



PAN-AFRICAN UNIVERSITY
INSTITUTE FOR WATER AND ENERGY SCIENCES
(Including CLIMATE CHANGE)

Master Dissertation

Submitted in partial fulfillment of the requirements for the Master of
Science degree in

WATER (POLICY)

Presented by:

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Reg. No: PAUWES/2022/MWP05

**HISTORICAL WETLAND CHANGE DETECTION
FOR SUSTAINABLE MANAGEMENT: A CASE OF
LUKANGA SWAMP, ZAMBIA**

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HISTORICAL WETLAND CHANGE DETECTION FOR SUSTAINABLE MANAGEMENT: A CASE OF LUKANGA SWAMP, ZAMBIA

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APRIL, 2024

DECLARATION

I hereby declare that this thesis is solely my original work and has not been presented as a Master degree thesis in any other university across the globe.

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DEDICATION.

I dedicate my Master's thesis to my late Grandmother and family who unwavering supported, encouraged and have been my guiding light throughout this academic journey. To my guardians, whose sacrifices has always been my source of strength. To my friends, who have stood by me through the challenges and celebrated with me in moments of triumph, I am profoundly grateful.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my heartfelt gratitude to the Almighty God, above all, for taking care of me throughout my studies and to the Pan African University Scholarship for this opportunity in pursuit of my Master of Science in Water Policy at the Pan African University Institute of Water and Energy Sciences, Including climate change (PAUWES), in Algeria.

Secondly, I extend my deepest gratitude to my advisor, Dr Tewodros Tena, for your timely academic, social and professional assistance, guidance, critics, and contribution towards a smooth execution of this research from its start to its achievement at PAUWES.

The dissertation is dedicated to my uncle, Brigadier General E Lungomesha and my aunt, Benignah Matakala Lungomesha, who have always inspired and motivated me. I would like also to dedicate further to my siblings Maluja, Choolwe, Thapelo and Sam Lungomesha, I love you guys.

Last but not least, I would like to express my warm appreciation and thanks to my classmates and friends who were always encouraging and rendering me necessary services and taking care of me during my stays in the study area.

ABBREVIATION AND ACRONYMS

LU	Land Use
LC	Land Cover
LULC:	Land Use/Land Cover
NDVI	Normalized Difference Vegetation Index
RS	Remote Sensing
GIS	Geographic Information System
TM	Thematic Mapper
ETM	Enhanced TM
OLI	Operational Land Imager
MSS	Multispectral Scanner
MODIS	Moderate Resolution Imaging Spectrometer
AVHRR	Advanced Very High-Resolution Radiometer
NOAA	National Oceanic and Atmospheric Administration
USGS	United States Geological Survey
EMS	Electromagnetic Spectrum
NASA	National Aeronautics and Space Administration
DEM	Digital Elevation Model
GPS	Global Positioning System.
NDWI	Normalized Difference Water Index
OBIA	Object-based Image Analysis
RS	Remote Sensing
SPOT	Satellite Pour l'Observation de la Terre
SWIR	Shortwave Infrared
Ha	Hectares
WWF	World Wide Fund for Nature
RCB	Ramsar Convention Bureau
WARMA	Water resource management Authority
OECD	Economic Cooperation and Development
IPCC	Intergovernmental Panel on climate Change

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ABSTRACT

Lukanga is one of the listed Ramsar Sites in Zambia, which contains a rich biodiversity and a highly productive ecosystem. However, the valuable landscape has undergone a radical change in its form over the decades. This study uses past and recent satellite data to evaluate the typical land cover change over the decades. The objective of the study was to investigate land use land cover changes (LULCC) in Lukanga Swamp from 2000 to 2023. The study utilized satellite images from the United States Geological Survey (USGS), specifically Landsat images from 2000, 2013, and 2023. The data was processed, analyzed, and presented. Image pre-processing was used to correct distortions, and Erdas Imagine 2014 was used for enhanced techniques. Both pre-classification and post-classification change detection approaches were used to assess the change in the results from 2000 to 2023. Furthermore, NDVI and NDWI analysis were implemented to assess the change scenario. The maximum likelihood supervised classification technique was performed to create the signature class of significant land cover category (deep water, shallow water, forest, irrigated farmland, grassland and settlement/ bare soil). After ensuring satisfactory accuracy value for each classified image, a detail post-classification change detection analysis was executed. The results of this study have shown a decrease in the classes of deep water, shallow water and forest areas by 9.4 %, 25.5% and 1.5%, respectively, over the 23-year period. The results have also shown an increase in the land use land cover classes categories of irrigated farmland land-irrigated, grassland, and settlements/bare soil by 0.28 %, 0.024%, and 36.3 %, respectively. The study also showed NDVI and NDWI values for 2000 and 2023. The maximum NDWI values were 0.32 and 0.15 for 2000 and 2023, respectively, indicating more water bodies or higher water content in 2000. Vegetation cover status was determined using NDVI values, with values of 0.61 and 0.45 in 2000 and 2023, respectively. A 2023 NDVI of 0.45 suggests vegetation presence despite a slightly lower density than in 2000. The study area faces biodiversity loss, soil and forest degradation, land scarcity, and food shortages due to LULC change. Adequate policy and strategy are needed to mitigate these impacts and improve wetland protection, restoration and management.

Keywords: land use land cover (LULC); Change detection; Landsat images; Data; Classification

CHAPTER ONE: INTRODUCTION

1.1 Background

Wetlands are extremely productive areas that support regional, local, and watershed ecosystems (Alikhani et al., 2021). They are becoming increasingly endangered, lost, and degraded despite laws designed to protect them. Wetland degradation is mostly caused by manmade influences and climate, although no single driving factor has been identified by literature to cause wetland development and changes (Salimi et al., 2021). Wetland destruction has significant environmental consequences, and only a select few, particularly in Africa, profit from its hydroelectric power resources. A change toward wetland conservation was signaled by the Ramsar Convention on wetlands of international importance in 1975 (Wang et al., 2024). This encouraged the sustainable use of wetlands for the environment and the livelihoods of those who depended on them. Wetland destruction thus persists, and an accurate assessment of the entire size of wetlands is still unclear. Policy intervention breakdowns due to inconsistency among government policies in diverse areas, including economics, environment, nature protection, and physical planning, contribute to wetland loss. Despite this, wetlands are essential for biological productivity and survival, making sustainable management of wetlands vital for the long-term health, well-being (Kadoma et al., 2023), and safety of many African communities.

Zambia, recognizing the importance of wetlands in the 1980s, implemented its National Conservation Strategy in 1985. The Ramsar Wetlands Convention was ratified in 1991, recognizing the Kafue Flats and Bangweulu Swamps as Ramsar sites (Kachali, 2007). Wetlands in Zambia significantly impact human settlement patterns, with most located near lakes, dams, rivers, and streams. The anthropogenic land use activities of agriculture, rural-urban growth, and other environmental changes like temperature and rainfall have put wetland ecosystems in grave danger (Lungomesha & Chabala, 2022). These modifications cause serious disruptions to wetlands' capacity to provide essential ecosystem goods and services and their hydrology, species composition, productivity, variety, and spatial distribution (Orsholm & Elenius, 2022). The extent of wetland degradation varies greatly across different regions.

Nearly 19 percent of Zambia's territory is made up of three different types of wetlands: riverine, lucerne, and palustrine(WWF, 2018). For various human activities, including agriculture, hunting, fishing, grazing animals, gathering firewood, making charcoal, and providing water, these wetlands act as transitory zones(WWF, 2019). Wetlands have an impact on human settlement patterns as well because they are commonly found next to rivers, lakes, and dams. The lack of thorough research on Zambia's vegetation community structure, however, has resulted in wetlands being degraded and species that depend on them being threatened. Almost all of the nation's wetlands are still severely threatened by overexploitation due to overfishing, illicit hunting, and deforestation. Because of its significance as a source of revenue and its closeness to the ecosystem of Kafue National Park, the Lukanga Swamp was selected for this study. Lukanga Swamp has experienced significant changes over the years, including alterations in land cover, hydrology, and overall ecosystem health. The research will explore the potential impact of historical changes on Wetland's capacity to provide essential services.

1.2 Problem Statement

Wetlands play a vital role in controlling flood waters, reducing erosion, improving water quality, and serving as habitats for diverse plant, animal, and micro-organism species(W. K. Balwan & Kour, 2021). The Lukanga Swamp in particular, is vulnerable to species threats and degrading vegetation communities because there haven't been enough thorough research done on Zambia's wetlands. The indiscriminate land use of wetlands without considering their ecological functions can result in irreversible damage to wetland ecosystems(Alikhani et al., 2021). These modifications could compromise the Wetland's capacity to deliver vital functions since they have an impact on hydrology, land cover, and ecosystem health. Studies review publicly reclaimed wetlands have often resulted in ecological and environmental damage that outweighs the value of agricultural output. Large scale changes in wetland use involve many stakeholders from different levels of society, and decisions regarding wetland use should be respected at these various levels.

Literature identifies two major limitations to sustainable wetlands management in Africa. The first is that wetland users and decision-makers lack understanding of the true values of wetlands and the consequences of alternative management and policy regimes on wetland functioning, ecosystem services, and human well-being(University of Pretoria, 2006). The

second limitation is the lack of understanding of the extent people are using wetland resources, as the extent into their livelihood strategies varies due to significant socio-economic differentiation. Understanding these differences is crucial for supporting rural livelihoods and promoting sustainable wetlands use

Policymakers need to understand past patterns of wetland changes to assess the impact of land use decisions, climate change, and human activity on wetlands. This knowledge aids in identifying risks, creating conservation plans, and implementing remedies, promoting environmental protection and human development. Sustainable wetland management requires an integrated approach for economic and environmentally sustainable use of moisture-rich wetlands. However, in Zambia, an integrated approach is lacking due to a lack of qualitative and quantitative information on past, current, and potential wetland resource use and their impact on wetlands' functions.

1.3 Aim

The main objective of this research is to analyze historical wetland changes in Lukanga Swamp, Zambia, over the past 23 years (2000-2023) to understand their impacts on Lukanga Swamp for sustainable wetland management.

Specific Objectives:

1. To assess the current wetland cover and land use within Lukanga Swamp.
2. To assess the trends and historical changes in land cover and land use within Lukanga Swamp.
3. To estimate NDVI and NDWI from the satellite imagery to quantify vegetation and water dynamics in Lukanga Swamp for 2000 and 2023

1.4 Research Questions

1. How has the land cover and land use within Lukanga Swamp changed over the past decades?
2. How has water presence and distribution within the Lukanga Swamp evolved over time using indices?

3. Based on the historical wetland change analysis, what are the current policies and most suitable strategies for ensuring the sustainable management and conservation of Lukanga Swamp?

1.5. Significance of the Research

This study investigates land use/cover changes in the Lukanga Swamp between 2000 and 2023, as well as the impact of ecological and anthropogenic processes on scarce resources. It provides vital information to researchers, politicians, and policy makers. Researchers utilize historical data to understand the elements that influence wetland degradation, while advanced tools such as remote sensing and GIS analysis provide a conceptual foundation for similar environments. Policymakers can utilize the data to develop measures for mitigating negative effects and promoting long-term preservation of the environment. The research can help development actors establish and carry out targeted interventions to improve wetland management and livelihoods. The local community benefits from greater conservation awareness and participation, which promotes community engagement and empowerment in sustainable natural resource management methods. Lastly, the study evaluates the sustainability of wetland resources by examining the effects of land use and land cover on catchments in Zambia. Besides completing gaps in the literature and encouraging more studies, it offers insightful information to the community and policymakers.

1.6 Limitation of the Study

The study aimed to gather information from primary and secondary sources but faced challenges in obtaining secondary data from Zambian organizations and remote sites. Data availability and quality were limited, and available data sources' reliability and accuracy may vary. The study faced constraints related to spatial and temporal scales of analysis, as wetland ecosystems are complex and can exhibit variability. Attributing observed wetland changes to specific drivers or causes may be challenging, and logistical factors like field access and resource constraints may limit the study's accuracy. The research's applicability and generalizability beyond the study area are also important considerations.

1.7 Organization of the thesis

This dissertation is divided into five chapters, each addressing a different aspect of land use land cover change (LULC) change. The first chapter introduces the problem, research questions, objectives, and limitations. The second chapter provides a literature review on LULC change, covering driving factors, major concepts, and classification. The third chapter discusses the materials and methods used, the study area, data analysis processes, and trends in the Lukanga Swamp. The fourth chapter presents results and discussions on trends, drivers, and implications of LULC change. The fifth chapter summarizes the main findings and offers recommendations for policy and practice

CHAPTER TWO: LITERATURE REVIEW

2.1 Definition of wetlands

2.1.1 Wetlands

A wetland is an ecological community that is inundated either year around or seasonally(Balwan & Kour, 2021), Wetland also refer to various wet ecosystems, including marshes, swamps, bogs, fens, and regions that experience seasonal flooding. According to the preface, the Convention on Wetlands of International Importance (Ramsar Convention) established the most commonly used and recognized definition.

2.1.2 Marshes

Marshes have varying water levels and are nourished by either surface or groundwater. Standing water or water that is moving slowly into flood marshes. The soil in marshes is primarily mineral-based, and the drainage is adequate. They are neutral to slightly acidic and have a medium to high fertility. Marshes are primarily found next to rivers and lakes on moderate slopes, particularly on the margins and floors of valleys(Xu et al., 2019).

2.1.3 Swamps

Surface runoff and groundwater from neighboring land provide swamps with a reasonably rich supply of nutrients, along with frequent sediment. Typically, peat and minerals make up the substrates of swamps(Chabwela et al., 2017). The water table is frequently above the earth in some areas, with numerous water channels. In addition to on valley floors, deltas, and plains, swamps typically occur in basins. Sedge, rush, reed, flax, tall plants, scrub, which are frequently separated, and woodland are the characteristic plant species found in swamps

2.2 Wetland ecosystems and their importance

Wetlands provide a range of benefits to humans, including habitats for various plants, animals, and other organisms that depend on a reliable source of water and nutrients(Alikhani et al., 2021). These wetland dependent organisms are most at risk if a wetland is threatened. Wetlands are crucial resources for poverty reduction and food security improvement in developing countries, with their goods and services bringing significant societal value as demonstrated in detail in below;

2.2.1 Water Storage, Stream flow Regulation and Flood management

Wetlands store water, slow movement, and buffer areas from storms and floods, benefiting the poor who lack the financial means for storm protection or recovery(Adegeh, 2015).Wetlands also positively impact the environment by slowing down storm floods, trapping sediments, protecting property damage in downstream areas, and silting dams(Kamble et al., 2012). They are vital sources of water and fodder, particularly during dry seasons and drought, for domestic and wild animals(Wahied Khawar Balwan & Kour, 2021).

2.2.2 Food and Medicine

Wetlands also serve as important sources of food for households and medicine for rural communities, contributing significantly to poverty reduction(Russi et al., 2012). Freshwater and coastal wetlands are crucial for maintaining fish populations, providing food, shelter, and clean water, while coral reefs and mangroves provide livelihoods for millions in tropical countries (WWF,2004). Reef-related fisheries account for 9-12% of global fisheries consumption and up to 25% of production in tropical developing countries (Moberg & Folke, 1999)

2.2.3 Livestock

Past and present wetlands areas have been and still are important sites for livestock grazing, particularly during the dry season. About 20% of rural households primarily graze cattle in Wetland, which can provide valuable grazing lands, especially temporarily and seasonally waterlogged areas(Adegeh, 2015).

2.2.4 Habitat for Wildlife

The ecological potential of a wetland lies in its habitat for various plant, bird, and mammal species and its water source for human and livestock consumption(Petros Menbere & Menbere, 2018). Wetlands provide food, protection from weather and predators, resting sites, reproductive sites, and molting grounds for various wildlife species. They support various types of animals, including invertebrates, fish, amphibians, reptiles, birds, and mammals. Recreational hunting could have regional or international significance. Wetlands contribute to the diversity and beauty of the landscape(WWF, 2004).

2.2.5 Erosion control, Nutrient Cycling and Water Quality Improvements

Wetlands deposit sediments and nutrients into downstream waterways, reducing siltation and absorbing nitrogen and phosphorus from agricultural runoff (Dixon & Wood, 2007). They also serve as buffers, capturing excess sediment that would otherwise enter the ocean and safeguarding coral reefs and seagrass habitats from siltation (Wang et al., 2024). Wetland vegetation prevents erosion by absorbing wave and current energy while binding and stabilizing soil. (Adegeh, 2015)

2.2.6 Historical and Cultural Knowledge

The cultural heritage includes historical buildings and artifacts, customs related to the use of water and land, and the religious importance of wetlands and associated fauna (Dixon & Wood, 2007).

2.2.7 Carbon retention

According to the OECD (1996), peat lands and wooded wetlands contribute more than 25% of the soil carbon pool, making them important carbon sinks. Massive emissions of carbon dioxide are an inevitable consequence of turning wetlands into agricultural land.

2.3 Land Use Land Cover

Land use and land cover change are influenced by human-induced actions, such as population growth, which affects land use in developing countries (Mishra et al., 2020). This complex process is influenced by socioeconomic and environmental factors, known as driving factors. These factors can be classified as proximate or underlying drivers, with proximate driving factors being immediate activities of local peoples to meet their demands from land use (Alam & Ahamed, 2022). Examples include agricultural development, wood extraction, and infrastructure expansion, which alter the physical status of land cover (Pfaff et al., 2013).

LULC change is crucial for understanding environmental change and the cause-to-cover relationship. It is observed through modifications caused by interactions between climatic and human activities. LULC change is influenced by climatic change but drives environmental and climate changes. Understanding and examining local and global factors, such as socioeconomic characteristics, politics, technological development, and culture (Nedd et al., 2021).

Land Cover describes the material on the lands surface, such as crops, water, forest, snow, grassland, bare soil, and urban infrastructure (Alam & Ahamed, 2022). Land perception is crucial for understanding the positive and negative impacts of agronomic LU for the protection of biodiversity and its relation to ecology services. Land Cover variation is observed as the most significant variable of worldwide change affecting environmental systems, with an influence on the atmosphere as small as that linked with changing climate.

Land Use/Land Cover study is important in defining the way land is currently used and providing a starting point for present and future planning. (Lungomesha & Chabala, 2022; Nedd et al., 2021) Cover change has become a fundamental component in current approaches for monitoring environmental changes and managing natural resources. Anthropogenic activities, such as mining, agriculture land, grazing, and arrangement, are key drivers of land dynamic and LULC changes, causing constant risks on regional areas and negatively impacting the living security of people relying on these land systems. There are a lot of techniques for LC change detection like composite analysis, change vector analysis, image difference, post classification and image regression (Salman et al., 2020). Land Cover change has become a fundamental component in present approaches for monitoring environmental changes and managing natural resources (Ansod & Dandekar 2018). These variations, in turn, disturb the surface properties, which impact the concentration of absorbed and reflected energy to the atmosphere (Mercy, 2017). Anthropogenic activities for example mining, agriculture land, grazing as well as arrangement, signify the key drivers of land dynamic and LULC changes. Studies show that LULC change detection is crucial in addressing issues like watershed features, environmental services, and urban development, as changes in land use/land cover are linked to human activities and water quality (Lungomesha & Chabala, 2022). Land Use/Land Cover changes in watershed region with growth and deforestation frequently impact the water accessibility and nature as well as range of subsurface and surface water connections therefore effecting watershed networks as well as the services delivered by them (Hu et al. 2012). With accurate perspective of the temporal and spatial changes happening in a watershed over time and the interaction of the hydrological factor of a watershed, respectively, improved water conservation plans can be formulated (Butt et al. 2015).

Water accounting relies on water quantity used through LU modules, with numerous outlines

separating valuable and nonvaluable use. This classification requires precise LULC classification (Amri et al. 2017).

2.4 Indices

Remote sensing data, including Landsat and Sentinel data, are crucial for visualization, classification, and analysis of area (Janga et al., 2023). These data are categorized based on resolution, electromagnetic spectrum, energy source, imaging media, and number of bands. Landsat data is commonly used for classification, with various bands based on wavelength (J et al., 2020). Landsat 5 and 8 data. For NDVI, and NDWI analysis, only four bands (Green, Red, NIR, SWIR) are used (Bahadur, 2018).

According to USGS, Landsat 5 and Landsat 8 satellite images have distinct spectral bands for calculating NDVI and MNDWI values. Landsat-5 assigns spectral bands 2, 3, 4, and 5 for green, red, near-infrared (NIR) and middle infrared (MIR), while Landsat-8 (OLI-TIRS) assigns bands 3, 4, 5, and 6 for NIR and MIR.

2.4.1 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is a widely used global vegetation index based on the fact that healthy vegetation absorbs the electromagnetic spectrum in visible reasons (Spadoni et al., 2020). Chlorophyll in green plants absorbs blue and red spectrums while reflecting green spectrums (Virtanen et al., 2022). This makes vegetation green to the eye. Healthy plants have high reflectance in Near Infrared (NIR) and absorption in red spectrums, which are used to calculate NDVI. The formula for NDVI is based on the internal structure of plant leaves.

$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red}) \dots\dots\dots (1)$$

For Landsat 7 data,

$$\text{NDVI} = (\text{Band 4} - \text{Band 3}) / (\text{Band 4} + \text{Band 3}) \dots\dots\dots (2)$$

For Landsat 8 data,

$$\text{NDVI} = (\text{Band 5} - \text{Band 4}) / (\text{Band 5} + \text{Band 4}) \dots\dots\dots (3)$$

The NDVI value ranges from -1 to 1, indicating high Near Infrared (NIR) and dense greenery (Salman et al., 2020). Water bodies, barren rocks, sand, snow, shrubs, grasslands, or

senescing crops, dense vegetation, or tropical rainforests are represented by values ranging from -1 to 1.0.

2.4.2 Normalized Difference Water Index (NDWI)

The Normalized Difference Water Index (NDWI) is a method used for analyzing water bodies using Green and Near-infrared bands of remote sensing images (Alam & Ahamed, 2022). It can enhance water information efficiently but is sensitive to land build-up and can result in over-estimated water bodies. Water bodies with low reflectance only reflect within visible portions of the electromagnetic spectrum, while those in their liquid state have higher reflectance on the blue spectrum (0.4 - 0.5 μm) than Green (0.5 - 0.6 μm) and Red (0.6 - 0.7 μm) spectrum (De Almeida Castanho et al., 2007).

Clear water has the highest reflectance in the blue part of the visible spectrum, making it appear blue (Warren et al., 2019). Turbid water has higher reflectance in the visible spectrum but no reflection in Near Infrared (NIR) and beyond. NDWI, developed by McFeeters in 1996, enhances water-related landscape features using the near-infrared and shortwave infrared bands. The formula for NDWI can be calculated using the formula:

$$NDWI = (NIR - SWIR) / (NIR + SWIR) \dots\dots\dots (4)$$

The Normalized Difference Water Index (NDWI) ranges from -1 to 1, with water bodies generally exceeding 0.5, while vegetation has smaller values, making it easier to distinguish between them, and build-up features have positive values.

2.5 Factors Influencing Wetland Ecosystem

Wetlands are experiencing rapid degradation and loss, with both freshwater and coastal wetland species deteriorating faster than other ecosystems. Wetlands are threatened by human activity and climate change, even with strict legislation in place to protect and conserve them (Ballut-Dajud et al., 2022). A number of factors, such as reclamation, agriculture, water use, infrastructural development, pollution of the environment, and unsustainable resource use causes wetland degradation. The Ramsar Convention Secretariat (RCS), 2010 list agriculture, reclamation, water use, infrastructural development, environmental contamination, and the unsustainable exploitation of wetland resources as examples of anthropogenic causes. These elements have an impact on the productivity, species variety, soil, hydrology, and composition of wetlands.

According to Gardner et al. (2018), one of the main causes of their degradation and extinction is pollution brought on by socioeconomic development and population expansion. Rebelo et al. (2010) discovered that the requirement for level, productive land with a water supply for agriculture is the slow but steady driver of wetland degradation. South Africa has lost wetlands as a result of building dams, overgrazing, pollution, crop production, urbanization, erosion, development, and inadequate land resource management. The rate of wetland degradation is also accelerated by the disappearance of connective rivers.

Pollution caused by population growth and socioeconomic development is a major factor leading to their degradation and loss. Climate change, particularly changes in rainfall patterns and global warming, is a major threat to wetlands, resulting in significant biodiversity configurations and wetland biochemical processes(Thamaga, 2021). Rising temperatures may aid the invasion of warmer-water species into older zones, out-compete dominant species, and cause habitat destruction, species composition shifts, and habitat degradation in existing wetlands (Boon et al., 2016). Acute pollution and siltation have exaggerated these sensitive systems in recent times

2.6 The Role of GIS and Remote Sensing in Wetland Mapping

The study of historical changes in land use, land cover (LULC), and geographic information system approaches are common. The ability to access historical data, lower data costs, and increased resolution from satellite platforms make remote sensing technologies well-positioned to have a significant impact on land-cover change monitoring(Mishra et al., 2020). Remote sensing and geographic information system techniques are widely used to study land-use change (LULC) changes, identifying vegetation cover, air pollution, water bodies, and soil characteristics. Since the launch of satellites in 1972, land cover mapping has been a widely researched issue utilizing satellite data since satellite photographs frequently contain easily analysed information(Treitz & Rogan, 2004)

A Geographic Information System (GIS) is a computer-based tool for gathering, managing, storing, manipulating, and displaying spatial or geographic data. The combined use of RS and GIS makes Earth observation and data processing possible. The accurate and timely recording of LULC is made possible by the cost-effective collection and analysis of this data using RS and GIS tools(Rane et al., 2023).

2.6.1 Change Detection and Validation Technique

Change detection is the process of identifying differences in an object's state by observing it at different times (García-Álvarez & Paegelow, 2022). Earth surface features are crucial for understanding human-natural interactions and promoting better decision-making. Successful use of RS for Land Use and Land Cover Change (LULC) change detection depends on understanding the study area, satellite imaging system, and information extraction methods (Petrovska & Dimov, 2020). Remote sensing technology has become a major application for LULC change detection analysis due to its repetitive coverage and consistent image quality. Good change detection research should provide information on area change, change rate, spatial distribution of changed types, change trajectories of land cover types, and accuracy assessment of change detection results (Horvat, 2012). Three major steps in implementing a change detection project include image pre-processing, radiometric, atmospheric, and topographic correction, selection of suitable techniques for change detection analyses, and accuracy assessment.

2.6.2.1 Accuracy Assessment

Accuracy assessment or validation is crucial for land cover/land use maps derived from remotely sensed data, as it helps decision-makers understand the developed results and employ them for analysis (García-Álvarez & Paegelow, 2022). The error matrix is a widely used approach for image classification accuracy assessment, comparing the relationship between reference field data (ground truth) and corresponding classification results (Foody, 2024). To generate an error matrix, factors such as ground truth data collection, classification scheme, sampling scheme, spatial autocorrelation, and sample size and unit must be considered. Accuracy data should be collected consistently and independent of reference or ground truth data (Horvat, 2012). Sampling schemes must include appropriate sample design, with special attention given to the type of sample unit, size, number of samples, and selection methods. Accuracy data should be collected as close as possible to the same vegetation season as the time of acquisition (García-Álvarez & Paegelow, 2022). Accuracy assessment can be categorized into various aspects such as overall accuracy, errors of omission, errors of commission, user's accuracy, producer's accuracy, and Kappa statistics. (Horvat, 2012).

User's accuracy is the probability that a pixel on an image accurately represents a specific class on the ground. It is calculated by dividing the correctly classified pixels by the row total

for that class. Producer's accuracy is the probability of a pixel being correctly classified, used to determine the classification effectiveness of an area (Petrovska & Dimov, 2020). Both terms are calculated by dividing the number of correct pixels by the column total for each class.

2.6.2 Wetland Plant Species Characterization

Remote sensing is a powerful tool for analysing, mapping, and monitoring wetland plant species using satellite datasets (Jafarzadeh et al., 2022). It offers a wide range of data at varying resolutions and extracts physiological, chemical, and phenological characteristics of a species to determine it (Sang et al., 2022). This data provides spatially-explicit information on the dynamics, structure, annual precipitation, hydrological pathways, and local physiological cycle of wetland species. Remote sensing techniques also provide information on inaccessible areas, which cannot be accessed during field surveys, contributing to the enhanced estimation of wetland plant species and understanding key factors impacting biodiversity and biomass (Humphrey Thamaga, 2021). However, the method of remote sensing for estimating vegetation in wetland ecosystems has not been extensively used, especially in developing regions. Multispectral satellite imagery faces challenges in detecting, delineating, and mapping wetland plant species due to the lack of spatial resolution of most satellites (Thamaga, 2021). Additionally, the use of wide spectral bands from coarse multispectral imagery for mapping wetland species remains difficult due to spectral overlap among species.

2.7 The Implications of the Remote Sensing of Wetland Vegetation

The geographical assessment of wetland ecosystems at different spatial scales is still difficult, even with the development of robust and sophisticated remote sensing techniques and modeling algorithms. This is mostly because marsh habitats are varied and challenging to take photos of, particularly with broadband and coarse spatial resolution sensors. Furthermore, wetland fragmentation has been found to cause a significant degree of similarity in the spectral properties of the vegetation, which adds to the confusion in species mapping.

Wetland classification is difficult because of the low inter-class and considerable intra-class variation. Wetland ecosystem classification can be enhanced by using cutting-edge techniques for modelling and remote sensing imagery. Due to the process of changing from one type of land cover to another, wetlands lack a clearly defined border and have fuzzy borders

(Dronova, 2015). As a result, care should be taken in how well feature extraction and picture interpretation are done. The limited spatial resolution of satellite pictures used for remote sensing may make it more difficult to identify small wetlands. However, other studies have looked into using data from remote sensing to monitor wetlands regularly (Ozesmi & Bauer, 2002). Wetland ecosystem mapping, estimating, and monitoring challenges can be addressed with the use of Drone Technology in current years.

2.8 Conservation (Management and Policies) on Wetland

The Ramsar Convention, established in 1971, focuses on the wise use and conservation of wetlands, particularly those used by waterfowl. It is one of the oldest ecosystem-specific international conservation treaties, promoting a balanced approach to addressing wetland conservation and human development challenges. The Convention's primary objective remains wetland conservation, but it acknowledges broader human development issues that both impinge on and partly depend upon wetland ecosystems. Each member nation is expected to designate at least one Wetland for the list of Wetlands of International Importance (the Ramsar List) and promote the conservation of these wetlands and the wise use of wetlands in their territory. Wise use of wetlands has emerged as a core principle for sustainable wetland management, reflecting the evolution of thinking within the Convention and the international community about conservation and the role of wetlands in human development. The current definition takes into account the Convention's mission statement, terminology used in the Millennium Ecosystem Assessment, the Ecosystem Approach and sustainable use applied by the Convention on Biological Diversity (CBD), and the 1987 Brundtland Commission's definition of sustainable development.

The Convention promotes the wise use of wetlands as a pragmatic strategy to stop and reverse widespread loss and degradation of wetlands. Guidelines for the wise use of wetlands were adopted by the Fourth (1990) and Fifth Conferences (1993) of the Convention, emphasizing the importance of adopting national wetland policies, developing wetland inventory, monitoring, research, training, education, and public awareness, and taking action at wetland sites. The key to managing wetlands sustainably is implementing wise use on the ground, including effective engagement of local communities and ensuring equity and transparency in making trade-offs between wetland users.

The Convention has developed tools for establishing local community participation in wetland management, emphasizing the importance of wise use and local and indigenous community involvement. This is particularly crucial in cases like the Lukanga Swamps, where access to natural resources is essential for livelihood, security, and cultural heritage. Participation can significantly contribute to maintaining and restoring the ecological integrity of wetlands, community well-being, and equitable access. However, a definitive list of criteria for successful participation and prerequisites for establishing participatory involvement is not available. The key issue is determining what participation will mean in any local context.

In 1991, Zambia ratified the Ramsar Convention, recognizing eight wetlands of international importance: Kafue Flats Wetland, Bangweulu Swamps, Barotse Floodplains, Luangwa Floodplains, Busanga Swamps, Lukanga Swamps, Lake Mweru Wantipa, and Lake Tanganyika. In 2018, Zambia adopted a national policy to manage and conserve these vital food sources, materials, and fresh water.(WWF, 2019). The September 2018 policy focuses on preserving wetland resources and protecting the environment for sustainable utilization. It identifies six wetland conservation and socioeconomic utilization objectives, enhancing biodiversity conservation, promoting tourism, fisheries, and pastoralism(Ministry of Land and Natural Resources, 2018). It also ensures sustainable agricultural activities, forest conservation, and water resource management. The policy also emphasizes political participation, empowering women, promoting equity in benefit sharing, and ensuring equitable stakeholder participation in wetlands management.

2.9.1 Wetland Institutional Framework in Zambia

The 2018 national policy on wetlands outlines a strong stakeholder collaboration, with key institutions like the Ministry for Natural Resources, Water Development, WARMA, and Zambia Environmental Management Agency playing leading roles, with specific responsibilities stipulated below;

The Ministry responsible for Natural Resources will oversee the implementation of the policy, develop policies and legislation to facilitate its implementation, coordinate international agreements on wetlands, and coordinate sectoral monitoring and evaluation. The Ministry responsible for Water Development will preside over wetlands under international shared water courses, while the Department of Water Resources Development will be responsible for water resources infrastructure development in wetlands.

The Water Resources Management Authority (WARMA) is mandated by the Water Resources Management Act No 21 of 2011, section 8 (2b) to protect, preserve, and conserve wetlands, dambos, and marshlands. WARMA manages all surface and groundwater resources in wetlands, regulate water resources, measure inflow and outflow, issue water rights, maintain records of groundwater points, register boreholes, and regulate underground water once groundwater legislation is in place.

The Zambia Environmental Management Agency will work in consultation with relevant stakeholders to conduct strategic environmental assessments of proposed policies, plans, and programs, as well as environmental impact assessments of projects that may impact wetlands. Civil Society Organizations (CSOs) will work with local authorities and communities to manage wetlands, develop platforms for environmental governance and monitoring, and lead innovative projects to build political participation and promote sustainable development.

The private sector will participate in wetlands conservation by practicing sustainable wetland tourism that protects the environment, conserves wildlife, respects host communities and cultural heritage, provides socioeconomic benefits to host communities, and contributes to investment in eco-tourism infrastructure.

In conclusion, the Ramsar Convention has recently addressed wetland tourism, acknowledging its potential negative impacts on wetlands but also recognizing its benefits. The private sector must participate in wetlands conservation by practicing sustainable tourism practices that protect the environment, respect host communities and cultural heritage, provide socioeconomic benefits to host communities, and contribute to investment in eco-tourism infrastructure.

2.10 Wetland Policy Implementation

Long delays in implementing policies can lead to unexpected outcomes, as the policy process and bureaucratic complexities can cause significant delays in bringing a policy into action (Tomick & Hendler, 1994). This can result in disturbances in the wetland ecosystem, such as encroachments into wetlands and floodplains.

In Bangladesh, the Jalmohal Management Policy, 2005, managed inland fisheries domains at three different administrative levels: district administration, Ministry of Youth and Sports, and Thana. The Bangladesh Water Development Board, Railway Department, and Roads &

Highways Department were responsible authorities for managing these wetlands, while the Department of Fishery was a primary institution for managing fisheries and aquatic resources. The institutional arrangement created enormous complexities for concerned departments to take development initiatives concerning the wetlands and fisheries resources (Hossain et al, (2006). Governments often fail to understand this power process and its impact on the whole governance system, making time lags a widely accepted intrinsic problem related to wetland policy implementation (Chabwela & Haller, 2010).

Lack of knowledge about the resources makes sustainable management of such resources difficult. Policymakers often have inadequate knowledge about the contribution of wetland resources to food security, poverty alleviation, and employment generation, leading them to allocate an insufficient budget to this sector (Hossain et al. 2006). Additionally, policymakers often lack information related to conservation requirements, leading them to implement less effective management measures. In Bangladesh, the fisheries policy suggests reducing fishers to lessen fishing pressure, but Mamun (2010) argues that if fish habitat (wetlands) stays healthy and is not degraded due to encroachment and loss of connectivity and siltation, fishing pressure does not threaten fish population, as many fish can escape from their gears and sustain fish production.

Gaps in communication and dissemination between management institutions hinder policy implementation, allowing local influential agencies and violators to defy management rules (Jahan et al., 2009). Conflicts like corruption and bribery are common in resource management, with illegal gear operators allowed to fish upon bribes (Toufique, 1997). Local non-fisher, influential people, and violators often illegally capture the right to fish by influencing management authorities. In Bangladesh, fishery officials apprehend illegal gear operators, who are allowed to continue fishing upon bribes. Studies suggest that a lack of communication and networking among different agencies prevents effective policy implementation (Bodin & Crona,2008). The lack of accountability and transparency in multi-stakeholder resource management creates mistrust, conflict, and disintegration among actors involved in resource management (Khan & Haque,2010).

These factors are crucial for promoting equal distribution of resources, reducing threats to vulnerable communities, and minimizing mistrust and conflict. In participatory wetland resource governance in the world, multiple institutions often fail to ensure accountability and

maintain information flow, leading to improper distribution of benefits and poor performance in collective action. Major intrinsic constraints in wetland policy implementation include time lags, policymakers' inadequate knowledge about resources, communication gaps among policy implementation apparatuses, and a lack of accountability and transparency. These factors contribute to the improper distribution of benefits and poor performance in collective action.

2.11 Strategies for Wetland Management

Wetland management involves activities conducted within and around wetlands, both natural and man-made, to protect, restore, manipulate, or provide for their functions and values (RCB, 1997). The best way to manage a wetland is a hands-off approach, which means not actively changing the key components of the Wetland to modify its natural functions. This means being conscious of potential threats to the Wetland and actively managing those threats (RCB, 1997).

The simplest way to manage your Wetland is not engaging in land use changes or hydrologic modifications. Many landowners want to engage in low level enhancement activities or do more to ensure their wetlands are protected for the long term. Adegeh (2015) lists the following tactics for managing wetlands that can be used:

- I. Buffers and greenbelts are the most effective management practices to protect wetlands from adjacent human activities. They consist of a band of vegetation along the perimeter of a wetland, preferably natural habitat, but including previously altered, stable native or introduced species. Establishing a greenbelt involves planting native trees, shrubs, ground cover, ceasing use of fertilizers and pesticides, and only cutting or removing select vegetation. The vegetation in the greenbelt uptakes excess nutrients and pollutants in overland flow and protects the Wetland.
- II. Stabilizing adjacent habitat is crucial for protecting the Wetland from pollutant storm water and upland activity that may adversely impact it.
- III. Fencing is one of the simplest ways to protect wetlands, especially in areas where livestock grazing or excessive human use is degrading them.
- IV. Storm water runoff is a crucial part of a wetland's hydrologic budget, but it can be damaging. Undeveloped vegetation absorbs most precipitation, while urbanized areas have impervious surfaces like roofs and concrete, increasing the quantity and quality

of water entering the Wetland. Landowners must consider three primary issues: minimizing storm water runoff beyond background levels, considering where and how to convey it, and refraining from activities that pollute it. The best way to minimize storm water is to minimize impervious surfaces on the ground. For projects that generate runoff, encourage it to soak into the ground and enter the Wetland. If runoff must be conveyed, construct a grass-lined swale to slow it down, absorb nutrients, and trap sediments.

- V. There are various safe alternatives to chemical fertilizers and pesticides in homes, including organic pesticide formulations, using insects to fight pests, and composting kitchen and yard waste. Soil tests should be done before using fertilizers to determine if they are necessary. If using fertilizers, follow manufacturer's directions carefully. Integrated Pest Management (IPM) technology and practice can reduce reliance on pesticides. Establishing a chemical-free greenbelt is crucial to buffer Wetland from upland use of fertilizers and pesticides.
- VI. Shoreline erosion control is crucial for protecting property and the environment in areas experiencing erosion. The first step is to evaluate the nature and extent of the problem, determining if it is serious enough to warrant corrective action. If erosion is primarily due to natural processes, erosion control may not be necessary.
- VII. To control invasive exotic species in wetlands, management activities depend on the size, type, invasion extent, and resources. Landowners should minimize invasion opportunities, avoid growing invasive species, and discourage neighboring species. Destroying plants that enter the Wetland and take root is the next defense. Early removal of introduced populations can prevent overruns, using methods like hand pulling or cutting vegetation before seeds set and cautious herbicide use.

CHAPTER 3: METHODS AND MATERIALS

3.1 Description of Study Area

The Lukanga wetlands, part of the Kafue River catchment in Zambia's Central Province, cover 2600 square kilometres (Figure 1). The Lukanga Swamp is located approximately 50 km west of the city of Kabwe in the Central Province of Zambia. It is strategically positioned within the catchment of the Kafue River (Mapedza et al., 2012). The watershed region is generally 1250 meters above sea level, while the major marsh is 1100 meters above. the primary marsh area is only 2500 km², expanding to 2600 km² during severe floods (Chabwela et al., 2017). The study covers 223104.6 Ha, including the main Swamp and islands and part of the catchment area along the Kafue River between Nkomonshya Ferry and Mongo.

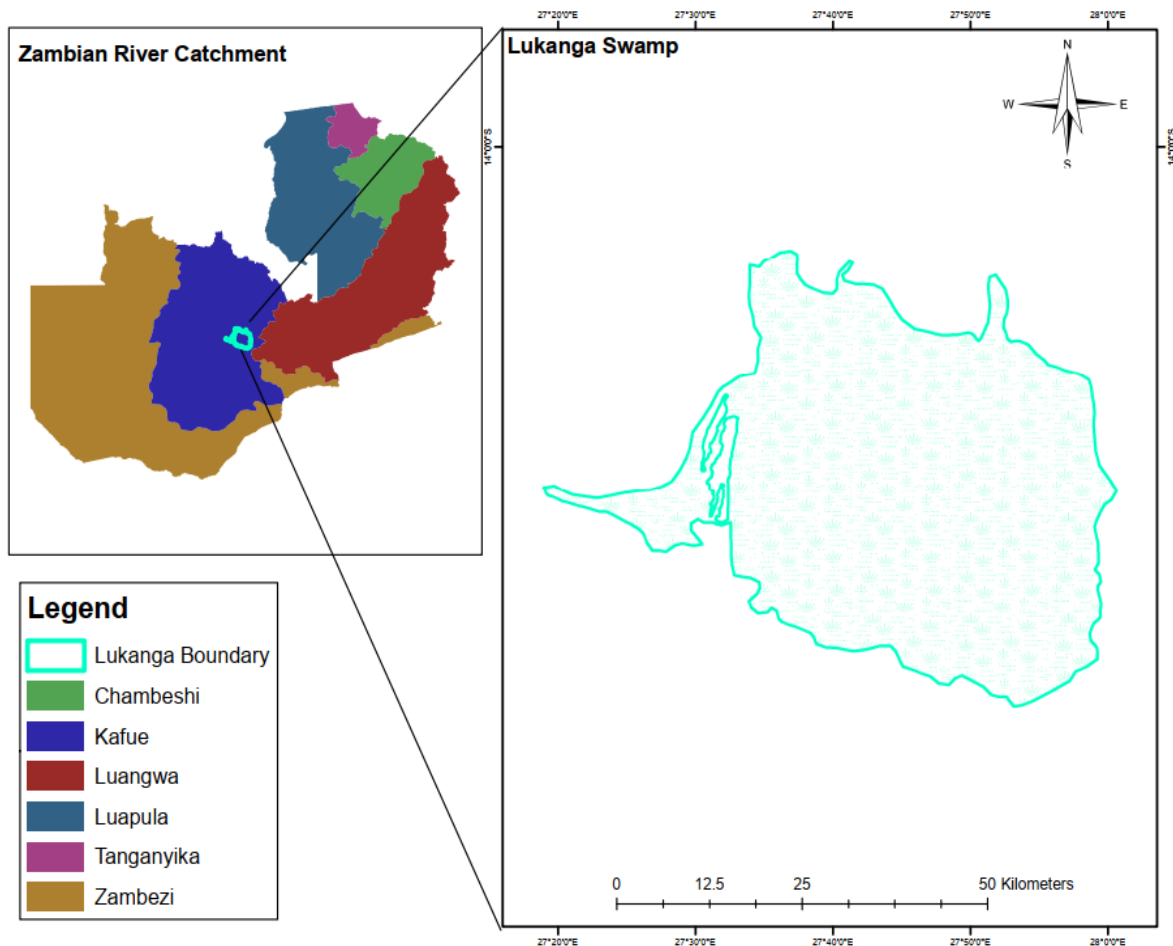


Figure 1: Map of study area

3.2 Geology and Soils

The Lukanga Swamp region is dominated by rock formations from the Pre-Cambrian assembly of the Gondwana supercontinent, including the Katanga system, which is the most dominant in the area. The second rock formation, the Kalahari system, originates from the late Mesozoic phase, covering the Cretaceous through the Tertiary to Quaternary. The Kalahari system, which includes poorly consolidated sand stones and unconsolidated windblown deposits, covers much of the western part of the Lukanga Swamp and Chilwa Island. Soil types in the region include organic swamp soils with high vegetative matter content, and sand veldt soils, which are loamy sands with clay content.

3.3 Climate

The Lukanga Swamp in Zambia has three distinct seasons: rainy/wet from November to March, cool dry from April to August, and hot dry from September to October/November. The mean maximum temperature is highest in October, and significant rainfall starts in November. Most rains occur in December, January, February, and March. Low rainfall can contribute to the Swamp's drying up. The mean maximum temperatures peak in October (31.8°C), and the mean minimum temperature is 14.8°C.

3.4 Demography and Livelihood

The Swamp is inhabited by 195, 993 individuals, with a rapid population growth rate of 3.5% per annum (CSO, 2010). The area covers the Chibombo and Kapiri Mposhi districts in the central province and Mpongwe district in the Copperbelt province. The people in and around the Lukanga swamps depend on it for fish, charcoal, and wildlife hunting. Their main activity, however, is agriculture, practiced mainly at the subsistence level. Crops grown are maize groundnuts, sweet potatoes, beans, citrus fruits and vegetables, which are grown for sale to residents of the nearby urban center of Kabwe (Chabwera 1998).

Resource exploitation is exacerbated by mass in-migration of different groups, particularly urban and rural, in Zambia. Urban unemployment rates have increased from 16.1% in 1990 to 26.5% in 2000, while rural unemployment rates have declined from 14.4% to 6.6%.

Seasonal migration by fishermen in Zambia has led to increased village populations, particularly in the Kafue flats downstream. This migration has also caused conflicts between indigenous Lenje people and predominantly Bemba fishermen. The majority of the 6 Metric

Tonnes (MT) fish caught annually in Zambia is by seasonal fishermen, with 70% being non-local fishermen. Many of these fishermen live outside the Swamp in slums, such as Kabwe's Makululu compound, which has a population of around 80,000 residents connected to fishing and the fish trade.

3.5 Ecological Features

The predominant ecosystem is *Brachystegia* woodland, although termitaria, reed marshes, open water bodies, and lakes tend to be found in the lower portions of the slope after mixed savanna vegetation types (Figure 2, and 3). Among the mammal species are the hippopotamus, waterbuck, red lechwe, and sitatunga (Zambia Wildlife Authority, 2002). Yellow-billed Duck (*Anas undulata*), Great White Egret (*Casmerodius albus*), and Grey Heron (*Ardea cinerea*) are among the birds that can be seen. Tilapia is the most common type of fish. Other species include *Marcusenius*, *Barbus*, *Characidae*, *Claridae*, and *Serranochromi Schilbe mystus*. Other than migrating for breeding and to find refuge from predators, there is no obvious evidence that these animals have a preferred environment (Zambia Wildlife Authority, 2002).



Figure 2: Deep water and grass land at Lukanga Swamp



Figure 3: Ariel photos of the study area

3.6 Methodology

This research will utilize remote sensing, spatial analysis, and social science methods to study land cover changes. It involves data collection, image analysis, field surveys and data integration.

3.6.1 Primary Data Collection

The study was initiated with a reconnaissance survey, defining the study's boundaries using available map resources. A brief field observation was conducted for primary documentation, followed by field introduction, objectives identification, previous survey evidence query, and scope identification.

3.6.2 Field survey

The study utilized available secondary data, but a short field survey was conducted to validate the data and gain insight into the natural setting and local people's perceptions, enhancing the study area's overall understanding. The field survey involved visiting swamp to appreciate the vegetation characteristics (Figure 4)



Figure 4:Field visit to the Swamp

3.6.3 Informal Short Interviews

Short informal interviews with locals, particularly the elderly, were undertaken to learn about their perceptions of land cover trends (figure 5). Informal interviews also assist in understanding their adaptive nature and resource consumption strategy.



Figure 5 : Interview with the community leader in Lukanga Swamp

A summary of the procedure to be adopted in this research work for deriving statistics of land use dynamics and subsequently acquiring the desired results is shown in Figure 6 below:

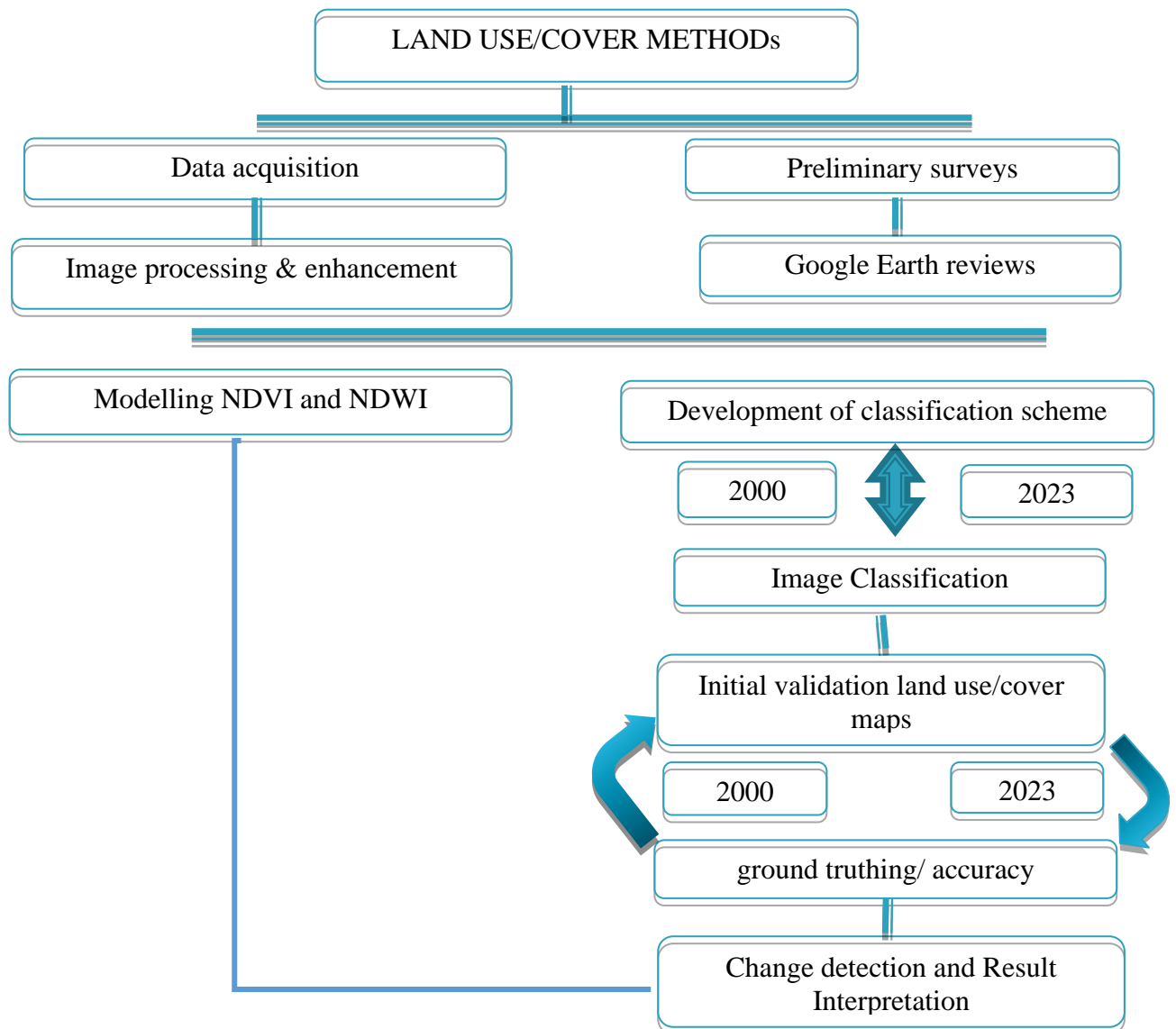


Figure 6: Methodology flow diagram

Multi-temporal LANDSAT satellite data of Lukanga Swamp were acquired for the years 2000, 2013 and 2024 to carry out the LULC classification. Images of the same season (Sept to Oct)) free from cloud cover and identifiable features not affected by seasonality were considered in the selection. Table 1 shows the images acquired from the United States Geological Survey (USGS), an open source available (<https://earthexplorer.usgs.gov/>).

Table 1: Acquired data and Source

Sn	Data Type	Year of Production	Worldwide Referencing System		Resolution
			Path	Row	
1	Landsat imagery	2000	172	70	30 m
2	Landsat imagery	2013	172	70	30 m
3	Landsat imagery	2023	172	70	30 m

3.5.1 Image processing and enhancement

The satellite image was imported in Erdas imagine Software and geo-referenced to the Universal Transverse Mercator (UTM) system in World Geodetic System (WGS) 1984 zone 35 S. Layer stack operations were used to combine the different spectral bands in multiband composite images (Figure 19). Mosaicking of the images was conducted which involved the process of joining the two geo-referenced images into one using ArcMap 10.7 as can be seen from annex Ib. Lastly, A shapefile of the study area was then used to clip out a subset from the merged image as the area of interest (Figure 19).

3.5.2 Indices Modelling

3.5.2.1 Normalized Difference Water Index (NDWI)

NDWI was used to identify and study the moisture condition of vegetation canopies, which frequently show significant thermal change over large areas (Delbert et al. ,2005). To calculate NDWI in this study, the green and near infrared (NIR) bands were used. The

formula was developed using green band (band 2 for Landsat 5, band 3 for Landsat 8) and NIR (band 4 for Landsat 5, band 5 for Landsat 8) reflectance measurements.

3.5.2.2 Normalized Difference Vegetation Index (NDVI)

NDVI was used as a tool to track vegetation growth and health and detect stress or damage. It can also map and identify vegetation types and track changes in vegetation cover over time. NDVI values have been calculated using multispectral bands from Landsat images acquired from 2000 and 2023, with bands 4 and 3 of Landsat 5 utilized for NIR and red measurements and bands 5 and 4 of Landsat 8 for NIR and red evaluations.

3.5.2.3 Image classification

A prior knowledge from field surveys was used to select training sites for the land cover categories listed in the classification scheme, as shown in Table 2. Using the basic colours red, green and blue (RGB), we used false colour composites (FCC) images. These false colour composite images are suitable to distinguish between different land cover types or ground objects like built-up forests (Salman et al., 2020). The FCC band combination of RGB is bands 4, 3 and 2, respectively.

The dataset was trained using the pixel colour and tone of specific land use class with each individual training site created by drawing polygons containing at least 50 pixels. In order to train a single land use class, polygons of pure pixels for that class were drawn. This procedure was repeated for all the 6 land use classes and saved as a signature file using the signature editor in ERDAS imagine Software. This signature file was then used during the supervised classification stage. A supervised digital image classification based on the maximum likelihood classifier (MLC) was done to categorize all pixels in the image into land use/land cover classes (Alam & Ahamed, 2022). Supervised classification enabled assigning each pixel in the image to a class to which it had the highest probability of being a member, thus generating land use/land cover categories. The classified image was then vectorized and exported as a shape file from which a land use/land cover map was generated for overall visualization. This procedure was repeated for all the images.

Table 2: Classification Scheme for training sites

Classes	Description
Forest	All forest cover
Settlements/ Bare soil	Temporary and permanent houses, villages (Rural dwelling) and associated structures and Areas of exposed soil and barren area influenced by human impact
Shallow Water	Semi-inundated land filled with marshy vegetation
Irrigated farmlands	Areas with cultivated crops using irrigation systems
Deep Water	River, permanent open water, perennial lakes and reservoirs
Grassland	Area covered with grass and shrubs

3.5.2.4 Accuracy Assessment

Accuracy Assessment was assessed by an error matrix using the Kappa coefficient (Takam Tiamgne et al., 2021). The kappa (k) coefficient is a strong and widely used statistical measure to assess the inter-raster agreement between variables. The Kappa coefficient lies between 0 and 1 which is often multiplied by 100 to give a percentage measure of classification accuracy. Kappa values are also characterized into 3 groupings: Strong Agreement (Kappa > 80%), Moderate Agreement (40% ≤ Kappa ≤ 80%), and Poor Agreement (Kappa < 40%) (Takam Tiamgne et al., 2021).

Using notation similar to Cohen (1960), the kappa coefficient of agreement, κ , is estimated from:

$$\kappa = \frac{\text{Observed agreement} - \text{Chance agreement}}{1 - \text{Chance agreement}} \dots\dots\dots (1)$$

3.5.2.5 Ground Truth

In this study, 130 number of ground control points were used to validate the classified image for the years 2000,2013 and 2023(Figure 7). This was achieved using a stratified random sampling design. The reference data for this study was obtained from field visits, drone imagery and high-resolution Google Earth Pro images.

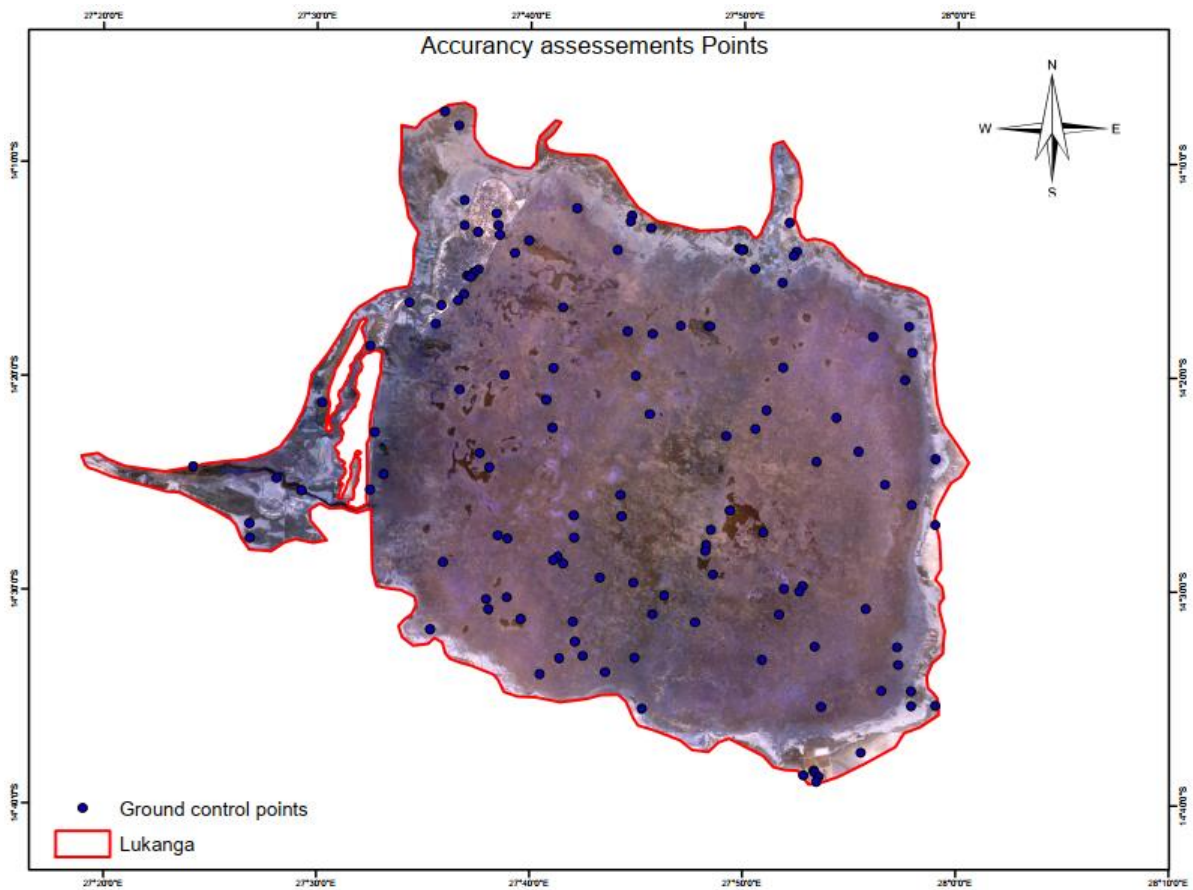


Figure 7: Ground control points for Lukanga Swamp



Figure 8 Ground truthing survey of Lukanga Swamp using a drone

3.5.2.6 Change detection analysis and post-classification

The study assessed land use and cover classes in Lukanga Swamp over three time periods (2000-2013, 2013-2023, and 2000-2023), using post-classification comparison as a change detection technique. Satellite images from different times were compared to determine the magnitude and direction of changes. Spectral differences are expected due to atmospheric conditions and sun angle changes.(Thamaga, 2021). The post-classification comparison technique identifies changes based on a pixel-by-pixel basis by overlapping LULC maps from different dates

3.5.2.7 Software Used

The Lukanga Swamp was analyzed using ArcMap 10.7.1 and ERDAS Imagine 2014 tools to track land use and land cover changes. These tools were crucial for managing and evaluating spatial data, allowing for creating, presenting, examining, and interpreting geographic data. ArcMap 10.7 was used in NDVI and NDWI Modelling, map creation and integration of different data layers, while ERDAS Imagine 2014, a remote sensing program, will be used for processing and analyzing imagery data, particularly for extracting important data.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Presentation of the wetland cover map

The Six LULC classes observed and recorded were deep water body, forest, shallow water, irrigated agriculture and settlements/bare land (Table 2). Figure 9, 10 and 11 shows the extent of LULC maps in the study area for the years 2000, 2013 and 2023 respectively. The land use patterns (six categories) identified for all years are shown in Table 3. A total of 223105 hectares of land area was estimated for the Lukanga Swamp catchment after image classification.

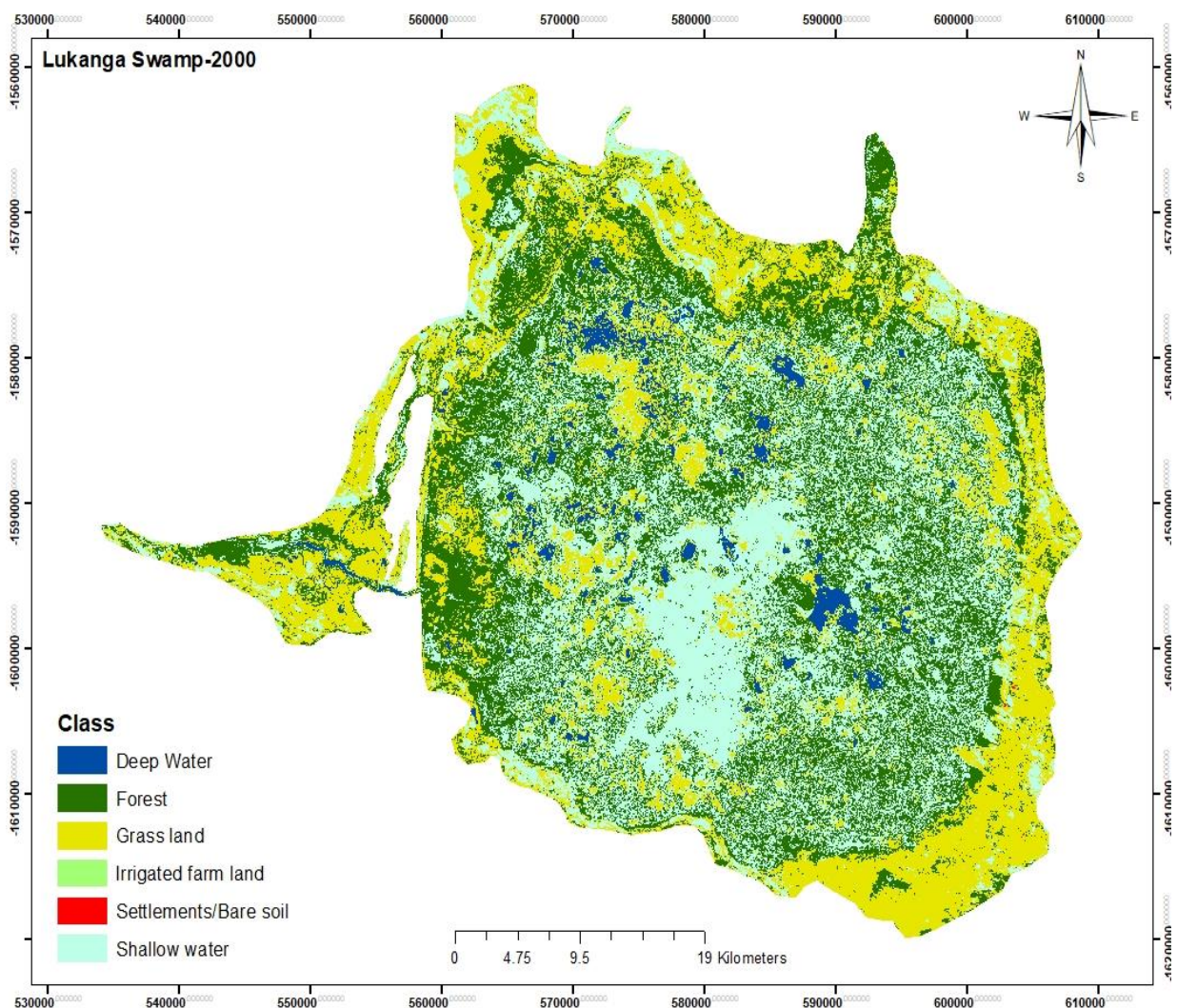


Figure 9: land use land cover change maps for 2000

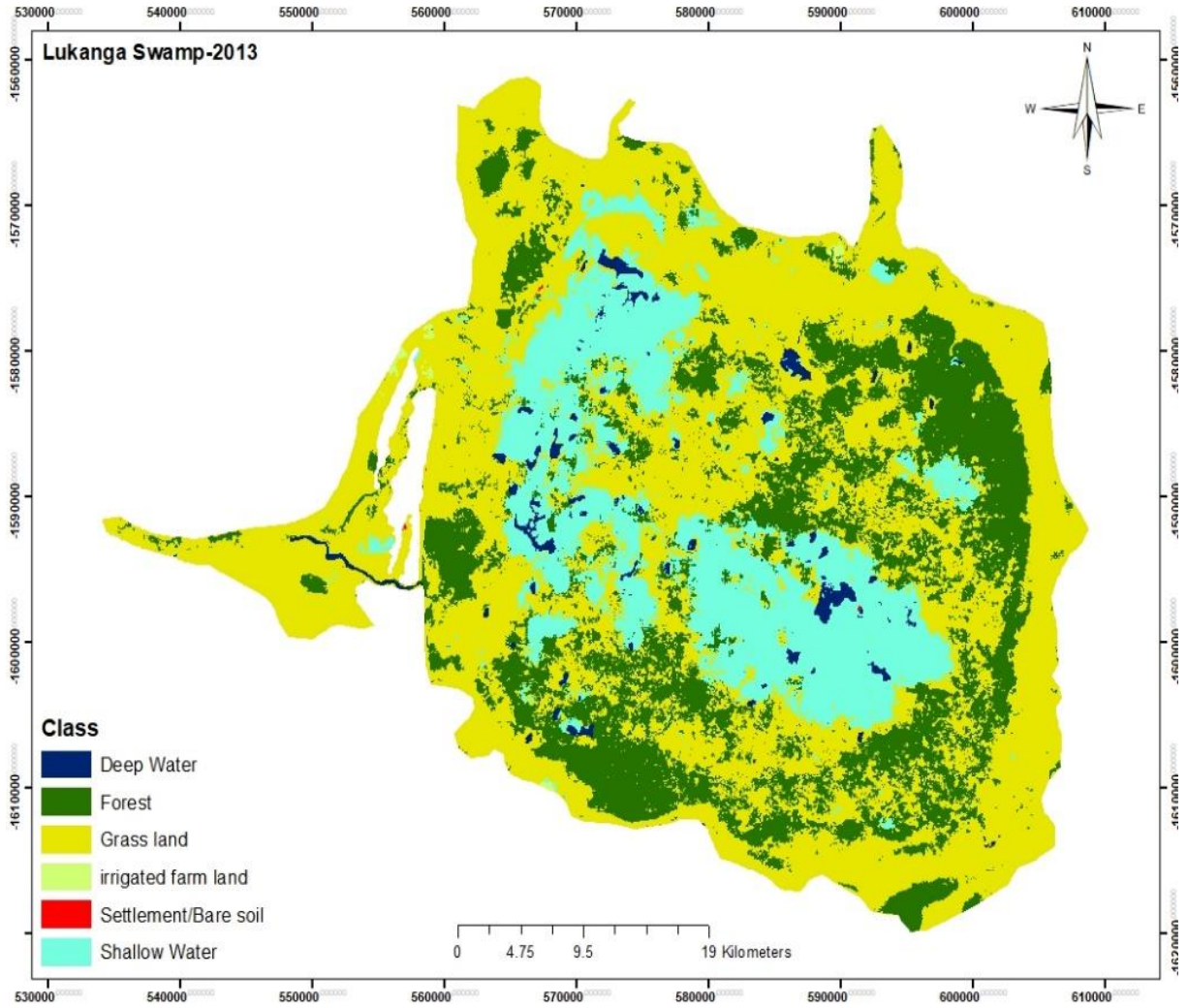


Figure 10: land use land cover change maps for 2013

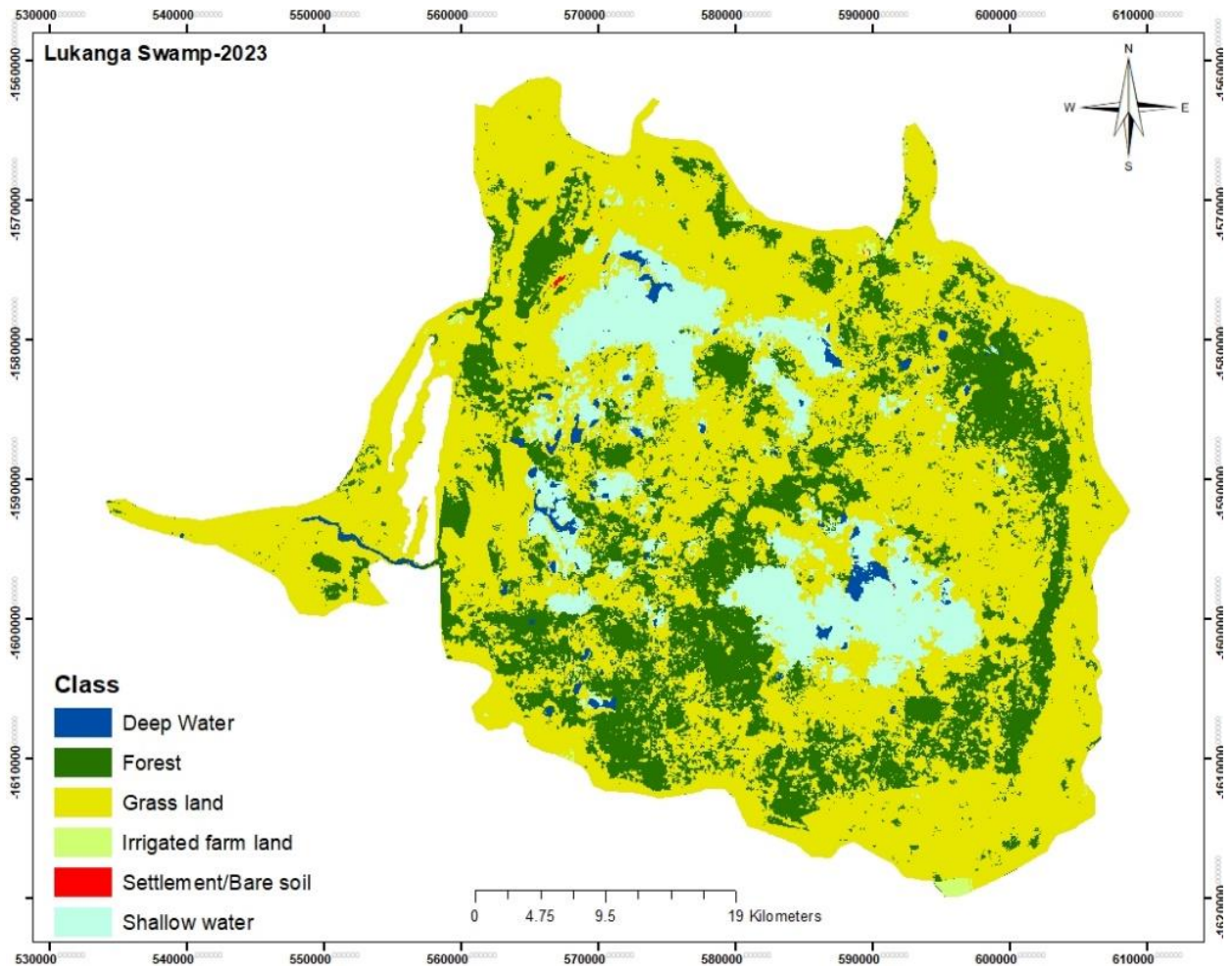


Figure 11: land use land cover change maps for 2023

Table 3: Summary of the land use land cover area coverage between 2000 and 2023 (area in ha)

Classes	2000			2013			2023		Difference 2000-2023 Ha
	Area -Ha	Percentage	Difference 2013-2023 Ha	Area Ha-	Percentage	Difference 2023-2013 Ha	Area (Ha)	Percentage	
Forest	74510.60	33.3972	-19270.30	55240.30	24.7598	-1592.30	53648.00	24.0462	-20862.60
Grass land	59858.90	26.8300	64107.10	123966.0	55.5641	16896.00	140862.0	63.1375	81003.10
Shallow water	82385.30	36.9268	-42143.8	40241.50	18.0371	-15260.10	24981.40	11.1972	-57403.90
Deep Water	6328.26	2.8365	-3052.51	3275.75	1.4683	-353.42	2922.33	1.3099	-3405.93
Irrigated Farm land	1.73	0.0008	351.05	352.78	0.1581	282.54	635.31	0.2848	633.58
Settlements/Bare soil	19.57	0.0088	8.67	28.25	0.0127	26.28	54.53	0.0244	34.96
Total	223104.6	100		223104.6	100		223104.6	100	

Figure 12 highlights the percentages of each land use land cover in 2000, 2013, 2023.

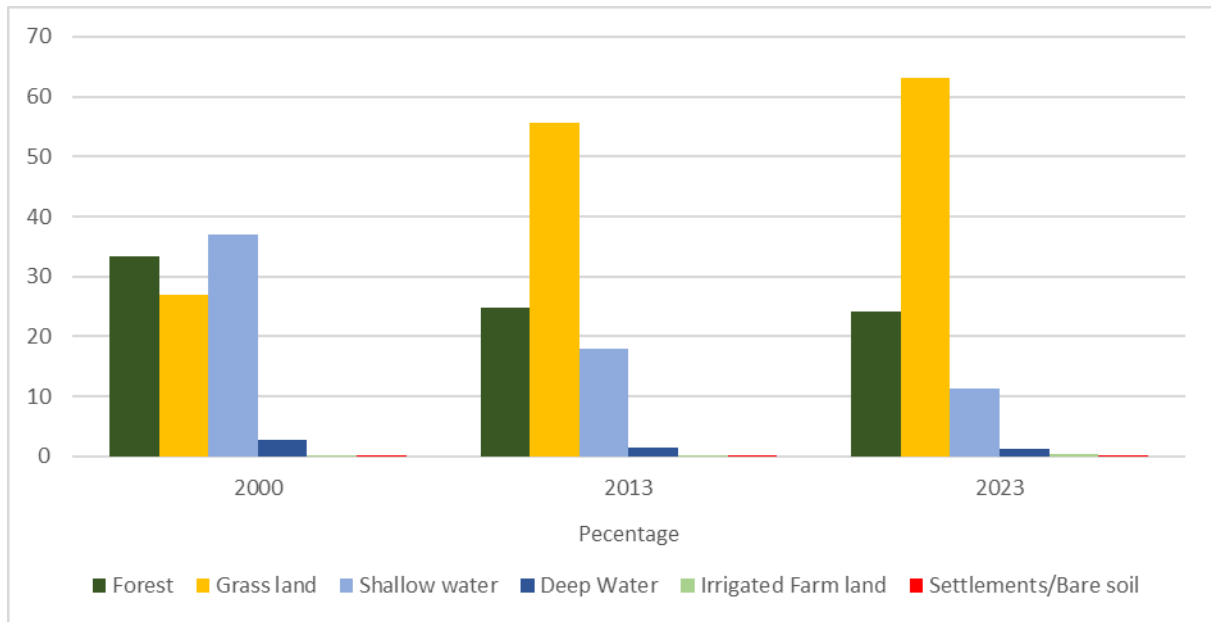


Figure 12: Land Use Land Cover Percentage per class

Figure 13 illustrates land use/land cover trend analysis depicts the dynamic changes in geographic areas over time, highlighting shifts in land use patterns.

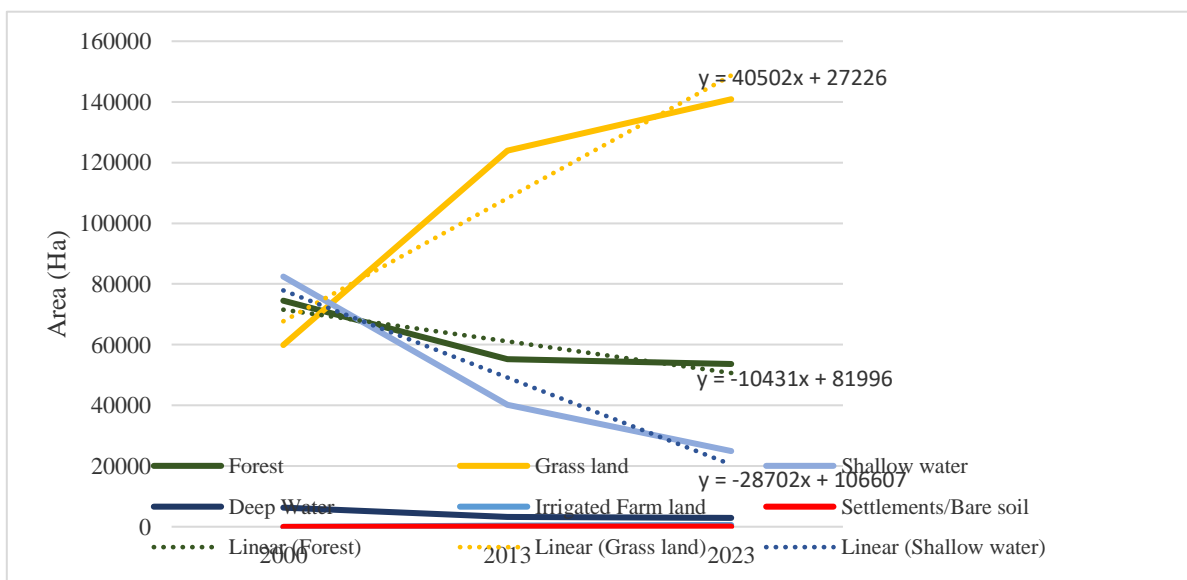


Figure 13:LULC Trend Analysis

4.2 Accuracy Assessment

The kappa coefficient, also known as Cohen's Kappa, was used to assess the level of agreement between two sets of categorical data, particularly in the context of thematic maps or classification accuracy assessments, for the 2000, 2013 and 2023 LULC maps, as shown in Tables 4 and 5 (Foody, 2020). It measures the difference between observed and expected agreement beyond what would be expected by chance. The kappa coefficient helps determine the reliability or accuracy of a thematic map and its suitability for decision-making (Aneseyee et al., 2020). The Kappa coefficient, which measures the reliability of a map, ranges from -1 to 1, with higher values indicating more reliable maps. In 2000, 2013 and 2023, the overall accuracy was 87.6 %, 90%, and 95%, respectively, with a Kappa Coefficient of 0.82, 0.87 and 0.94, indicating accurate classification.

Table 4: Land use land cover classification accuracies for 2000

Class	Grass land	Forest	Deep Water	Shallow water	Irrigated Farm land	Settlements/Bare soil	Total	User Accuracy	Commission Error
Grass land	58	3	1	0	1	0	63	0.92	0.08
Forest	4	21	0	0	1	0	26	0.79	0.21
Deep Water	0	0	8	2	0	0	10	0.8	0.2
Shallow water	0	0	0	11	0	0	11	1	0
Irrigated farm land	1	1	0	0	8	0	10	0.8	0.2
Settlements/Bare soil	2	0	0	0	0	8	10	0.8	0.2
Total	65	25	9	13	10	8	130	0	
Producer Accuracy	0.89	0.83	0.89	0.85	0.8	1	0	0.88	
Omission Error	0.11	0.17	0.11	0.154	0.2	0			
Overall Accuracy	0.876								
Kappa	0.82								

Table 5: Land use land cover classification accuracies for 2013

Classes	Forest	Grass land	Shallow water	Deep water	Irrigated farm land	Settlements/Bare soil	Total	User Accuracy	Commission Error
Forest	34	1	1	0	0	0	33	0.94	0.06
Grass land	2	25	0	0	0	0	27	0.93	0.074
Shallow water	0	0	36	1	0	0	37	0.97	0.027
Deep Water	0	0	2	8	0	0	10	0.8	0.2
Irrigated Farm land	0	3	1	0	6	0	10	0.6	0.4
Settlements/Bare soil	0	2	0	0	0	8	10	0.8	0.2
Total	36	31	40	9	6	8	130	0	
Producer Accuracy	0.94	0.81	0.9	0.89	1	1	0	0.90	
Omission Error	0.06	0.20	0.1	0.11	0	0			
Overall Accuracy	0.9								
Kappa	0.868								

Table 6 : Land use land cover classification accuracies for 2023

Class	Forest	Grass land	Shallow water	Deep Water	Irrigated Farm land	Settlements/B are soil	Total	User Accuracy	Commission Error
Forest	25	1	0	0	0	0	26	0.96	0.04
Grass land	1	55	0	0	0	0	56	0.9821	0.0179
Shallow water	0	0	18	0	0	0	18	1	0
Deep Water	0	0	0	10	0	0	10	1	0
Irrigated Farm land	0	2	0	0	8	0	10	0.8	0.2
Settlements/Bar e soil	0	2	0	0	0	8	10	0.8	0.2
Total	26	60	18	10	8	8	130	0	
Producer Accuracy	0.96	0.9167	1	1	1	1	0	0.953	
Omission Error	0.04	0.0833	0	0	0	0			
Overall Accuracy	0.954								
Kappa	0.935								

4.3 Increase and loss of land use land cover (net change)

The study's spatial data, as shown in Figures 9,10,11 and Table 3, indicates both gains and losses occurred within the Lukanga wetland boundary. The net changes, as a result of gains or losses for each LULC type between 2000-2013, 2013-2023 and 2000-2023, are depicted in figure 13. It was observed that much of the shallow water, deep water and forest were lost by 42,143.8 ha, 3,052.51 ha and 19,270.30 ha, respectively, between 2000 and 2013, while the grassland, irrigated farms and settlement areas increased by 64,107.10 ha, 351.05 ha and 8.67 ha, respectively.

Between 2013 and 2023, the Shallow water, deep water and forest areas lost 15,260.10 ha, 353.42 ha and 353.42 ha, respectively, while the settlement/bare soil areas (26.3 ha), grasslands (16896.00 ha) and irrigated farm area (282.54 ha) gained in their spatial extent. The area lost an aerial wetland extent (deep water and shallow water) of about 60,808.93 ha between 2000 and 2023. In the same period, forest (20862.60 ha) lost its spatial coverage over the same time-frame, while grass lands and irrigated farmland gained coverage by 81003.10 ha and 633.588 ha, respectively. This extent of land use land cover dynamics resulted from a number of anthropogenic activities(Chabwela et al., 2017), resulting in the alteration of the climate system in the region surrounding the Swamp over the next few decades and reduced forest harvest and other forest-based products. Field observations and studies on the Lukanga swamp show that profits from fuel wood and charcoal from Lukanga can increase by up to 300% when sold in towns(Kachali, 2007). The Wetland's primary natural resource utilization is fishing, hunting, livestock grazing, and cultivation(McCartney et al., 2011). Settlements are mostly around the Wetland's edge, with some fishing camps on larger islands(McCartney et al., 2011). Fish is a crucial source of protein for local households and income for fishermen, who sell a portion of their catch in towns like Kabwe and Lusaka. The area's agricultural production methods are inadequate, with the majority of smallholders farming at or below the subsistence level. There is limited irrigation, and recession agriculture is common, with many plots lying close to the Wetland's border(Chabwela et al., 2017; McCartney et al., 2011). Maize, cotton, groundnuts, pumpkins, sweet potatoes, cassava, and sunflowers are the most common crops. The Wetland also offers dry-season grazing and drinking for cow and goat herds, but the quantity of livestock that rely on it remains unknown(Kachali, 2007).

Rural-urban migration in tropical Africa is paradoxical, as rural migrants prioritize long-term employment opportunities over immediate employment in urban areas. (Tadaro, 1996). In

Zambia, net out-migration rates in urban areas and in-migration to rural areas show lower employment opportunities compared to agricultural and fishing opportunities in rural areas. Furthermore, while drought and livestock diseases in the Southern Province have affected the agricultural livelihood of the Tonga people, they have moved to the Central Province in search of more reliable weather (George Marechera and Joseph Ndwiga, 2015). Lastly, Retired Kabwe miners have taken up residence in areas surrounding the wetlands of Lukanga (Sanzionatorio et al., 2002).

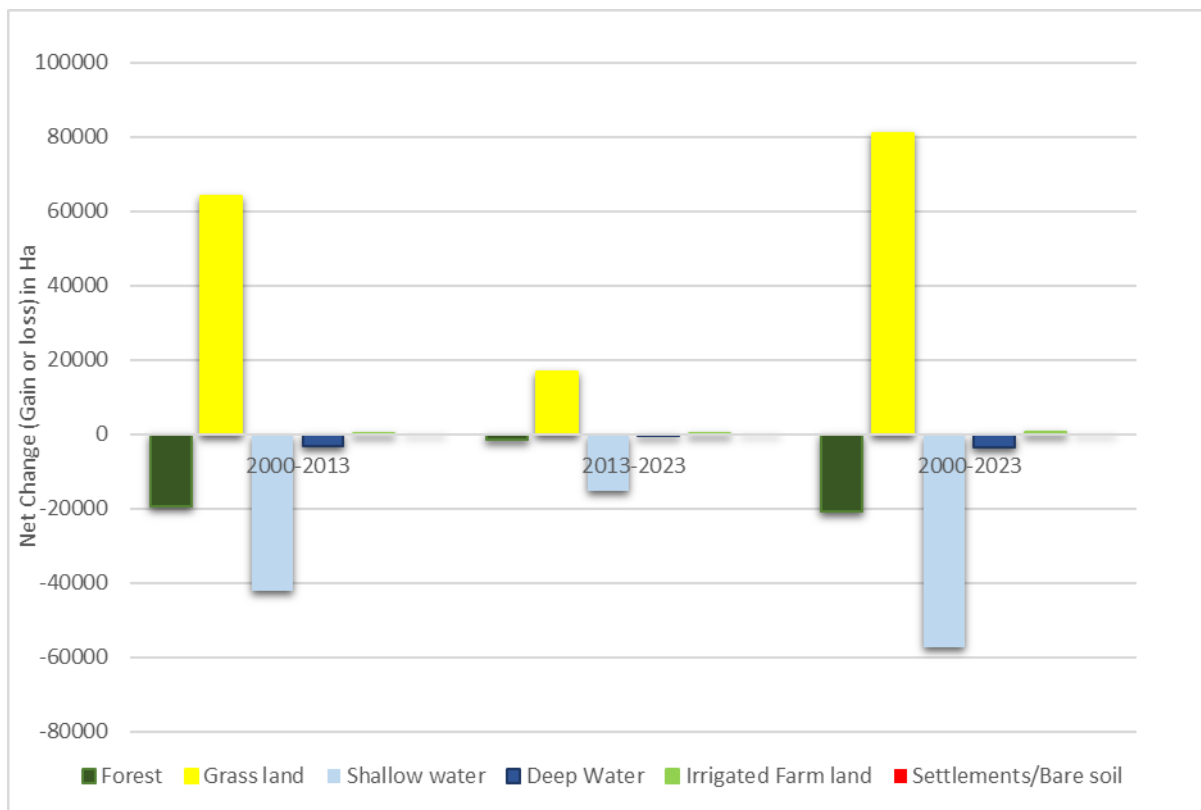
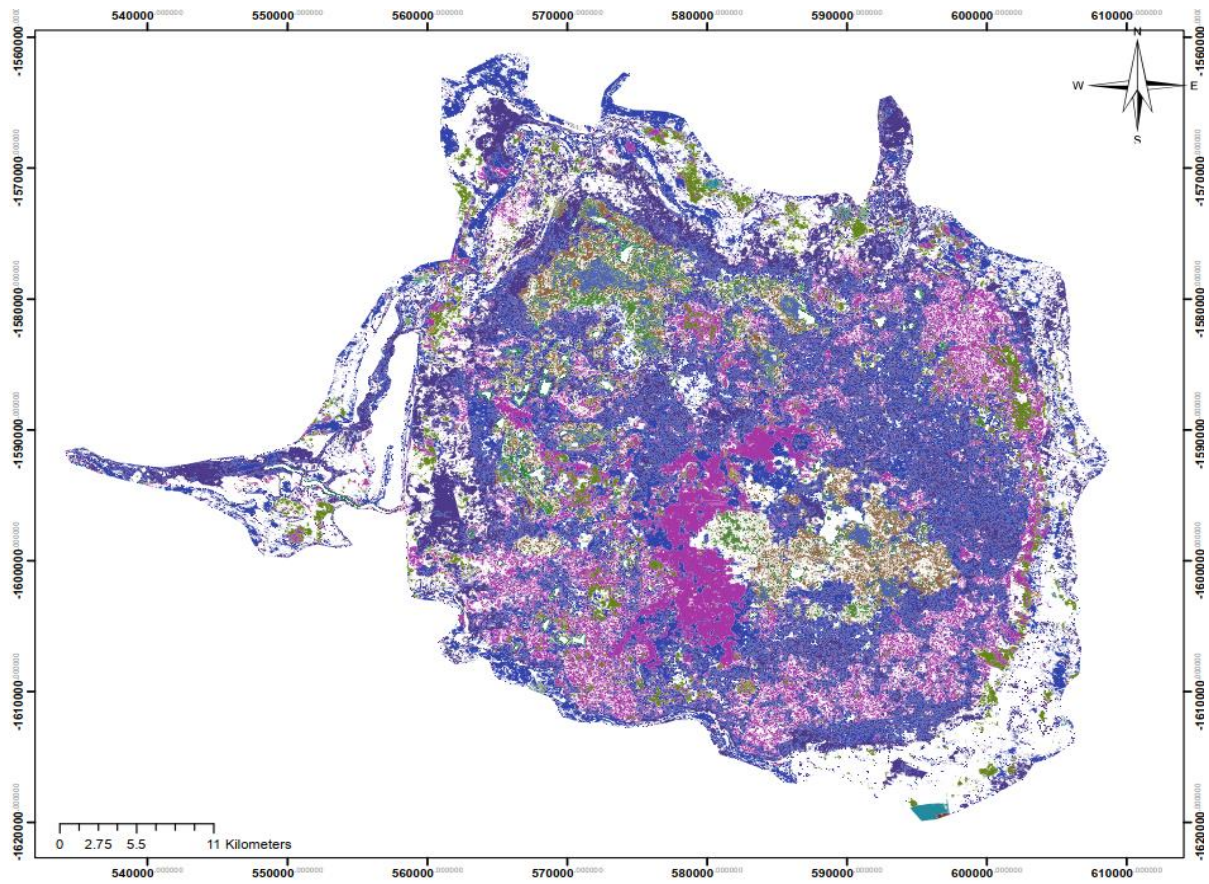


Figure 14: Net change (gains/losses) on wetland area between 2000 and 2023

4.4 Change detection measurements that occurred over a 23-year period

Over time, the Lukanga 'Swamp's spatial expanse has decreased in comparison to other types of LULC. The Wetland has seen significant changes between 2000 and 2023, as shown in Figure 13 as a result of anthropogenic activities. Figure 14 shows that the areas that were formerly shallow water, deep water, and forest have all been mostly grassland. The wetland area was replaced, especially in the low-lying sections, by the LULC cover transition. Also transformed into different LULC classifications were pockets of Wetland.



2000-2023 Change

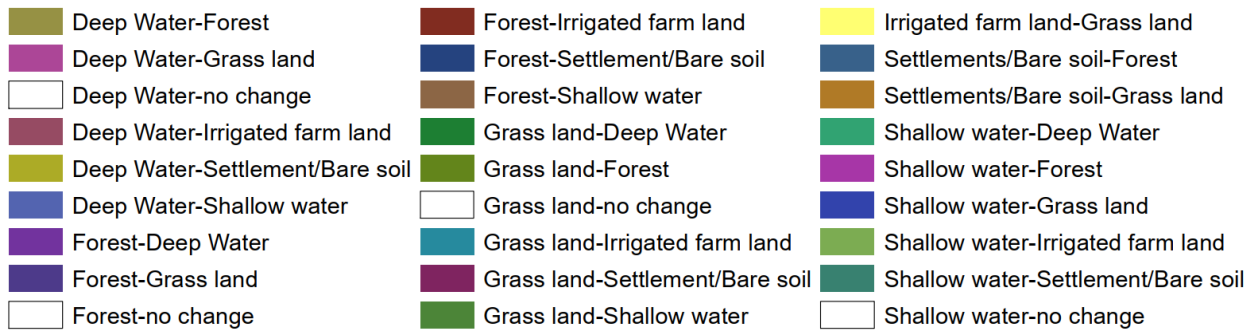


Figure 15: land use and land cover conversion 2000 to 2023 ((post classification))

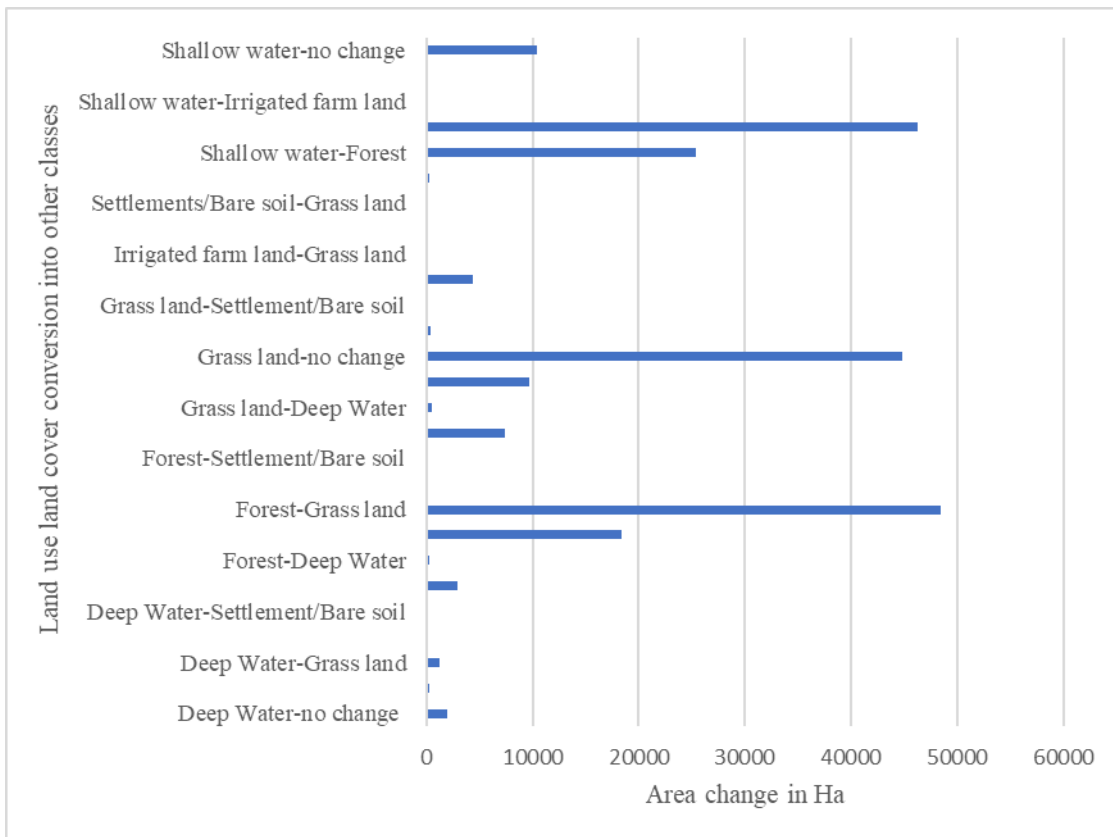


Figure 16 Areas of the Lukanga Swamp converted into other LULC

4.5 NDWI for 2000 and 2023

The wetland status for Lukanga Swamp was evaluated by calculating the value of NDWI for 2000 and 2023. The result revealed that the maximum values of NDWI were 0.32 and 0.15 for 2000 and 2023, respectively (Figure 16). In 2000, a higher NDWI value suggested more water bodies or higher water content. By 2023, a lower NDWI value indicates a decrease in water presence due to factors like climate variability. According to Chabwela (1998), the inter-annual fluctuation in the swamp water level sometimes results in the drying up of large patches of the Swamp and the consequent lowering of oxygen levels in other areas. These values provide insight into the dynamics of water presence over time, with a decrease from 2000 to 2023 indicating potential changes in water availability or distribution in the studied area.

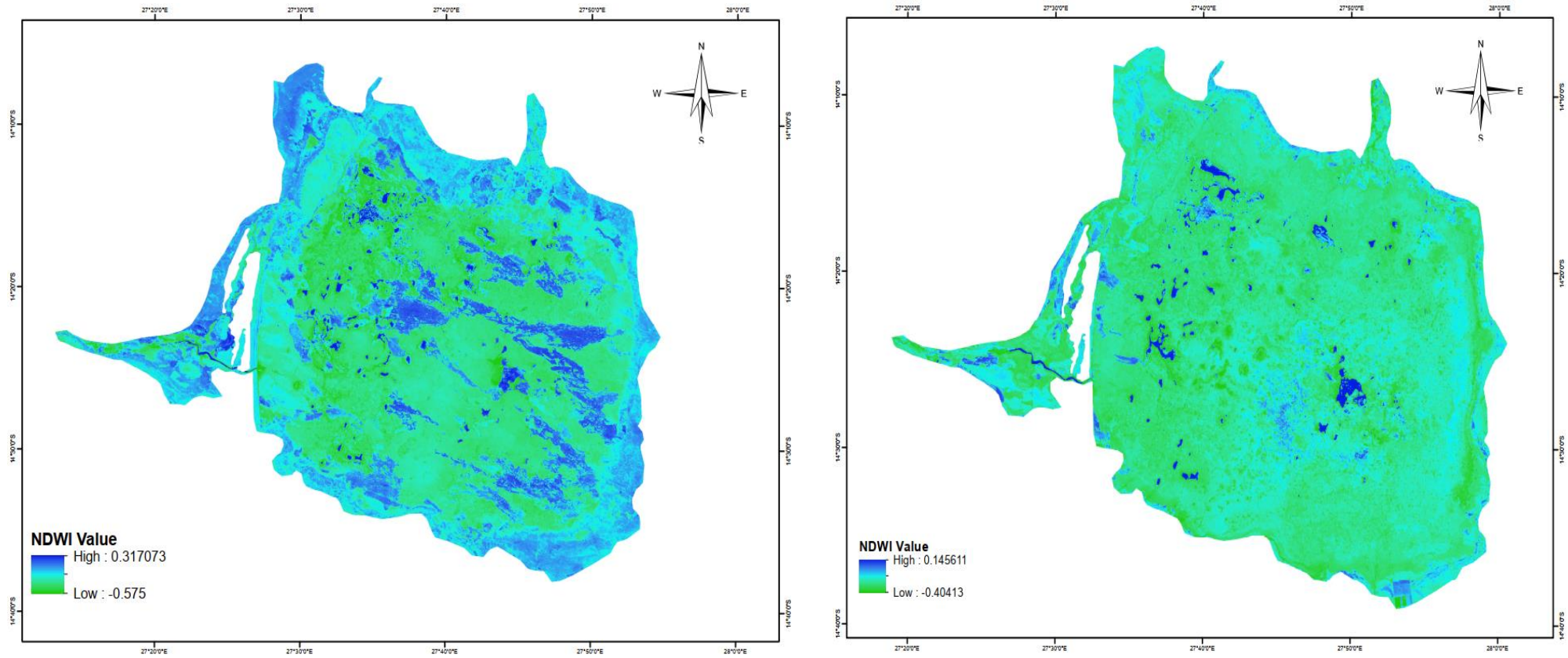


Figure 17: NDWI map of (a) 2000 and (b) 2023

4.6 NDVI for 2000 and 2023

The status of vegetation cover determines the greenness and non-greenness, which was evaluated based on the calculated value of NDVI. The calculated NDVI values within the study area were 0.61 and 0.45 in 2000, and 2023, respectively (Figure 17). NDVI values indicate water bodies, barren land, vegetation cover, and density in forests. A 2023 NDVI of 0.45 suggests vegetation presence, despite a slightly lower density than 2000.

A decrease in NDVI from 2000 to 2023 could indicate changes in vegetation health or density over time, potentially due to factors such as deforestation, land use changes, climate variations (Figure 18). This decrease in NDVI could indicate degradation or loss of vegetation, which may have implications for biodiversity, ecosystem services, and overall environmental health. Amede et al. (2001) equally illustrated the destruction of vegetative cover because of the expansion of farming practices into steeper slopes, particularly in the higher elevated lands without appropriate conservation practices resulted in (the depletion of fertile soil) barren lands and less dense forests in surrounding areas of the Swamp. Understanding the reasons behind these changes could help inform conservation efforts, land management strategies, and policies aimed at preserving or restoring vegetation in the area.

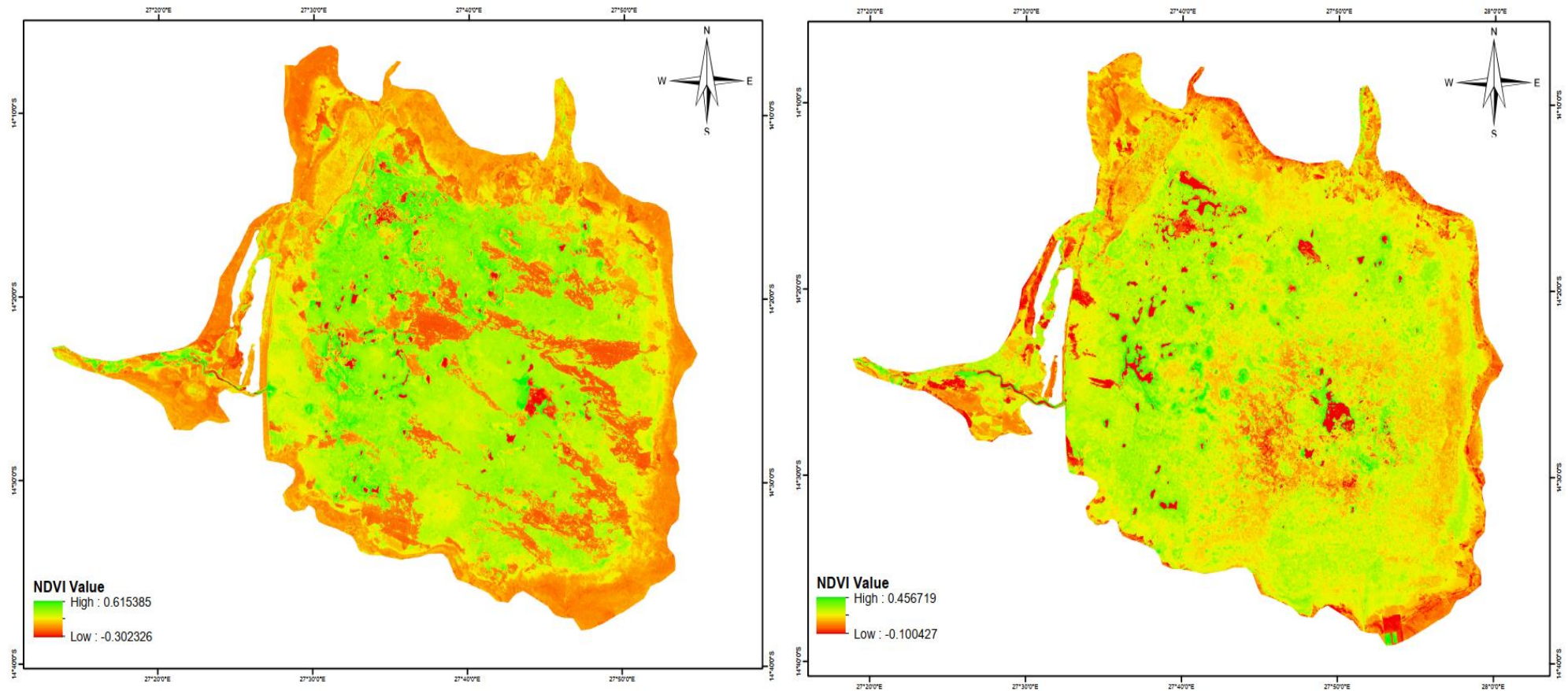


Figure 18:NDVI map of (a) 2000; and (b) 2023

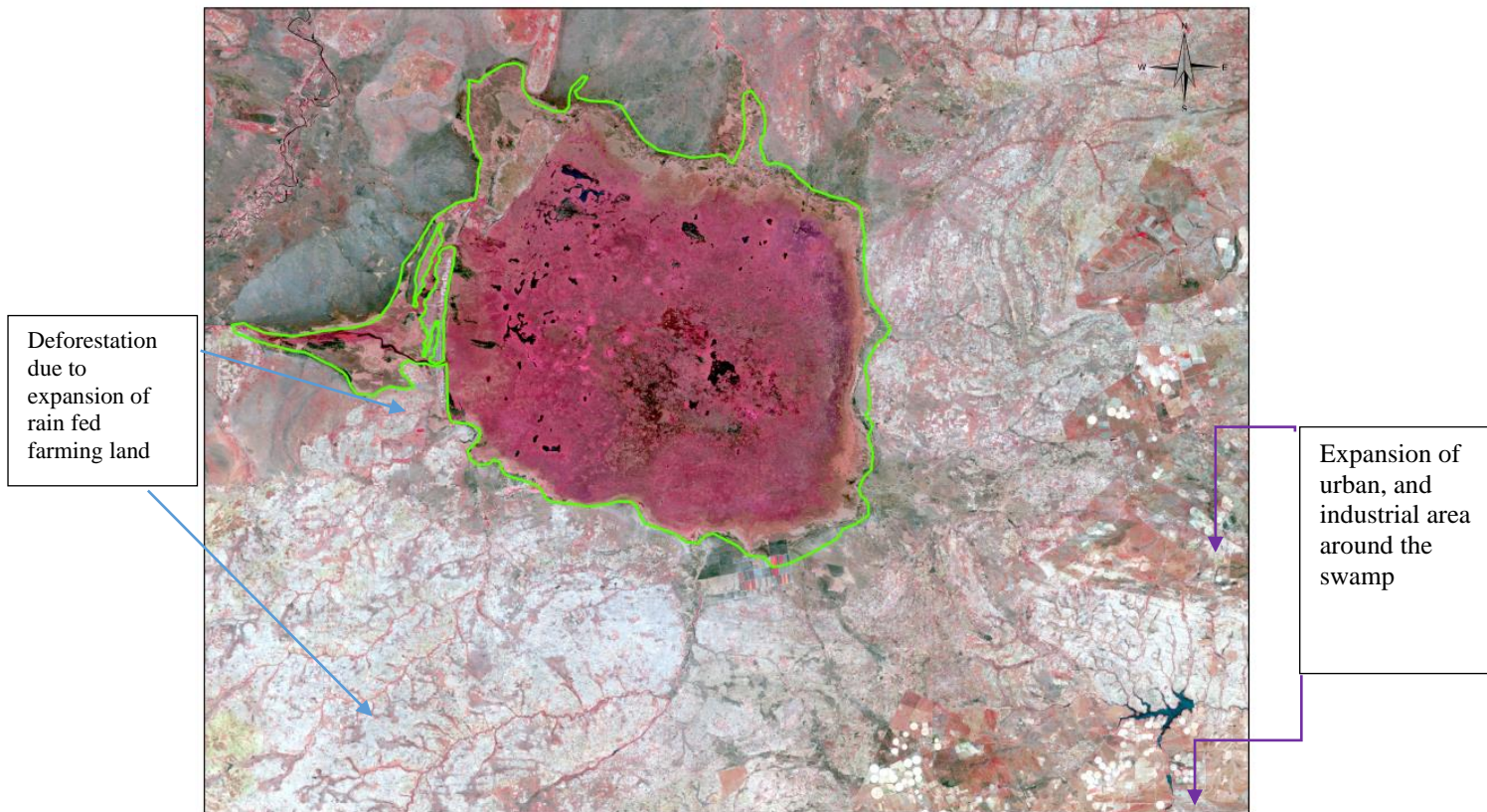
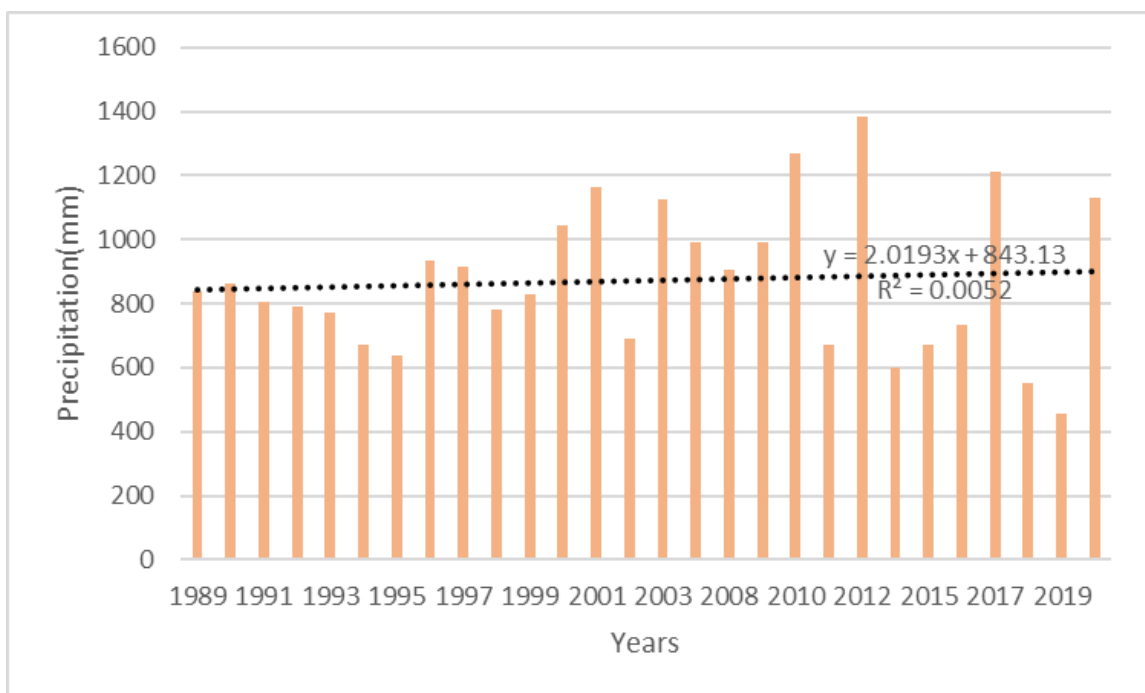


Figure 19:Satellite imagery of activities surrounding the swamp

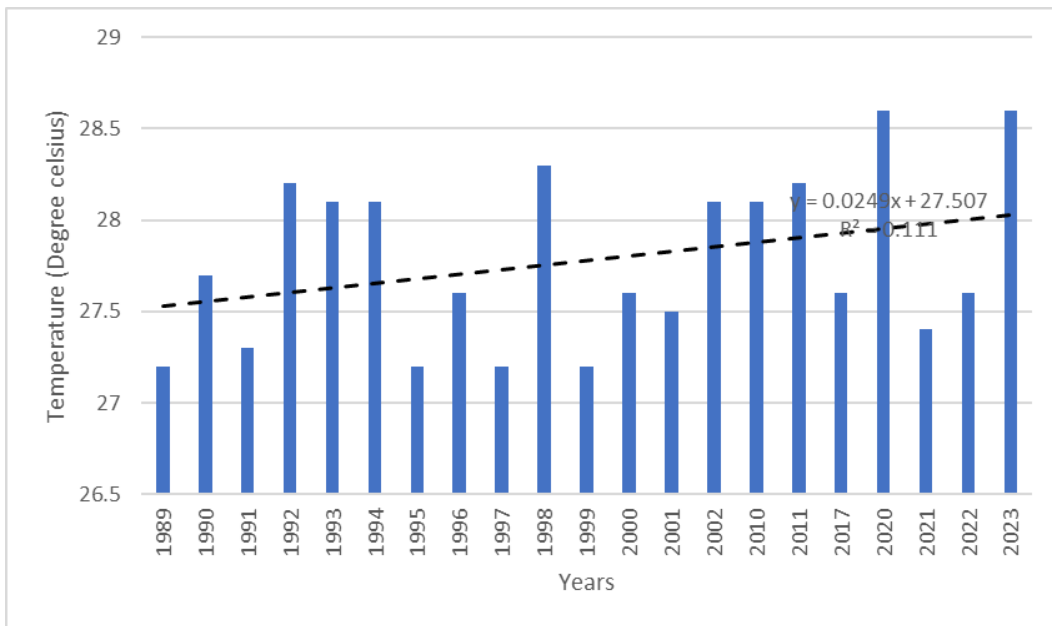
4.6 Temporal Variability of Climatic Factors and their Implications on Land Use/Land Cover Dynamics in the Lukanga Swamp

Figure 19 and 20 displays an annual rainfall and mean temperature trend in the Lukanga swamp, revealing both low and high precipitation and temperatures. The precipitation was higher in 2012, 2010, 2017, and 2001, with a Mann-Kendall trend analysis indicating insufficient evidence to conclude that there is a significant trend in the rainfall data. (Table 10). The temperature data also showed year-to-year variability, with slight increases from 1990 to 1992, a decrease from 2001 to 2002, a fluctuation around 27.8°C from 1996 to 2010, and a slight increase from 2020 (Table 11). The Mann ' 'Kendall's trendline showed a p-value greater than the significance level $\alpha=0.05$ (Table 8), suggesting no significant trends in the temperature time series.

The investigation of yearly rainfall and mean temperature trends in the Lukanga Swamp reveals that climatic parameters vary significantly over time. Despite changes in precipitation and temperature over time, the Mann-Kendall trend analysis finds insufficient evidence to demonstrate significant trends in either rainfall or temperature during the chosen timeframe. These findings show that, while climatic conditions may fluctuate, the existing data do not reveal a clear long-term trend. However, more data or more advanced approaches may provide deeper insights into the link between climatic variability and land use/land cover changes in the Lukanga Swamp.



(a)



(b)

Figure 20:(a) Annual mean rainfall and (b) temperature for the period between

Table 7: Precipitation trend analysis

Mann-Kendall trend test / Two-tailed test (837.6):

Kendall's tau	0.003
S	1
Var(S)	2301.00 0
p-value (Two-tailed)	0.983
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H₀: There is no trend in the series

H_a: There is a trend in the series

As the computed p-value is greater than the significance level $\alpha=0.05$, one cannot reject the null hypothesis H₀.

Table 8: Temperature Trend analysis

Mann-Kendall trend test / Two-tailed test
(27.21):

Kendall's tau	0.087
S	30
Var(S)	2290.667
p-value (Two-tailed)	0.531
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H₀: There is no trend in the series

H_a: There is a trend in the series.

As the computed p-value is greater than the significance level $\alpha=0.05$, one cannot reject the null hypothesis H₀.

Ties have been detected in the data and the appropriate corrections have been applied.

4.8 Wetland Policies and its Implementation in Zambia

Wetland management in Zambia faces challenges due to poor legal support and insufficient political will. The Zambian government has a national policy for wetlands, which is managed through various enabling Acts. These include the Water Resources Management Act No. 21 of 2011, which protects and preserves wetlands, and the Environmental Management Act No. 12, which declares wetlands as ecologically sensitive areas (Ministry of Land and Natural Resources, 2018). The Fisheries Act No. 22 of 2011 supports sustainable fisheries and aquaculture development, while the Agriculture Act No. 13 of 1994 promotes sustainable agricultural practices. The Lands Act Cap 184 manages land on wetlands, and the Forest Act No. 4 of 2015 protects forests and trees, thereby protecting wetlands. The National Policy on Climate Change of 2016 provides a framework for coordinated response to climate change issues, promoting sustainable economic growth and the achievement of Vision 2030. However, little has been achieved since this provision (Ministry of Land and Natural Resources, 2018). None of the wetlands has an approved management plan, which is a key requirement under the Ramsar convention. Urgent implementation of relevant provisions such as the Water Resources Management Act and the Environmental Management Act is needed to ensure better protection, sustainably managed, and wise use of wetlands for resilient biodiversity and ecosystem services.

From the National policy for Wetland 2018, government ministries and agencies of government are expected to review their legislation in order to effectively contribute to sustainable management of Wetland. However, this creates an enormous complexity for concerned departments to take development initiatives concerning the wetlands and fisheries resources management. From studies conducted it has been noted that governments often fail to understand this power process and its impact on the whole governance system, resulting into time lags a widely accepted intrinsic problem related to wetland policy implementation (Chabwela & Haller, 2010). Lastly, the country needs to create institutions that focus on wetlands management, develop financial sources for wetlands conservation, and raise awareness about the benefits of wetlands for maximum satisfaction. This will help secure resilient biodiversity and ecosystem services in Zambia.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

The Lukanga wetland is crucial for ecological, food, freshwater, and climate security, requiring national and international cooperation to protect and restore. The study identifies significant land use and land cover changes (LULCC) in the Lukanga Swamp between 2000 and 2023. Satellite imagery and advanced analytical techniques reveal changes in land use landcover. The findings show an overall trend, with substantial decreases in deep water, shallow water, and forest areas of 9.4%, 25.5%, and 1.5%, respectively, throughout the 23-year period. Conversely, the categories of irrigated agriculture, grassland, and settlements/bare soil have increased by 0.28%, 0.024%, and 36.3%, respectively.

The NDWI assessment showed an ecological alteration change with maximum NDWI values falling from 0.32 in 2000 to 0.15 in 2023, indicating a decrease in water bodies or water content with time. Similarly, NDVI assessments dropped from 0.61 in 2000 to 0.45 in 2023, implying a decrease in vegetation density, even if vegetation is still present in the area. The NDVI and NDWI analyses found a decrease in water bodies and vegetation cover, demonstrating a complicated interaction between human activities and natural processes in the Swamp. Addressing these concerns proactively can assure the long-term preservation of this vital natural resource for today's and future generations. Overall, based on the findings of this study, the following recommendations are provided:

- I. Despite its existing policy, Zambia needs to swiftly implement laws and regulations on wetland management to ensure smooth implementation and protect the unique ecosystems of wetlands.
- II. A dynamic monitoring system is needed for Zambia's wetland status assessment, utilizing remote sensing and field observation. This technology efficiently assesses global wetlands, revealing ecosystem structure and function changes. Continuous improvement can improve data resolution and speed.
- III. Technical training for local communities on wetland management is vital for wetland conservation, addressing LULC change impacts, and improving the sustainable use of the Wetland
- IV. Zambia's government should take a bottom-up strategy involving local communities in wetland management.
- V. The government, stakeholders, and non-farm diversification should collaborate to

support local communities and implement resource conservation practices to mitigate the impacts of LULC change.

- VI. Government agencies and stakeholders should collaborate on developing comprehensive wetland management plans for Lukanga Swamp and all the other wetlands, focusing on biodiversity conservation, sustainable resource utilization, pollution control, and community engagement.
- VII. Additional research is required to investigate the impact of LULC modifications, develop alternate resource management strategies, and improve wetland management

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APPENDICES

Work plan

Table 9: Work plan of the research.

Activity	Nov 2023	Dec 2023	Jan 2024	Feb 2024	March 2024	April 2024	May 2024
1. Proposal writing							
2. Desktop Literature review							
3. Field survey and Ground truthing							
4. Data Processing and analysis							
5. Draft and Final Report writing, binding & submission							

Table 10: Annual Temperature at Lukanga Swamp

Station_Name	Year	Annual Precipitation (Mm)
Kabwe Met	1989	837.6
Kabwe Met	1990	862
Kabwe Met	1991	804.3
Kabwe Met	1992	789
Kabwe Met	1993	772
Kabwe Met	1994	673.1
Kabwe Met	1995	636.7
Kabwe Met	1996	935.5
Kabwe Met	1997	913.9
Kabwe Met	1998	780.8
Kabwe Met	1999	830.1
Kabwe Met	2000	1044.7
Kabwe Met	2001	1162.6
Kabwe Met	2002	690.3
Kabwe Met	2003	1127.9
Kabwe Met	2004	992.3
Kabwe Met	2008	906.6
Kabwe Met	2009	990.5
Kabwe Met	2010	1271.1
Kabwe Met	2011	670.1
Kabwe Met	2012	1383
Kabwe Met	2014	601.6
Kabwe Met	2015	669.9
Kabwe Met	2016	732.7
Kabwe Met	2017	1211.7
Kabwe Met	2018	552.7
Kabwe Met	2019	456.5
Kabwe Met	2020	1128.2

(Source; Zambia Meterological Department (ZMD))

Table 11: Annual Temperature Maximum and Minimum

Station Name	Year	Temperature Maximum (Degree Celsius)	Temperature Minimum (Degree Celsius)
Kabwe Met	1989	27.2	14.7
Kabwe Met	1990	27.7	14.7
Kabwe Met	1991	27.3	14.4
Kabwe Met	1992	28.2	15.1
Kabwe Met	1993	28.1	14.7
Kabwe Met	1994	28.1	14.9
Kabwe Met	1995	27.2	15.1
Kabwe Met	1996	27.6	15.3
Kabwe Met	1997	27.2	14.7
Kabwe Met	1998	28.3	15.6
Kabwe Met	1999	27.2	14.9
Kabwe Met	2000	27.6	15.2
Kabwe Met	2001	27.5	15.3
Kabwe Met	2002	28.1	15.8
Kabwe Met	2010	28.1	15.8
Kabwe Met	2011	28.2	15.9
Kabwe Met	2017	27.6	15.6
Kabwe Met	2020	28.6	14.6
Kabwe Met	2021	27.4	13.4
Kabwe Met	2022	27.6	15.7
Kabwe Met	2023	28.6	15.6

(Source; Zambia Meterological Department (ZMD))

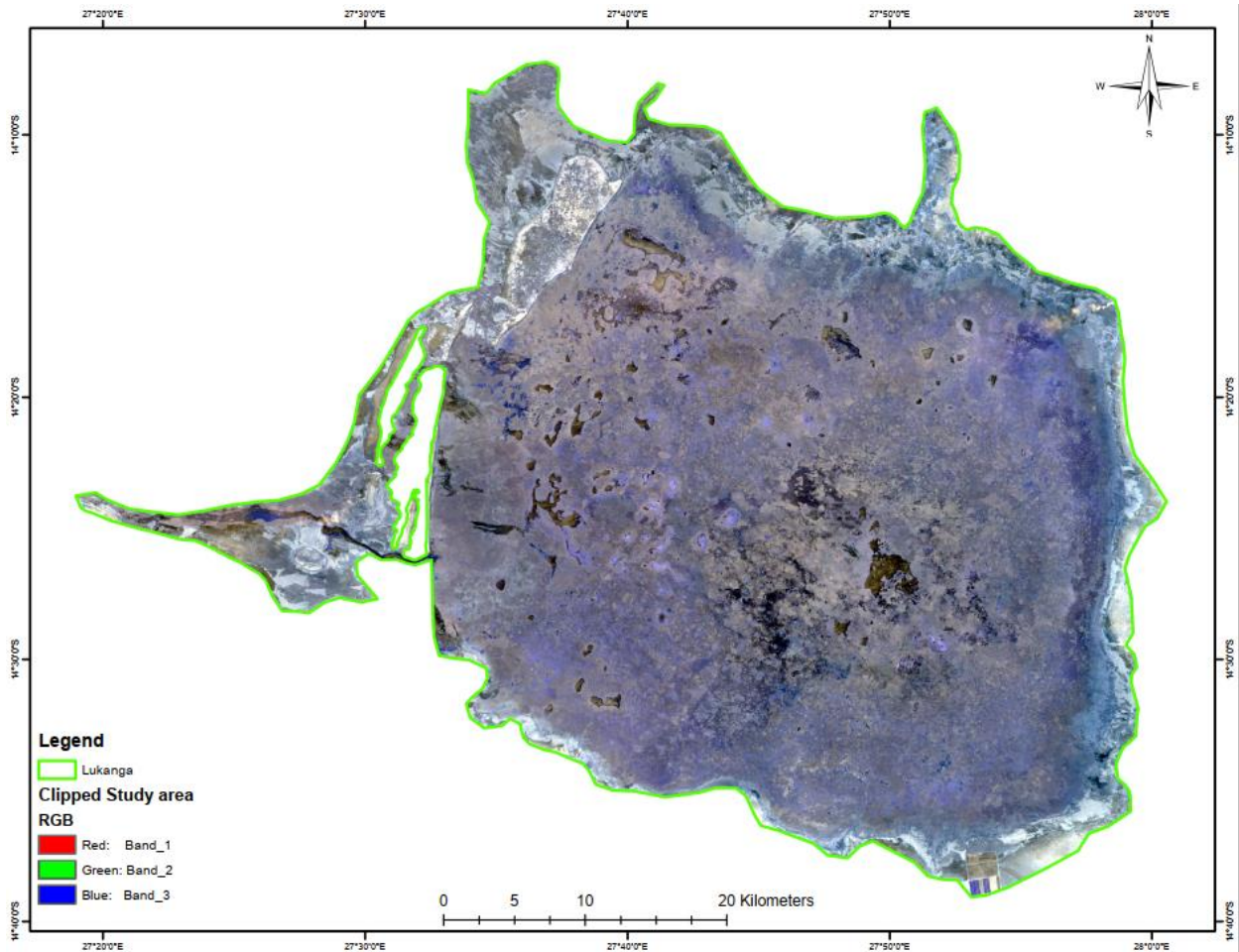


Figure 21: Clipped study area

Signatures

Dr Tewodros Tena
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20th March, 2024

Stephen Lungomesha
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22nd March 2024

