in nature (Liz, 2003; Kadigi and Mdoe, 2004). Thus besides the normal growth that comes with the natural population increases through the balance of births and deaths, there is an immigrant population among this agriculturally active population who began to acquire land in the wetland only recently. Such a trend could cause a conflict between wetland conservation and the human uses which would most likely worsen with increasing human population size around the wetland (Mvula and Haller, 2009; Kioko and Okello, 2010).

The proposition is further strengthened by about 6% of the total respondents in the survey that were not well fitted by the model because of a high delta Chi (χ^2) that caused a high Pearson Residual. This could indicate that these respondents were not from the riparian communities or were recent immigrants who had poor knowledge of the issues that were being investigated or that their responses were simply unreliable. About 62% of the study population seems to have acquired ownership in the last two (2) or so decades and rental/lease tenured segment (4%) within the last decade. This implies that even though activity has been going on in the wetland for close to several decades, there is a segment of new entrants into the wetland farming activity. However, this could also be associated with the spatial variations in distance-decay parameter estimates, which are ascribed to variations in user-resource interaction decision-making processes as influenced by distance from the wetland as a resource (Fotheringham, 1981; Verma, *et al.*, 2013). In the study, the odds ratio for distance was estimated at 0.28. It means that for each additional unit increase in distance from the wetland, the odds of wetland farming decreased by 28% all other factors held constant. This shows a relatively weak influence of a distance as deterrent on farming inside the wetland (Brant, 1990; Verma, *et al.*, 2013).

As presented in the scatter plot, distance from where a household lives to the location of the wetland does not have a strong influence on the farmers' decisions to move into the wetland, open it up and set up farmlands in it. This does not conform to known principles of distance-decay as espoused by Fotheringham (1981) and can be attributed to other factors much stronger than distance operating in the study area. The odds ratio for maize returns, which was signifying fertility or productivity of wetland soils, was further examined and found to be 1.0. This however meant that for each unit increase in maize returns, while the other variables were held constant, the odds of wetland farming do not change at all. This could be explained by the fact that the values of maize returns is given in thousands of Shillings. Therefore, a 1 shilling increase would bear a negligible effect on the decision of a farmer to farm inside the wetland instead of utilizing his land outside the wetland. Furthermore, animal destruction was significant in this particular model and is reported by many respondents but the other benefits of wetland farming alleviate the effects of this variable in the model. Other variables such as fertility change (z = -0.14, p = 0.89) (z = -0.23, p = 0.82) and flood frequency (z = 0.14, p = 0.89), (z = 0.10, p = 0.27) have p-values greater than 0.05 hence they do not have statistically significant effects on wetland farming. This may be so because of the way the questions were put to respondents or because returns from wetland activities smother the effects of these variables in the model. On the other hand, it was established that for every unit increase in soil moisture whose odds ratio is 2.80. The odds of wetland farming increased by 180% all other factors held constant. This typifies a very strong influence and appears to be the strongest attraction to the wetland which is overriding the element of distance-decay among other factors.

In this regard, the respondents ranked as second priority the lack of "water/drought at 16%. This shows that the competition for natural resources in the wetland is driven by the search for areas where water is constantly available for crops and livestock. Consequently, besides, fertility influenced by flooding events and decayed wetland organic matter; the main "*pull"* factor to these areas is availability of all-year-round adequate soil moisture. This assures higher crop production and economic returns for the farmers activities in such areas and is comparable to findings of Kairu (2001), Dobiesz, *et al.* (2010), Adero and Kiema 2011) and LVBC 2011. According to the local people, this factor causes them to encroach the wetland area for agricultural crop farming. This has led to the intensification of agricultural activities on the banks of river Nyando mainly on the flood plains in the lower reaches, at the edges of the wetland and inside the wetland as observed from the satellite image data. Consequently, at least 85% of the households, sampled in this study, relied on the wetland area for subsistence agricultural activities.

With all the above factors at play in the study area, increasing human population implies increased resource use now and in the future (KNBS, 2010; NCPD, 2013; National Academy of Sciences, 2015). The human population growth has a strong relationship with small-scale subsistence agriculture and Rice farms and turbid paddy water surfaces. There is however a negative adjusted R^2 value when it is included in a multiple regression model indicating that regressing it along with these other variables is not meaningful. This is because population increase per-se does not necessarily have a direct influence on the area of the wetland. Its influence depends on the socio-economic characteristics of the population in question and is location and technology specific (Ningala, *et al.*, 2008). Tiffen, *et al.*, (1994) suggests a similar explanation in their findings. In this study, the regression model suggests that population growth affects the wetland area, indirectly through the anthropogenic activities, that is small-scale subsistence agriculture and Rice farms and turbid paddy water surfaces.

This fact coupled with the fact that sixty three (63%) of households use a combination of methods to clear the wetland habitat for agricultural purposes could imply a gloomy future for Nyando Wetland. It could mean that, for the last 3 or so decades, respondents have been using all manner of tools and methods at their disposal to reclaim the wetland for agricultural expansion and encroachment (Chikomo, 2014). This is regardless of whether the tools and methods are environmentally friendly or not. The result echoes the principles of the “tragedy of the commons” in the use of common property resources as expounded by Hardin (1968) and Mvula and Haller (2009). The apparently “free” access to the resources of the wetland and the pressures generated by the drivers of change (UNDP, 2009) in space and time presents the motive of uncontrolled utility approaches laced with high potential for degradation and detriment for the wetland.

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The Driver-Pressure-State-Impact-Response framework of analysis (OECD, 1994; Millennium Ecosystem Assessment, 2005; Zhang and Fujiwara, 2007; Arthurton, *et al.*, 2008; Valkering, *et al.,* 2009) used in this study has provided useful insights into the underlying causal relationships between human activities, resultant impacts on the Nyando Wetland and concomitant responses. Analysis within the framework has shown that there is evidence of fragmentation and habitat change caused by the impacts of anthropogenic and hydrodynamic drivers on the Nyando Wetland. For instance, between 1980 and 1990, a significant proportion (47%) of the respondents (χ^2 = 9.02, df = 2, p < 0 05) reported that there is a progressive decline of indigenous birds in the wetland. They have been replaced by shoals of grain eating birds exotic to the area which are pests to their crops. Between the periods of 1991-2000 and 2001-2010, there were massive increases in these birds (χ^2 = 44.68, df = 2, p < 0.00 and χ^2 = 71.16, df = 2, p < 0 05), respectively. This signifies an impact of habitat change occasioned by conversion of more land in the wetland into agricultural fields (Mensing, Galatowitsch and Tester, 1998; Chikomo, 2014), largely of grains attracting the granivourous birds and is comparable to what Syphard and Garcia (2001) found in their studies elsewhere. The changes in the habitat could trigger grave consequences not only for the physico-chemical functions of the wetland but also its biodiversity and other ecosystem services it offers to the environment.

The situation is further complicated by the receding lake level exposing an area prone to agricultural invasion (Obiero, *et al.*, 2012; Rongei, *et al.,* 2013). The area exposed by the receding shoreline observed by the present study, which signifies Lake level changes was (-) 752 ha at an annual rate of change of 29 ha over the 26-year period. This observation compares with Obiero, *et al.* (2012) which found that as much as 1,336.3 ha of new land had been left behind by the receding lake. Even though the two studies give different results, the concurrence that there is an exposed area is significant. The quantitative differences could be as a result of time-frames, methods applied and the area covered by both studies. The results of regression analysis showed that if all other factors were held constant in an analysis of all other variables against the wetland area, 94.5% of the reductions in Nyando Wetland area could be accounted for by the decrease in the water area due to the shifting shorelines. Further, analysis of Lake level data showed that the average Lake level reduced by 1.88 metres. With the highest levels (1136.05 m.s.a.l.) recorded in year 1998 to its lowest (1134.17

m.s.a.l.) recorded in 2007. If however, the period between 1970 and 2010 was considered, the decline reached a maximum amplitude of 2.62 m over a 40-year-period. There were clear decadal cyclic patterns (every 9 to 10 years) of high and low peaks and an overall variance of 0.19. A best-fit trend line drawn through the peaks exhibited a generally declining gradient during the study period. Similar results were obtained by the Republic of Kenya, (2004); Kull (2006), Kiwango and Wolanski (2008), Ambeje, *et al.* (2009), Vuglinskiy, *et al.* (2009), Omondi (2010), Adero and Kiema, (2011) and Muvundja, *et al.* (2014).

The declining gradient further indicates a reducing lake level, which has the effect of moving the water of Lake Victoria away from the wetland. This progressively opening up areas of new rich and moist lacustrine land on the shoreline areas as the Lake recedes. This creates conditions that promote fragmentation of the wetland as observed in earlier studies (Rongei, *et al.,* 2013). Given the obvious link between a low Lake level and a declining wetland area, a strong correlation was anticipated. However, while there is a strong correlation between the area exposed by the shifting shoreline and the declining wetland area (r^2 =0.94, R^2 = 0.89), there was a low linear correlation between the declining wetland area and the declining mean lake levels (r^2 = 0.45). The probability statistic of the mean Lake level was higher than the common alpha level of 0.05 at 95% confidence. This could mean that the correlation of Lake level with wetland area is affected by other factors such as sedimentation at the mouth of River Nyando.

The effects of this could be seen in north-westerly extents of the shoreline located in the irrigation scheme and parts of southern and south western Kadhiambo sub-locations. An area that did not experience much shift compared to other shoreline areas located near the delta of the river Nyando. Differences in the magnitude of shifts in these areas could be attributed to the high levels of sediment loads deposited (Gikuma-Njuru, 2010) at the mouth of River Nyando. This load significantly modifies the depth of Lake levels and subjects this area to accelerated desiccation and conversion into drier land areas, thereby distorting the relationships. The findings of this study compares well with those by Mungai, Swallow, Mburu, Onyango and Njui (2004), and Tobella (2009) who cited sedimentation visible as a plume on satellite imagery at the mouth of river Nyando, as a cause for concern in the wetland and the gulf area. This is especially important because accelerated sedimentation could enhance drying up processes of large areas of lake-wetland littoral zones as the shoreline retreats with declining Lake level (Azza, 2006).

The Lake level data measured at station 1HB04 and analyzed by this study over a 40-year period indicates that while the Lake's level has been declining over the years, Lake Victoria has held it most observed mean at 1135.5 m.s.a.l. which was above the long-term mean for the Lake of 1135.0 m.s.a.l. However, abnormally low decadal peaks observed, after the year 2005 distorts this relatively stable cyclic pattern and suggests a sudden and significant accelerated decline. The drop was also found by Kite (1982), Awange, *et al.* (2008), Adero and Kiema (2011) and Khisa, *et al.* (2013). This could be explained by a combination of factors ranging from the variability in rainfall trends, prolonged long-term and short-term droughts, decrease in river flows to crustal movements. However, the most likely explanation so far is the ambitious expansion programme of the Owen Falls Dam (Nalubaale) in Uganda. After 1977, a hydropower bypass was set up at the Ruzizi. In addition to this the Ruzizi channel was dredged and widened, these activities seems to have disturbed the Lake level regime considerably (Muvundja, *et al.*, 2014).

Since, 1993 the Ugandan government has been expanding the hydro-power generation capacity by constructing a second dam about 1 Kilometre downstream of the Nalubaale dam across the White Nile, which has greatly modified the Lake's outlet. It is possible that after commissioning in 2003, the power company operating the dams may have drawn too much water through to meet rising demands for electricity both nationally and regionally. It is reported (Muvundja, *et al.*, 2014) that they have been using water at a rate of 20% to 50% above the allowable discharge agreed on between Uganda and Egypt in 1957 (USDA, 2005; Kull, 2006; Kiwango and Wolanski, 2008). Consequently, the areas occupied by Lake Victoria are expected to continue to shrink away from shoreline wetlands as long as the situation is not addressed. Shrinking Lake level conditions could create dry conditions denying the wetland, which has a lateral hydrological connectivity to the Lake such as Nyando its hydro-graphic requirements for proper functioning (Khisa, *et al.*, 2013). Such a condition could promote increased agricultural activities in the wetland and worsen its future. Further research is however required to determine the relativeness between the water use at Ruzizi and the decline in the Lake levels.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Nyando Wetland is an ecosystem besieged by unrelenting negative forces of environmental change which are anthropogenic and hydro-dynamic in nature. These forces have led to an unprecedented decline in the area of the wetland and degradation of its natural resources. In addressing the first objective of the study, it was concluded that there are significant changes in area covered by various land uses between 1984 and 2010. The areas exposed by the declining area of the wetland have been occupied largely by small-scale subsistence agriculture. The areas under the greatest pressure of agricultural encroachment are in the north-western, northern and north-eastern parts of the wetland and are largely characterized by fertile flood plain deposit from frequent fluvial and flood events.

Based on the second objective of the study, it is concluded that during the 1979 to the 1989 period, significant differences in population increases occurred in a generally rapid exponential growth. Although the population growth rate has levelled off, its relative constancy is a major cause for concern for the resources of Nyando Wetland. It is further concluded that the population growth, per see, does not seem to have a direct influence on the changes in the wetland area but causes indirect changes through the anthropogenic activities whose magnitude expands in space and time in response to the growing population size.

Data derived from studying the third objective led to the conclusion that fluctuations of Lake Victoria water level is a cyclic event which occurs almost every decade with the lowest level and steepest declining trends recorded after 2005. Subsequent decline thereafter, were mainly due to adverse human activities and to a limited extent climatic variations (frequent droughts). Therefore both the fluctuations in Lake level and the decrease in the water area occasioned by the shifting shoreline as a result of the declining Lake level had a strongly significant relationship to the declining wetland area, all other factors held constant.

6.2 Recommendations

The study therefore recommends as follows;

1. The County Government of Kisumu and non-governmental organizations operating in the study are such as VIRED international, VI-Agro and care-Kenya should as matter of priority, promote programs that encourage local communities to embrace innovation and agricultural systems that increase production through vertical expansion such as aquaponics, use of improved drought and disease resistant high yielding crop varieties and organic farming with proper control and management of their ecological effects in the neighbourhoods of the wetland.

2. The organizations should also encourage income diversification as a strategy for reducing exploitation pressure on the resources of Nyando wetland.

3. A joint effort among the County Government of Kisumu, NEMA, various development partners and the local communities should urgently be initiated to develop and implement a participatory Wetlands' Management Plan (WMP) that focusses on the conservation and effective management of Nyando Wetland for its long-term health.

4. The County Government of Kisumu, National Environment Management Authority (NEMA) and the development partners in the study area should promote participatory wetland rehabilitation of degraded areas. Such a promotions should embrace wise use principles that integrate non-destructive uses of the wetland's resources to reduce livelihood pressures on the wetland.

5. While reproductive health is a human right, the National Council for population Development, the County Government of Kisumu and local non-governmental organizations should empower local community institutions such village community workers, with sufficient knowledge and resources to encourage the local communities to balance such rights with development. This should be aimed at creating an environment suitable for a successful transition from current family sizes

to smaller and ecologically sensitive families to reduce population growth rates in the study area.

6. The County and National Government, especially the National Environment Management Authority (NEMA), should ensure that Nyando Wetland is treated as fragile common property resource on the edge of degradation and should be conserved through clear policy frameworks based on public trust doctrines reinforced with sound traditional practices. The conservation should thus embrace wise use principles postulating that the wetland is vital for the survival of people, plants and animals living on or near it and therefore must be protected by the local communities from further degradation for the common good.

7. The organizations, such as VIRED International, presently carrying out education and awareness activities on the importance of ecologically friendly wetland management practices in the study area, should intensify their efforts to stem the rapid loss of the area covered by the wetland.

8. There should be close and effective joint monitoring and control of non-returnable abstraction of waters for socio-economic development from Lake Victoria by a joint body with jurisdiction in the countries riparian to Lake Victoria such as the East African Community to ensure compliance with the "agreed curve" agreements.

9. The stakeholder institutions such as NEMA, LBDA, Ministry of Water and LVBC should take the lead in ensuring checks against over-release of Lake water for hydropower production and measures for sustainable land and water management not only in the Nyando Wetland study area but also in the entire basin.

10. Finally, the combination of remote sensing, GIS and socio-ecological tools in a mixed methods research is recommended as an effective approach for wetland ecosystem studies which can offer timely conservation data, even for physically inaccessible areas of the wetland. However, there is need for higher resolution imagery to improve accuracy of results for well-targeted interventions.

6.3 Areas for Further Research

1. Integrated and participatory adaptive research to stimulate quick responses and regenerative actions that could restore and conserve the wetland ecosystem should be carried out in the study area.

2. Further research on the extent to which the human induced area reduction in the size of Nyando Wetland would compromise the biochemical functions of the ecosystem especially with a focus on the nutrient budgets of the wetland should be conducted

3. The effects of sedimentation on the future of biodiversity in Nyando Wetland should be studied.

4. A quantification of the hydrological drawdown effects of the declining water levels of Lake Victoria on Nyando Wetland should be carried out.

5. The links between sedimentation and wetland desiccation in Nyando Wetland ecosystem should be investigated.

6. The links between the water use at Ruzizi in Uganda and the declining Lake levels should be studied in more detail.

7. Indigenous knowledge and sustainable wetland management practices for the Nyando Wetland ecosystem should be studied.

8. The potential of Nyando Wetland for alternative uses such tourism as a pressure release mechanism for sustainable management of the wetland should be investigated.

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APPENDICES

Appendix 1: Land Use Decisions and Hydrodynamics Questionnaire

Part I: Background Information

1. Interview date	
2. Name of Enumerator	
3. Name of Respondent	
4. Place of Birth	
4. District	
5. Division	
6. Location	
7. Sub-location	
8. Village	
9. Clan	
10. GPS location of Homestead/Respondent	

11. What is the type of household?
    - a. Male- headed [ ]
    - b. Female headed [ ]
    - c. Male –headed, female run [ ]
    - d. Child –headed (Headed by someone less than 18years old) [ ]
    - e. Elderly supporting orphans [ ]

12. What is the role of the respondent in the household?
    - a. Household head [ ]
    - b. Husband [ ]
    - c. Wife [ ]
    - d. Child [ ]
    - e. Worker [ ]
    - f. Other (specify)…………………………………………………

Household information

13.	14.	15.	16.	17.
Age (yrs)	**Sex/ gender**	**Marital Status**	**Type of marriage**	**Level of education**
	1=Male 2=Female	1=Married 2=Single 3= Widowed 4= Divorced 5=Other (specify)	1=Monogamous 2=Polygamous 3=Inheritance 4= Others	1= None 2=Lower Primary (Std1-3) 3= Upper primary (Std4-8) 4= Post primary training 5=Secondary (Form 1-4) 6=Post-secondary training 7=Middle level colleges 8= University

Part II: Household characteristics

18. Describe the Households characteristics?

No. in household	No of females	No. of males	Children	Grand-children	Relatives	Workers

Others (specify)..

19. Indicate if you cultivate or farm the following inside or outside the wetland and how many seasons you do so per year;

	a	B	c	d	e	f	g	H
	Crop	**In the wetl**	**Out the wetl**	**Returns (Ksh)**	**No. of Seasons (in)**	**Reason**	**No. of Seasons (out)**	**Reason**
i	Maize							
ii	Rice							
iii	Sugar Cane							
iv	Green Grams							
v	Beans							
vi	Cow peace for seed							
vii	Cow peace for veg.							
viii	Sorghum							
ix	Millet							
x	Water melon							
xi	Butter nut							
xii	Sweet Potatoes							
xiii	Arrow roots							
xiv	Dek							

20. What constraints do you face in crop production inside the wetland?

[1] High cost of inputs
[2] Lack of water / drought
[3] Difficulty in obtaining farm inputs
[4] Damage by insects, animals or diseases
[5] Technical matters (specify them)
[6] Lack of reliable market
[7] Low yields
[8] Lack of machinery
[9] Shortage of working capital
[10] Others (Specify) ....

21. A part from farm income, do you have another source of income?

[1] =Yes, [2] =No

22. If yes, from which source and how much per year?

	Tick	**Returns (Ksh)** **1= <1000** **2= 2,000-5,000** **3= 6,000-10,000** **4 = >10,000**	**Remarks**
[i] Petty Trade			
[ii] Remittances			
[iii] Interest from shares/savings			
[iv] Brewing			
[v] Mat making			
[vi] Rope making			
[vii]Bodaboda			
[viii] Tailoring			
[ix] Casual labour (Amal)			
[x] Leasing out land			
[xi] Bar wa bar (leasing)			

[l] Other sources (specify)..

23. If you own livestock, where do they graze?

		Wet Season	Dry season
[i]	Cattle		
[ii]	Sheep		
[iii]	Goats		
[iv]	Donkeys		
	[1]On the plains with the short grass next to homestead [2]On remains of crops and fallow land next to homestead [3]On remains of crops and fallow land inside the wetland [4]On dense papyrus areas of the wetland [5]On *Vossia* (hippo Grass) along open water channel [6]Cut *Vossia* (hippo grass) and bring home [7] Others (specify) …………………………………………………………………………		

23. b. Indicate if you graze or farm the following inside or outside the wetland and how many seasons you do so;

a	b	c	d	e	f	g	H
Livestock	**In wetland**	**Out the wetland**	**Returns in Kshs.**	**No. Of Seasons (in)**	**Reason**	**No. Of seasons (out)**	**Reason**
Cattle							
Sheep							
Goats							
Chicken							
Ducks							
Donkeys							
Fish farming							
Bees							
Others (specify)							

Part III: Land ownership

24	**25**	Area of land (acres) owned		
Do you have land for use	Property rights/tenure		**26** in wetland	**27** outside the wetland
1=Yes 2=No	1=Family land 2=Bought 3=Inherited 4=Rented	Family land		
		Bought		
		Inherited		
		Rented		

Part IV: Perception of Socio-ecological Changes and mitigation

28. Which year did you start farming in the wetland? ……......................................……

29. When you started farming in the wetland, did you clear the land yourself or had it been farmed before you started using it?

[1**]** = self [2**]** =other person.

30. If the answer to Qn. 29 is [1] which method did you use for land clearing in the wetland?

1= Uprooting [....**]**
2= Burning [....**]**
3= Cutting/slashing [....**]**
4= All above [....**]**
5= Others (specify)..

31. Since you started using the land, have the sizes of land parcels used for various purposes in the wetland changed and why?

Change in size of land Used for		[1] = Remained the same [2] = Increased [3] = Decreased			
		Remained the Same	**Increased**	**Decreased**	**Reason**
[i**]**	Maize				
[ii**]**	Rice				
[iii**]**	Sugar Cane				
[iv**]**	Green Grams				
[v**]**	Beans				
[vi**]**	Cow peace for seed				
[vii**]**	Cow peace for veg.				
[viii**]**	Sorghum				
[ix**]**	Millet				
[x**]**	Water melon				
[xi**]**	Butter nut				
[xii**]**	Sweet Potatoes				
[xiii**]**	Arrow roots				
[xiv**]**	Others				

32. What changes have you seen in the wetland since you started working in it or living near it?

		1980 -1990	**1990- 2000**	**2000-2010**
		[1] = Remained the same [2] = Increased [3] = Decreased		
Change				
[i]	Area of papyrus vegetation			
[ii]	Area of Reeds			
[iii]	Area of sedges (“*see*”)			
[iv]	Area of cropland			
[v]	Area of wetland			
[vi]	Land fertility			
[vii]	Flooding frequency			
[viii]	Quantity of fish caught			
[ix]	Wetland animals			
[x]	Wetland birds			
[xi]	Grain eating birds			
[xii]	Lake water has turned more brown			
[xiii]	Human diseases			
[xiv]	Others (specify)			

33. What actions have you or others taken in relation to the above changes?

Change	**Respondent Action**	**Community action reduce/mitigate change**	**Government department or ministry/Organization (NGO, CBO) action reduce/mitigate change**

34. During what time of the year/season do you use the following resources within the wetland and why?

[1] = Dry season [2] = Wet season

Wetland resource	Time of the year/ season	Reason
[i] Land		
[ii] Papyrus		
[iii] Sedges (see)		
[iv] Fish		
[v] Grass		
[vi] Saka-Livestock feed		
[vii] Modhno		
[viii] Osika		
[ix] Omburi Sesbania		
[x] Asawo		
[xi] Oundho		
[xii] Maganda (dried Sugar cane)		
[xiii] Charcoal		
[xiv] Others (specify)		

35. In your view, rank in the Table below in order of severity the resources above that are in danger of depletion?

[1] = Extremely depleted (80%) [2] = severely depleted (75%)
[3] = Moderately depleted (50%) [4] = depleted (30 - 40%)
[5] = Slightly depleted (10- 30%) [6] = Not depleted (0-9%)
[7] = Don't know

Wetland resource	Rank	Reason
[i]Usable Land in wetland		
[ii]Papyrus (Oundho)		
[iii]Sedges		
[iv]Fish		
[v]Thatching Grass (*See*)		
[vi]*VossiaSp* -Saka- (Livestock feed)		
[vii]*Synodon D*. (Modhno)		
[viii]Osika		
[ix]*SesbaniaS*. (Omburi)		
[x]Asawo		
[xi]Maganda (dried Sugar cane)		
[xii]Charcoal		
[xiii]Others (specify)		

Part V: Lake /water level Changes

36. Are there times when the shoreline moves inwards or outwards?
    - i) Yes [ ]
    - ii) No [ ]

37. What term is used to refer to this phenomenon in local language? ....

38. When does this movement usually occur in this area?
    - i) January [ ]
    - ii) February [ ]
    - iii) March [ ]
    - iv) April [ ]
    - v) May [ ]
    - vi) June [ ]
    - vii) July [ ]
    - viii) August [ ]
    - ix) September [ ]
    - x) October [ ]
    - xi) November [ ]
    - xii) December [ ]

39. How often does it occur?
    - i) Once a year [ ]
    - ii) Twice a year [ ]
    - iii) Thrice a year [ ]
    - iv) Four times a year [ ]
    - v) Continuous, slow and permanent [ ]
    - vi) Continuous, slow and temporary [ ]
    - v) Other (Specify)……………………………………………………………

40. a) What do you do with the areas that are exposed when the shoreline retreats?
    - i) Cultivate them [ ]
    - ii) Use them for grazing [ ]
    - iii) Burn [ ]

iv) Harvest the wetland plants [ ]

v) Leave them fallow [ ]

vi) Other (specify) ……………………………………………………………

b) What do you do when the shoreline/water level rises?

i) Abandon the land [ ]

ii) Do trenches to control water [ ]

iii) Change to semi aquatic crop plants such as arrow roots [ ]

iv) Change to sugarcane [ ]

v) Others (specify) [ ]

41. Has the shoreline retreated permanently since you started farming in the wetland?

i) Yes [ ]

ii) No [ ]

42. How has the changes in the shoreline affected your use of the Land?

i) Minimally [ ]

ii) Moderately [ ]

iii) Adversely [ ]

iv) Very adversely [ ]

43. What is your opinion on the land use changes that are taking place in the Wetland?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………

44. Suggest any solutions to the land use changes that are taking place in the Wetland

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

Appendix 2: Tables[a] for Finding a Base Sample Size[b] According to Watson, (2001)

+/- 5% Margin of Error[c]

	Sample Size				
	Variability				
Population	**50%**	40%	30%	20%	10% [d]
100 [e]	**81**	79	63	50	37
125	**96**	93	72	56	40
150	**110**	107	80	60	42
175	**122**	119	87	64	44
200	**134**	130	93	67	45
225	**144**	140	98	70	46
250	**154**	149	102	72	47
275	**163**	158	106	74	48
300	**172**	165	109	76	49
325	**180**	173	113	77	50
350	**187**	180	115	79	50
375	**194**	186	118	80	51
400	**201**	192	120	81	51
425	**207**	197	122	82	51
450	**212**	203	124	83	52
500	**222**	212	128	84	52
600	**240**	228	134	87	53
700	**255**	242	138	88	54
800	**267**	252	142	90	54
900	**277**	262	144	91	55
1,000	**286**	269	147	92	55
2,000	**333**	311	158	96	57
3,000	**353**	328	163	98	57
4,000	**364**	338	165	99	58
5,000	**370**	343	166	99	58
6,000	**375**	347	167	100	58
7,000	**378**	350	168	100	58
8,000	**381**	353	168	100	58
9,000	**383**	354	169	100	58
10,000	**385**	**356**	**169**	**100**	**58**
15,000	**390**	**360**	**170**	**101**	**58**
20,000	**392**	362	171	101	58
25,000	**394**	363	171	101	58
50,000	**397**	366	172	101	58
100,000	**398**	367	or172	101	58

Qualifications for [a], [b], [c], [d] and [e] are presented in items a, b, c, d, and e below;

Qualifications

a) This table **assumes a 95% confidence level,** identifying a risk of 1 in 20 that actual error is larger than the margin of error (greater than 5%).

b) Base sample size should be **increased** to take into consideration potential non-response.

c) A **five per cent margin of error** indicates willingness to accept an estimate within +/- 5 of the given value.

d) When the estimated population with the smaller attribute or concept is less than 10 per cent, the sample may need to be increased.

e) The assumption of normal population is poor for 5% precision levels when the population is 100 or less. The entire population should be sampled, or a lesser precision accepted.

Appendix 3: List of Key Informants

NO.	NAME	MIN/ORG	CONTACT
1	Rhoda Apunda	Agriculture	[redacted]
2	Betty Okello	Scc-Vi Agroforestry	[redacted]
3	Samson A. Gillo	Ag. Chief	[redacted]
4	Mark D Nyadiang'a	Chief West Kochieng'	[redacted]
5	Raymond Oluoch	Chief Kakola	[redacted]
6	John Omiti	Asst. Chief Wasare	[redacted]
7	Susan Odhiambo	Fisharies – Nyando	[redacted]
8	Walter Oyosi	Chief Nyalunya	[redacted]
9	Paul Abura	Chairman Flood Control – Ogenya	[redacted]
10	Walter Ogada	Opinion Leader – Bwanda	[redacted]
11	Benard Opaa	D.E.O. - Nema	[redacted]

Appendix 4: Key Informants Interview Protocol for the Nyando Wetlands Study (2010)

1. What is your current position in the community or in your current employment and your employer?
2. What role does your organization or agency play in the management of wetland resources in the Nyando Wetlands area?
3. What are the challenges that face the area in terms of land use, wetland resource use and the entire wetland ecosystem?
4. In decision-making process about wetland, what are the influencing factors?
5. What do you think the public or residents know about the resource depletability of the wetland ecosystem resources?
6. How does the public view wetlands in the Nyando wetlands area?
7. What environmental changes, particularly with wetlands have occurred over the years?
8. How have wetland changes impacted the public and wetland biodiversity in the Nyando Wetlands area?
9. What relationship exists between wetlands and the declining Lake Victoria levels in the Nyando Wetlands region?
10. How do farmers respond to areas left behind by the receding Lake Victoria shoreline and are there any structure institutional controls at the community level of at governmental levels?
11. Who are the key stakeholders in decision-making about the use of wetland resources?
12. Which of these stakeholders exert the most influence?
13. What role can the public play in the design of sustainable wetland management measures?
14. How does the public influence regulatory decision-making in the area?
15. How effective is current Wetlands policy if it exists or regulation?
16. What can be done to improve current or future wetland resource utilization controls?
17. Explain, in your own opinion, the link between population growth and the land use changes in and around the Nyando wetlands?
18. I notice some negative population growth rates in some locations such as Kawino South, Bwanda, Nyalunya and Pap Onditi. Could you explain these trends?
19. Any suggestions on mitigating the changes in the wetland, the decline in the Lkake levels and population growth?
20. Anything you would like to add that we have not covered?

Thank you for your time!

Appendix 5: List of FGD Participants

FOCUS GROUP DISCUSSION – LOWER NYAKACH AT PAP ONDITI CENTRE ON 12TH MAY, 2010

ATTENDANCE LIST

NO.	NAME	AGE	POSITION	S/LOCATION	TEL. NO.	SIGNATURE
1	Peter Owino Olewo	45	RICE FARMER	[redacted]	[redacted]	
2	EUNICE AKINYI	35	MAT MAKER, FARMER	[redacted]	[redacted]	
3	JOHN NGIGE	50	BEE KEEPER	[redacted]	[redacted]	
4	PEHINA OKELLO	55	FISH TRADER	[redacted]		
5	BENTER OLIECH	65		[redacted]	[redacted]	
6	PETER SIMON OKELLO	32	FARMER SAND HARVESTER	[redacted]		
7	Elkana Okeyo.	65	farmer.	[redacted]	[redacted]	
8	Violet Akinyi	42	Tomato & Vegetable trader	[redacted]	[redacted]	
9	Lameck Otieno	50	farmer.	[redacted]		
10						
11						
12						

FOCUS GROUP DISCUSSION – NYANDO AT AHERO ON 5TH MAY, 2010

ATTENDANCE LIST

NO.	NAME	AGE	POSITION	S/LOCATION	TEL. NO.	SIGNATURE
1	THOMAS ACHUNGO	55	AGROFORESTRY FARMER	[redacted]	[redacted]	
2	SILVANCE TUGI	62	FARMER. Cooperative Society	[redacted]	[redacted]	
3	ROSE ORUKO	42	BOAT OWNER/ FISH SELLER	[redacted]	[redacted]	
4	ROSE ODHIAMBO	42	TOMATOE FARMER	[redacted]	[redacted]	
5	REBECA JUMA	35	FISH TRADER	[redacted]	[redacted]	
6	SOLOMON OGENDA	60	HORTICULTURE FARMER	[redacted]	[redacted]	
7	Gradus Owino.	60	farmer Bee keeping.	[redacted]	[redacted]	
8	ROSELINE ADONGO	40	MAT MAKER	[redacted]	[redacted]	
9	KENNEDY OBURA	39	FARMER HORT	[redacted] SOUTH	[redacted]	
10						
11						
12						

Appendix 6: Letter for the Recruitment of Focus Group Discussion Participants for the Nyando Wetlands Study in 2010

***Has Nyando Wetlands responded to anthropogenic and hydrodynamic drivers of land use/cover changes in space and time over the last three decades*?**

Dear Sir/Madam,

My name is Joseph Okotto-Okotto. I am a graduate student at Egerton University taking a course in Natural Resources management. I am currently in the research phase of my course of study and I am studying the human and hydro dynamic drivers of change in Nyando Wetlands over the past 26 years. My aim is to integrate what I can see and gather from technical scientific views with what people can tell me as they see or experience or know on the ground to corroborate and understand the dynamics of these drivers. This will help in the planning and design of measures that could influence policy and not only be of benefit to the communities but also to the Nyando wetlands ecosystem for posterity. The Wetlands happen to be in an area where you live/under your jurisdictions. I am interested in contacting residents to have a small group discussion about the issues affecting the Wetlands and how citizens' actions could influence the course of these challenges.

I have contacted you because you have been identified as knowledgeable, keen, nurturing a great interest in wetland resources and their utilization. The one to two hour discussion will comprise approximately 9 individuals and will be recorded if all participants agree to it. All given responses will not be identified and will be kept secure and confidential. Any contact information will not be shared under any circumstances. If you would be willing to participate in the discussion, kindly fill out the contact information below, cut it off and send it back to me. You will be contacted further via email or phone.

If you have any additional questions at any time or would like more information, please feel free to contact; Dr. Obati G. Obwoyere **-** +254 725 214 510 or onacha2002@yahoo.com in the Department of Natural Resources management, or Dr. Mironga J. Momanyi – mmironga@yahoo.com in the Department of Geography, Egerton University or Prof. Phillip O. Raburu – +254 717 631 789 or praburu2002@yahoo.com in the Department of Fisheries and Aquatic Sciences, School of Natural Resources Management University of Eldoret or myself , telephone; +254 713 925 989 or jokotto@hotmail.com.

Yours faithfully

J. Okotto-Okotto

I wish to participate in the Focus Group Discussion.

Name: ________________________________ Email: ___________________________

Phone: ________________________________ Address: _________________________

Appendix 7: Focus Group Discussion Questions for the Nyando Wetlands Study in 2010

Part A: Introductory Remarks

My name is Joseph Okotto-Okotto from the Lake Basin Development Authority. I am a graduate student at Egerton University taking a course in Natural Resources management. I am currently in the research phase of my course of study and I am studying the human and hydro dynamic drivers of change in Nyando Wetlands in space and time. My aim is to integrate what I can see and gather from technical scientific views with what people can tell me as they see or experience or know on the ground to corroborate and understand the dynamics of these drivers. This will help in the planning and design measures that could not only be of benefit to the communities but also to the ecosystem for posterity. The Wetland happens to be in an area where you live/under your jurisdictions. I am here before you hoping you would be willing to answer for me a few questions. I wish to assure you that anything you tell me is confidential. Nothing you say will be personally attributed to you in any reports that result from this interview. My thesis report will be written in a manner that no individual comment can be attributed to a particular person. Are you willing to answer my questions for me today? Do you have any questions before we begin?

Part B: Guide Questions

1. What are the wetland resources in the Nyando wetlands area?
2. What are the challenges facing Nyando Wetlands and when did they start affecting the wetlands. (Probe: every challenge mentioned; what needs to happen to help in addressing these challenges? Think back to the challenges we talked about in No. 1….., What could be done about those?)
3. What is the link between population growth and the Challenges that Nyando wetlands is currently phasing (Probe: Negative population growth in some locations, immigrant impacts, why people close to the wetlands have smaller plots that than those further away etc.)
4. Briefly describe local institutional/Agency/organization/community’s interest in promoting sustainable wetland management with specific reference to Nyando wetland management (Probe: every challenge mentioned).
5. Briefly tell me what you know about the levels of Lake Victoria and how you think it is affecting the Nyando wetlands (Probe: the challenges posed by the declining lake level and what should be done to address the changes).
6. Discuss the issue of water scarcity (Probe: Is this is a problem we face in the Nyando wetlands area? Why or why not? In which ways? How is it affecting the uses of land for agriculture, how are people adapting to this? Any relationships to wetland farming)?
7. Who or what group has the most say in how wetland resources are used or managed in the Nyando Wetlands area?
8. What changes have you observed in wetland environments near you?
9. What values do you place on wetlands? (attitudes towards the wetlands, a ranking Exercise)
10. What would you like to share or discuss about the wetlands that we have not touched in our discussion?

Appendix 8: Average of Lake Levels in Metres

	Average of Lake levels (m)												
Year	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
1970	1135.94	1135.95	1135.96	1136.08	1136.20	1136.20	1136.11	1136.00	1135.93	1135.85	1135.84	1135.82	**1135.99**
1971	1135.79	1135.72	1135.63	1135.69	1135.81	1135.77	1135.68	1135.61	1135.54	1135.50	1135.48	1135.45	**1135.64**
1972	1135.43	1135.40	1135.36	1135.38	1135.43	1135.45	1135.42	1135.31	1135.23	1135.19	1135.27	1135.37	**1135.35**
1973	1135.39	1135.37	1135.36	1135.45	1135.57	1135.57	1135.45	1135.36	1135.30	1135.25	1135.26	1135.27	**1135.38**
1974	1135.22	1135.16	1135.17	1135.42	1135.59	1135.58	1135.57	1135.49	1135.38	1135.30	1135.26	1135.24	**1135.36**
1975	1135.20	1135.14	1135.15	1135.24	1135.31	1135.36	1135.32	1135.30	1135.29	1135.29	1135.25	1135.24	**1135.26**
1976	1135.22	1135.18	1135.17	1135.21	1135.29	1135.28	1135.22	1135.14	1135.08	1134.98	1134.94	1134.96	**1135.14**
1977	1134.98	1134.98	1134.96	1135.10	1135.24	1135.26	1135.22	1135.18	1135.14	1135.07	1135.17	1135.24	**1135.13**
1978	1135.23	1135.22	1135.37	1135.63	1135.87	1135.87	1135.80	1135.71	1135.61	1135.57	1135.62	1135.72	**1135.60**
1979	1135.75	1135.78	1135.85	1135.97	1136.14	1136.18	1136.12	1136.03	1135.93	1135.81	1135.77	1135.75	**1135.92**
1980	1135.69	1135.62	1135.58	1135.59	1135.66	1135.65	1135.53	1135.41	1135.29	1135.19	1135.18	1135.21	**1135.47**
1981	1135.17	1135.08	1135.08	1135.21	1135.35	1135.33	1135.23	1135.17	1135.13	1135.09	1135.08	1135.07	**1135.17**
1982	1135.06	1134.99	1134.95	1134.99	1135.15	1135.20	1135.12	1135.02	1134.92	1134.92	1135.08	1135.23	**1135.05**
1983	1135.22	1135.15	1135.07	1135.12	1135.29	1135.32	1135.24	1135.18	1135.12	1135.09	1135.08	1135.07	**1135.16**
1984	1135.06	1135.00	1134.94	1135.01	1135.09	1135.03	1134.94	1134.85	1134.74	1134.63	1134.63	1134.72	**1134.89**
1985	1134.73	1134.74	1134.72	1134.91	1135.11	1135.14	1135.08	1134.97	1134.89	1134.82	1134.78	1134.78	**1134.89**
1986	1134.75	1134.71	1134.74	1134.86	1135.01	1135.03	1134.92	1134.79	1134.68	1134.62	1134.65	1134.74	**1134.79**
1987	1134.81	1134.82	1134.84	1134.96	1135.12	1135.20	1135.15	1135.02	1134.94	1134.89	1134.91	1134.91	**1134.96**
1988	1134.90	1134.90	1134.94	1135.13	1135.35	1135.35	1135.28	1135.25	1135.28	1135.30	1135.32	1135.35	**1135.20**
1989	1135.36	1135.32	1135.33	1135.49	1135.64	1135.68	1135.62	1135.51	1135.40	1135.37	1135.41	1135.55	**1135.47**
1990	1135.62	1135.60	1135.72	1135.97	1136.11	1136.10	1135.97	1135.86	1135.75	1135.66	1135.63	1135.62	**1135.80**
1991	1135.62	1135.60	1135.61	1135.75	1135.86	1135.87	1135.81	1135.73	1135.64	1135.60	1135.62	1135.61	**1135.69**

Average of Lake levels (m)

Year	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec	Total
1992	1135.54	1135.48	1135.40	1135.37	1135.43	1135.41	1135.35	1135.23	1135.11	1135.06	1135.05	1135.07	**1135.29**
1993	1135.11	1135.11	1135.06	1135.09	1135.20	1135.24	1135.15	1135.05	1134.93	1134.81	1134.76	1134.72	**1135.02**
1994	1134.67	1134.62	1134.63	1134.75	1134.90	1134.96	1134.89	1134.82	1134.74	1134.71	1134.75	1134.83	**1134.77**
1995	1134.85	1134.84	1134.89	1135.01	1135.19	1135.24	1135.20	1135.10	1135.01	1134.99	1135.02	1135.02	**1135.03**
1996	1135.08	1135.10	1135.15	1135.27	1135.41	1135.44	1135.37	1135.27	1135.19	1135.13	1135.11	1135.13	**1135.22**
1997	1135.14	1135.09	1135.01	1135.09	1135.21	1135.21	1135.14	1135.04	1134.91	1134.86	1134.99	1135.39	**1135.09**
1998	1135.72	1135.80	1135.86	1136.08	1136.33	1136.36	1136.27	1136.17	1136.08	1136.02	1135.98	1135.90	**1136.05**
1999	1135.86	1135.77	1135.78	1135.93	1136.06	1136.01	1135.93	1135.85	1135.75	1135.72	1135.70	1135.74	**1135.84**
2000	1135.69	1135.60	1135.54	1135.54	1135.52	1135.42	1135.31	1135.17	1135.04	1134.98	1135.00	1135.07	**1135.32**
2001	1135.12	1135.11	1135.11	1135.21	1135.32	1135.35	1135.26	1135.17	1135.09	1135.04	1135.10	1135.14	**1135.17**
2002	1135.14	1135.09	1135.08	1135.15	1135.29	1135.30	1135.20	1135.11	1135.01	1134.93	1134.96	1134.99	**1135.10**
2003	1135.00	1134.92	1134.85	1134.97	1135.18	1135.25	1135.25	1135.18	1135.12	1135.09	1135.13	1135.16	**1135.09**
2004	1135.12	1135.06	1135.03	1135.07	1135.20	1135.16	1135.04	1134.92	1134.83	1134.81	1134.88	1134.98	**1135.01**
2005													
2006													
2007		1134.14	1134.12	1134.13	1134.20	1134.25	1134.20	1134.15	1134.18	1134.16	1134.18	1134.19	**1134.17**
2008	1134.17	1134.21	1134.20	1134.19	1134.21	1134.24	1134.67	1134.73	1134.69	1134.73	1134.66	1134.67	**1134.45**
2009	1134.68	1134.62	1134.21	1134.21	1134.20	1134.10	1134.12	1134.08	1134.26				**1134.27**

Appendix 9: Population Projections

a) Population Projections (1979-1985)

	Year Location	1979	1980	1981	1982	1983	1984	1985
1	Kawino South	4,068	4,100	4,133	4,166	4,200	4,233	4,267
2	Bwanda	5,334	5,008	4,703	4,416	4,146	3,893	3,656
3	Kakola	7,797	8,210	8,645	9,103	9,586	10,094	10,629
4	Kochogo	4,707	4,876	5,052	5,233	5,422	5,617	5,820
5	North Nyakach	3,637	3,727	3,821	3,916	4,014	4,114	4,218
6	Nyalunya	7,971	7,819	7,671	7,525	7,382	7,241	7,104
7	Kombura*	4,410	4,604	4,807	5,018	5,239	5,469	5,710
8	Pap Onditi	10,193	10,142	10,091	10,041	9,991	9,941	9,891

b) Population Projections (1986-1992)

	Year Location	1986	1987	1988	1989	1990	1991	1992
1	Kawino South	4,301	4,335	4,370	4,415	4,481	4,548	4,615
2	Bwanda	3,433	3,224	3,027	2,817	3,028	3,254	3,497
3	Kakola	11,192	11,785	12,410	12,987	13,552	14,141	14,756
4	Kochogo	6,029	6,246	6,471	6,675	6,795	6,916	7,040
5	North Nyakach	4,323	4,431	4,542	4,650	4,694	4,739	4,784
6	Nyalunya	6,969	6,837	6,707	6,596	6,579	6,562	6,545
7	Kombura*	5,961	6,223	6,497	6,803	6,816	6,828	6,841
8	Pap Onditi	9,842	9,792	9,743	9,741	9,593	9,447	9,303

c) Population Projections (1993-1999)

	Year / Location	1993	1994	1995	1996	1997	1998	1999
1	Kawino South	4,684	4,754	4,825	4,897	4,970	5,044	5,073
2	Bwanda	3,758	4,039	4,341	4,665	5,014	5,388	4,922
3	Kakola	15,397	16,067	16,766	17,495	18,255	19,049	18,634
4	Kochogo	7,166	7,294	7,425	7,558	7,693	7,831	7,870
5	North Nyakach	4,830	4,876	4,922	4,969	5,016	5,064	5,093
6	Nyalunya	6,529	6,512	6,495	6,479	6,462	6,445	6,427
7	Kombura*	6,853	6,866	6,878	6,891	6,904	6,916	6,928
8	PapOnditi	9,161	9,022	8,884	8,749	8,616	8,485	8,258

d) Population Projections (2000-2006)

	Year / Location	2000	2001	2002	2003	2004	2005	2006
1	Kawino South	5,021	4,969	4,918	4,867	4,817	4,768	4,719
2	Bwanda	5,021	5,122	5,224	5,329	5,436	5,545	5,657
3	Kakola	18,939	19,248	19,563	19,882	20,207	20,537	20,873
4	Kochogo	8,059	8,253	8,451	8,654	8,862	9,075	9,293
5	North Nyakach	5,204	5,318	5,434	5,553	5,674	5,798	5,924
6	Nyalunya	6,569	6,714	6,862	7,014	7,169	7,327	7,489
7	Kombura*	7,047	7,168	7,291	7,416	7,543	7,672	7,804
8	Pap Onditi	8,354	8,451	8,549	8,648	8,749	8,850	8,953

e) Population Projections (2007-2005)

	Year Location	2007	2008	2009	2002	2003	2004	2005
1	Kawino South	4,670	4,622	4,551	4,918	4,867	4,817	4,768
2	Bwanda	5,770	5,886	5,910	5,224	5,329	5,436	5,545
3	Kakola	21,214	21,561	21,679	19,563	19,882	20,207	20,537
4	Kochogo	9,516	9,745	9,761	8,451	8,654	8,862	9,075
5	North Nyakach	6,054	6,186	6,205	5,434	5,553	5,674	5,798
6	Nyalunya	7,654	7,823	7,846	6,862	7,014	7,169	7,327
7	Kombura*	7,937	8,074	8,116	7,291	7,416	7,543	7,672
8	Pap Onditi	9,057	9,162	9,217	8,549	8,648	8,749	8,850

f) Population Projections (2006-2009)

	Year Location	2006	2007	2008	2009
1	Kawino South	4,719	4,670	4,622	4,551
2	Bwanda	5,657	5,770	5,886	5,910
3	Kakola	20,873	21,214	21,561	21,679
4	Kochogo	9,293	9,516	9,745	9,761
5	North Nyakach	5,924	6,054	6,186	6,205
6	Nyalunya	7,489	7,654	7,823	7,846
7	Kombura*	7,804	7,937	8,074	8,116
8	Pap Onditi	8,953	9,057	9,162	9,217

g) Estimated Population Growth Rates by Locations

Year Location	1979-1989	1989-1999	1999-2009
Kawino South	0.8	1.4	-1.1
Bwanda	-6.1	5.7	1.8
Kakola	5.3	3.7	1.5
Kochogo	3.6	1.7	2.2
North Nyakach	2.5	0.9	2
Nyalunya	-1.9	-0.3	2
Kombura*	4.4	0.2	1.6
Pap Onditi	-0.5	-1.6	1.1

Appendix 100: Variance of Lake Levels in metres (m)

Variance of Lake levels (m)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1970	0.0003	0.0001	0.0004	0.0021	0.0005	0.0005	0.0013	0.0007	0.0008	0.0002	0.0001	0.0000	**0.0167**
1971	0.0003	0.0003	0.0007	0.0035	0.0003	0.0008	0.0003	0.0005	0.0005	0.0002	0.0000	0.0001	**0.0150**
1972	0.0005	0.0000	0.0003	0.0002	0.0004	0.0000	0.0006	0.0008	0.0006	0.0000	0.0018	0.0003	**0.0073**
1973	0.0000	0.0000	0.0002	0.0029	0.0005	0.0009	0.0015	0.0005	0.0001	0.0004	0.0003	0.0001	**0.0118**
1974	0.0005	0.0001	0.0016	0.0069	0.0003	0.0001	0.0002	0.0013	0.0010	0.0003	0.0001	0.0000	**0.0251**
1975	0.0005	0.0002	0.0005	0.0013	0.0012	0.0001	0.0001	0.0001	0.0000	0.0000	0.0006	0.0002	**0.0048**
1976	0.0008	0.0001	0.0002	0.0011	0.0008	0.0004	0.0004	0.0004	0.0006	0.0008	0.0001	0.0000	**0.0140**
1977	0.0000	0.0000	0.0000	0.0037	0.0012	0.0001	0.0004	0.0000	0.0007	0.0000	0.0023	0.0001	**0.0118**
1978	0.0001	0.0004	0.0053	0.0065	0.0024	0.0001	0.0010	0.0008	0.0009	0.0000	0.0010	0.0008	**0.0465**
1979	0.0001	0.0002	0.0018	0.0025	0.0017	0.0001	0.0008	0.0006	0.0011	0.0011	0.0000	0.0000	**0.0251**
1980	0.0010	0.0006	0.0000	0.0001	0.0008	0.0011	0.0012	0.0016	0.0009	0.0006	0.0004	0.0001	**0.0378**
1981	0.0007	0.0005	0.0015	0.0014	0.0020	0.0013	0.0003	0.0003	0.0001	0.0001	0.0001	0.0001	**0.0094**
1982	0.0002	0.0007	0.0001	0.0009	0.0034	0.0002	0.0011	0.0009	0.0004	0.0008	0.0038	0.0002	**0.0115**
1983	0.0003	0.0007	0.0003	0.0027	0.0022	0.0004	0.0007	0.0001	0.0005	0.0000	0.0000	0.0001	**0.0074**
1984	0.0001	0.0004	0.0006	0.0027	0.0000	0.0008	0.0006	0.0010	0.0014	0.0006	0.0007	0.0005	**0.0264**
1985	0.0001	0.0002	0.0003	0.0070	0.0015	0.0003	0.0007	0.0015	0.0004	0.0004	0.0000	0.0001	**0.0229**
1986	0.0004	0.0000	0.0003	0.0032	0.0013	0.0005	0.0015	0.0018	0.0009	0.0000	0.0003	0.0013	**0.0176**
1987	0.0001	0.0000	0.0007	0.0037	0.0015	0.0001	0.0013	0.0014	0.0003	0.0003	0.0006	0.0004	**0.0167**
1988	0.0002	0.0001	0.0010	0.0070	0.0012	0.0004	0.0004	0.0002	0.0002	0.0000	0.0003	0.0001	**0.0307**
1989	0.0001	0.0002	0.0018	0.0017	0.0022	0.0001	0.0007	0.0012	0.0006	0.0001	0.0002	0.0027	**0.0155**
1990	0.0004	0.0001	0.0045	0.0048	0.0005	0.0012	0.0013	0.0008	0.0013	0.0002	0.0001	0.0001	**0.0354**
1991	0.0000	0.0000	0.0004	0.0013	0.0008	0.0001	0.0008	0.0002	0.0015	0.0007	0.0001	0.0001	**0.0105**

Variance of Lake levels (m)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1992	0.0005	0.0007	0.0006	0.0001	0.0002	0.0005	0.0003	0.0018	0.0009	0.0000	0.0000	0.0002	**0.0294**
1993	0.0001	0.0002	0.0001	0.0005	0.0020	0.0001	0.0019	0.0007	0.0015	0.0012	0.0002	0.0004	**0.0285**
1994	0.0001	0.0001	0.0006	0.0026	0.0020	0.0004	0.0003	0.0005	0.0005	0.0000	0.0010	0.0001	**0.0115**
1995	0.0001	0.0001	0.0007	0.0021	0.0018	0.0001	0.0005	0.0013	0.0004	0.0002	0.0000	0.0002	**0.0165**
1996	0.0002	0.0000	0.0015	0.0016	0.0012	0.0004	0.0005	0.0010	0.0004	0.0002	0.0001	0.0000	**0.0156**
1997	0.0002	0.0009	0.0001	0.0032	0.0003	0.0003	0.0008	0.0009	0.0019	0.0005	0.0034	0.0241	**0.0221**
1998	0.0019	0.0001	0.0015	0.0081	0.0023	0.0003	0.0015	0.0007	0.0003	0.0002	0.0004	0.0004	**0.0413**
1999	0.0001	0.0012	0.0007	0.0044	0.0001	0.0008	0.0004	0.0007	0.0010	0.0001	0.0002	0.0001	**0.0139**
2000	0.0006	0.0007	0.0001	0.0002	0.0003	0.0010	0.0018	0.0014	0.0012	0.0001	0.0004	0.0009	**0.0630**
2001	0.0001	0.0000	0.0001	0.0020	0.0011	0.0003	0.0008	0.0009	0.0004	0.0000	0.0004	0.0000	**0.0091**
2002	0.0001	0.0003	0.0001	0.0015	0.0007	0.0003	0.0011	0.0008	0.0008	0.0002	0.0006	0.0001	**0.0139**
2003	0.0003	0.0007	0.0002	0.0051	0.0009	0.0001	0.0003	0.0002	0.0006	0.0001	0.0000	0.0001	**0.0158**
2004	0.0003	0.0003	0.0000	0.0012	0.0001	0.0008	0.0013	0.0010	0.0002	0.0001	0.0007	0.0018	**0.0155**
2005													
2006													
2007		0.0027	0.0048	0.0015	0.0024	0.0004	0.0017	0.0017	0.0006	0.0022	0.0003	0.0003	**0.0030**
2008	0.0011	0.0004	0.0040	0.0002	0.0004	0.0001	0.0173	0.0005	0.0004	0.0009	0.0007	0.0013	**0.0626**
2009	0.0006	0.0008	0.0002	0.0004	0.0003	0.0007	0.0007	0.0007	0.0023				**0.0443**
Total	**0.1501**	**0.1701**	**0.1939**	**0.2217**	**0.2407**	**0.2374**	**0.2046**	**0.1942**	**0.1729**	**0.1492**	**0.1414**	**0.1359**	**0.1916**

Appendix 11: Sample t-test for Returns on Crops Cultivated Inside or Outside the Wetland

Crop	t-statistic	p – value at α=0.05
Maize	0.59	0.561
Rice	0.45	0.652
Sugar cane	0.06	0.952
Beans	0.81	0.423
Cow Peas for Seed	0.47	0.637
Cow Peas for Vegaetables	2.23	0.029
Sorghum	-1.23	0.233
Water Melon	2.47	0.033