IMPACTS OF CLIMATE CHANGE AND HUMAN ACTIVITIES ON THE WALUKUBA-MASESE WETLAND ECOSYSTEM (LAKE VICTORIA BASIN)

BY

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DECLARATION

I, **VICTORIA KAKAIRE**, hereby declare that this dissertation is a result of my original effort except where cited and has never been submitted for any other degree award at this or any other University or institution of higher learning.

Candidate

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ACRONYMS

BOD	Biological oxygen demand
FGD	Focus group discussion
COD.	Chemical oxygen demand
IPCC	Intergovernmental Panel on Climate Change
LULC	land use and land cover changes
SPI	Standardised precipitation index
NDVI	Normalised Difference Vegetation Index
PC	Principal Component
SDI	Site Degradation Index
PDM	Parish Development Model
NEMA	National environmental management authority
GPS.	Global positioning system
NGO.	None governmental organization
PET	Potential evapotranspiration

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ABSTRACT

Urban wetlands function as critical ecosystems, offering essential services such as water filtration, flood control, and biodiversity conservation to mention a few. However, this type of ecosystem faces immense pressure from both climate and anthropogenic stressors. Numerous studies have documented the effects of these stressors on wetland processes and ecosystem services; however, these studies span a wide range of geographical scales, and the findings may not be directly applicable at local scales. The aim of this study, therefore, was to examine the socio-ecological dynamics of the Walukuba Masese wetland system in Jinja District, Uganda, focusing on its ecological condition, user characteristics, perceived drivers of change, and community adaptation strategies. Using a mixed-methods design combining structured household surveys, in-depth focus group discussions, and systematic field observations this study gathered insights from 257 wetland users and key institutional stakeholders. Findings revealed four core insights. First, long-term climate data revealed inter annual variability in rainfall, with no significant trend, and a ~2°C rise in temperature over 40 years, likely intensifying evapotranspiration and stressing wetland hydrology. Second, satellite imagery revealed a greater than 50% loss of wetland area alongside a fivefold increase in built-up and agricultural land, which has fragmented the wetland area and increased the incidence of flooding. Third, water samples showed elevated biological oxygen demand (BODs) up to 80 mg/L, chemical oxygen demand (COD) up to 130 mg/L, elevated coliforms, and a 10–15% drop in Shannon diversity at highly degraded sites. Fourth, household interviews showed that changes in wetland's ecological status have affected fish abundance and other wetland-derived services, especially for low-income households. Adaptation strategies are diverse, depending on the impacted user, but can broadly be grouped into four categories: diversification (especially for the low-income households), innovation, participation, and modification (especially for users who mainly degrade the wetland). Four logistic regression models, representing each of the adaptation strategies above, showed that training, income, awareness, and gender increase the odds of adaptation, while age and experience reduce the odds of adaptation. In conclusion, this study showed evidence of climate variability at a local scale, consistent with the regional and global trends. There is also evidence of significant land cover change, but this is primarily driven by human activities rather than climate variability. Wetland ecosystem services (using water quality, biodiversity, and livelihoods as proxy indicators) are also likely more threatened by anthropogenic stressors (habitat degradation) than by climate variability. Based on these findings, it is vital to strengthen policy enforcement, integrate user groups into development initiatives, and support local initiatives with training, compensation, and incentives. These measures may enhance both the resilience of wetlands and the livelihoods of local communities.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Urban wetland ecosystems play a vital role in sustaining environmental and human well-being, through the provision of a range of ecosystem services such as water filtration, flood control, carbon sequestration, and biodiversity conservation (Alikhani et al., 2021; Das et al., 2025; Ferreira et al., 2023a; Mitsch et al., 2015). Flood control is a particularly crucial service, especially in urban settings, as wetlands act as natural sponges that absorb excess stormwater, thereby mitigating the risk of urban flooding and protecting infrastructure and human settlements (Sharma & Ayuba, 2024). Additionally, wetland plants contribute to carbon sequestration by capturing and storing large amounts of carbon in their shoots, which helps reduce greenhouse gas emissions, and hence regulates the global temperatures (Lolu et al., 2019). Beyond these services, wetlands also provide valuable ecosystem goods such as fish, reeds for construction and handicrafts, medicinal plants, and raw materials for fuel, including peat and firewood (Maua et al., 2022). These goods sustain local economies, enhance livelihoods, and support cultural practices, underscoring the necessity of wetland conservation and sustainable management. For example, in Sub-Saharan Africa, wetlands constitute an integral part of the landscape, supporting livelihoods through agriculture, fishing, and tourism(Rebelo et al., 2009; Wood, Dixon, & Mccartney, 2013).

Uganda stands out in Sub-Saharan Africa for its robust wetland management policies, which have garnered global recognition for promoting both conservation and sustainable utilisation. For instance, Uganda's wetlands, such as the Nabajjuzi and Lutembe Bay RAMSAR sites, not only support biodiversity but also serve as vital resources for livelihoods through activities like papyrus harvesting, fishing, and ecotourism. The National Wetlands Policy (1995) underscores the importance of integrating wetland management with socio-economic development, highlighting initiatives such as community-driven restoration projects and strict regulations on wetland encroachment. These efforts ensure that wetlands continue to provide critical ecosystem services, including flood control, water purification, and carbon sequestration, while supporting local economies and communities.

Despite the vast array of ecosystem services provided by wetlands, they are increasingly threatened by climate change and anthropogenic activities, resulting in deterioration of their health and functionality (Priya et al., 2023). Climate variability and human-induced activities significantly compromise wetland ecosystem services by altering hydrology, biodiversity, and carbon dynamics. Rising temperatures and changes in precipitation patterns disrupt the water balances of wetlands, reducing their capacity for flood control, water storage, and biodiversity conservation (Moomaw et al., 2018; Muluneh, 2021). Human activities, such as urbanisation, agricultural encroachment, industrialization and pollution, exacerbate these impacts, leading to habitat loss and reduced ecosystem functionality (Chandra Voumik & Sultana, 2022; Jiang et al., 2024). For example, in Uganda, the degradation of the Nakivubo wetland in Kampala due to urban pressures has resulted in diminished water filtration and increased flood risks (Isunju & Kemp, 2016).

Studies have shown the influence of climate change on species composition and greenhouse gas emissions, with evidence of shifts in wetland flora and fauna in response to altered climatic conditions (Beyene et al., 2024; Sati et al., 2025). Despite these studies, research on urban wetlands remains sparse, presenting a critical gap and a strong justification for studies on how climate variability and human-induced activities impact ecosystem services.

The Intergovernmental Panel on Climate Change (IPCC) has documented significant downward shifts in hydrological patterns, particularly in tropical and subtropical regions, leading to reduced water availability in wetlands due to changes in precipitation, increased evaporation, and more frequent extreme weather events such as droughts and floods (Bates et al., 1996; Bolan, 2024). In urban wetlands, reduced water availability is often exacerbated by disruptions to river flow regimes, as seasonal flooding, which is critical for wetland function, becomes increasingly unpredictable or absent (Bhaga et al., 2020). Such changes degrade wetland ecosystems, reducing biodiversity and essential services such as water filtration (Adla et al., 2022). Urban sprawl compounds these effects, as wetlands are drained or filled to meet the demand for housing and infrastructure, leading to habitat loss and diminished ecological functions (Asante et al., 2024). Poor waste management and deforestation contaminate urban wetlands with pollutants, while intense rainfall exacerbates runoff, introducing hazardous chemicals and sediments that further degrade water quality (Ferronato & Torretta, 2019; Hajam et al., 2023). Rapid urbanisation around cities near Lake Victoria, including substantial population growth and industrial activities, has increased industrial discharges and agricultural runoff, further threatening wetland ecosystems.

However, the specific impacts of these stressors on urban wetlands around Lake Victoria, particularly in areas like Jinja, remain underexplored, highlighting a critical gap in research (Nyamweya et al., 2023a; Ruffins, 2015).

The Walukuba-Masese wetland, located along the shores of Lake Victoria in Uganda, is a vital urban ecosystem that provides essential services such as water purification, flood control, and habitat provision (Agaton & Guila, 2023). However, it faces significant degradation driven by human-induced activities and climate (Nabihamba, 2019). Rapid population growth around the wetland has increased pressures from unregulated urban development, sand mining, agricultural expansion, and pollution from domestic and industrial sources(Kuchara et al., 2023). Climate variability has exacerbated these impacts through erratic rainfall patterns, which disrupt hydrology and reduce the wetland's capacity to regulate water flow and filter pollutants *(Bhaga et al., 2020).* Encroachment from the urban sprawl of Jinja has further aggravated these issues, with studies showing a shrinking wetland, declining vegetation cover, sedimentation, and increasing eutrophication (Adla et al., 2022; Kabiri et al., 2022; Tyole, 2023). Despite the wetland's importance to local livelihoods through agriculture, fishing, and water supply, limited research exists on the extent of these changes and their socio-economic implications.

1.2 Statement of the problem

Urban wetlands, which function as critical ecosystems, offering essential services like water filtration, flood control, and biodiversity conservation (Muñoz et al., 2024; Peng et al., 2023), face immense pressure from both climate and anthropogenic stressors(Alikhani et al., 2021). Numerous studies have documented the effect of these stressors on wetland processes and ecosystem services (Keith et al., 2022; Ostrowski et al., 2021; Vilas-Boas et al., 2021). However, these studies span geographical scales, and their findings may not be applicable at local scales. In particular, the Walukuba-Masese wetland, situated around Lake Victoria in Jinja, Uganda, is facing severe degradation due to the combined pressures of climate and human activities, which may result in diminished ecological functions and increased environmental risks for the local population. However, these effects have not been studied. Current research lacks specific insights into the scale and nature of these impacts, especially in urban settings. This study aims to fill this gap by assessing the combined effects of climate and anthropogenic pressures on the wetland's ecosystem processes and services. The research will provide valuable data to inform sustainable management and conservation efforts, ultimately guiding policy decisions that can balance urban growth with the preservation of wetlands.

1.3 Objectives of the study

1.3.1 General objective

The primary objective of this study was to evaluate the impact of climate change and anthropogenic activities on the health and services of an urban wetland ecosystem, using the Walukuba-Masese wetland on Lake Victoria as a case study.

1.3.2 Specific objectives

i. To determine long-term trends in climate (using rainfall and temperature) and anthropogenic activities around the Walukuba-Masese wetland.
ii. To determine the spatial and temporal changes in selected wetland ecosystem attributes (wetland cover, water quality, biodiversity index) around the Walukuba-Masese wetland system .
iii. To assess the relationship between climate (rainfall, temperature) and selected wetland ecosystem attributes (vegetation cover, water quality, biodiversity)
iv. To assess the relationship between anthropogenic activities (land use/cover change) and selected wetland ecosystem attributes (vegetation cover, water quality, biodiversity).

1.4 Research Question

The research questions that guided the study were;

i. Has climate and anthropogenic activities intensified around the Walukuba-Masese wetland system over the past four decades?
ii. Are there notable temporal or spatial changes in wetland ecosystem indicators such as wetland cover, water quality, and biodiversity index around the Walukuba-Masese wetland system?
iii. Is there a significant relationship between climate and the selected wetland ecosystem attributes?

iv. Is there a significant relationship between anthropogenic activities (land use change) and the selected wetland ecosystem attributes?

1.5 Rationale of the Study

This study is significant because urban wetlands play a crucial role in providing ecosystem services that are vital for both environmental health and the well-being of local communities. By investigating the extent of changes in the wetland ecosystem, attributed to climate and anthropogenic activities on a significant urban wetland like the Walukuba-Masese wetland on Lake Victoria, this study provides valuable insights into the ecological states of most urban local wetlands. This is crucial for identifying effective strategies to restore and maintain the wetland’s ecological balance and resilience in the face of ongoing environmental pressures.

The findings from this research can inform policymakers and urban planners in Uganda and other regions with similar ecosystems. By highlighting the impacts of land-use changes and climate change on the wetland, the study provides evidence-based recommendations for sustainable wetland management and conservation practices. This is particularly important in the context of urban development around Lake Victoria, where wetlands are increasingly being converted for human use.

1.6 Conceptual Framework of the Study

The dependent variables for this study included proxy indicators for wetland ecosystem services, such as vegetation cover (a proxy for flood control), water quality (a proxy for water purification), floral diversity, and livelihoods. It is expected that these variables are driven by climate variability, represented by rainfall, temperature, and the frequency of extreme weather, as well as anthropogenic activities, represented by urban expansion, industrial Discharge, and agricultural encroachment. Regulatory frameworks, governance structures, and community-based conservation efforts can mediate the influence of these independent variables on the dependent variable. The link between these variables is shown in Figure 1.

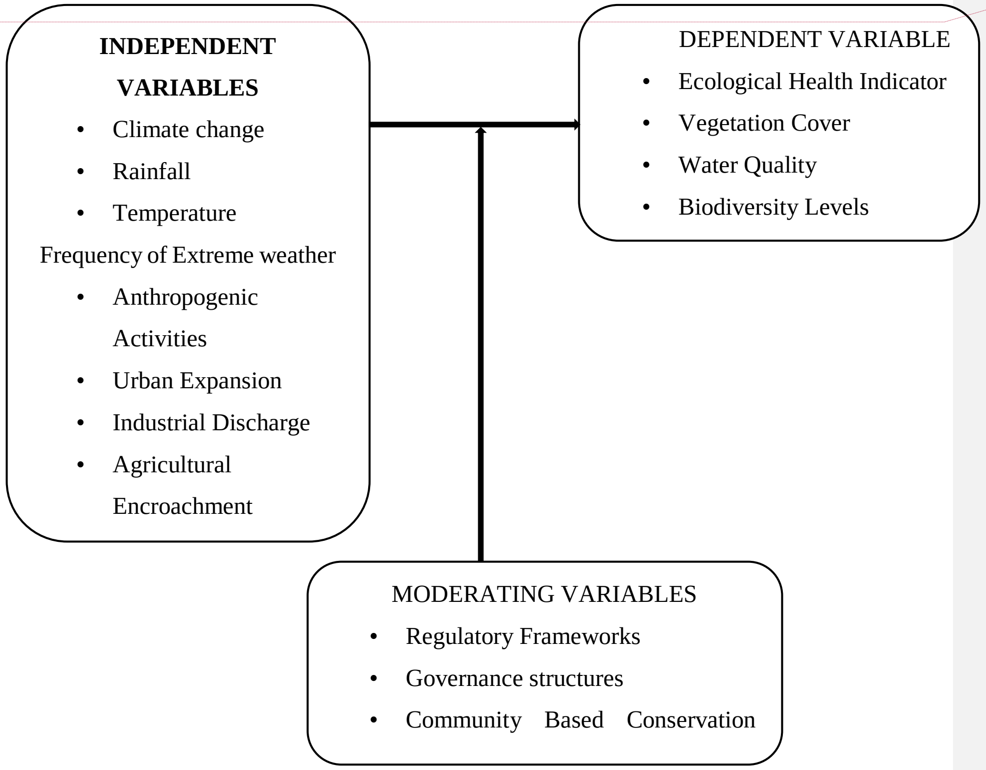

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Figure 1: Conceptual Framework of the Study

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CHAPTER TWO: LITERATURE REVIEW

2.1. Wetland ecosystems and their services

Wetland ecosystems are defined as transitional landscapes where terrestrial and aquatic environments converge, including marshes, swamps, peatlands, and seasonal floodplains. In Uganda, these systems are further classified as lacustrine and riverine wetlands, reflecting their strong association with permanent or seasonal water bodies (Cheeseman, 2025; Hedman, 2019).

The Millennium Ecosystem Assessment framework categorizes ecosystem services provided by wetlands into four groups. Provisioning services supply food, water, and raw materials; regulating services ensure water purification, flood control, and carbon sequestration; cultural services offer recreational, educational, and aesthetic benefits; and supporting services maintain biodiversity and habitat quality (de Groot et al., 2018; Hedman, 2019). This categorization is critical to understanding and quantifying the multifaceted contributions of wetlands to ecological processes and human livelihoods.

In Uganda, wetlands are integral to the well-being of communities, with 8–10% of the population directly relying on them for fishing, agriculture, and resource collection, despite these ecosystems covering 10–13% of the country’s land area (Cheeseman, 2025). Anthropogenic pressures such as agricultural expansion, urban development, and unsustainable resource harvesting are accelerating wetland degradation (Cheeseman, 2025; Matovu et al., 2024). Research by Ugandan scholars further highlights critical gaps in local perceptions and economic valuations of wetland services, emphasizing the need for community-based management strategies and informed policy frameworks (Xu et al., 2020).

2.2 Global and local threats to wetland integrity

Wetlands function as critical reservoirs of biodiversity, hydrological regulators, and sources of economic and cultural benefits, yet their integrity is increasingly under threat from a convergence of anthropogenic and climate-driven factors (Cantonati et al., 2020). Global pressures, ranging from rapid urban sprawl and agricultural expansion to the widespread discharge of industrial and domestic pollutants, have resulted in significant shifts in wetland landscape structure and function (Cantonati et al., 2020). Concurrently, climate change is altering fundamental hydrological regimes in ways that destabilize the delicate water balances upon which wetland vegetation and faunal communities depend (Fay et al., 2016; Meng et al., 2020).

These dual forces are encapsulated by the “squeeze” concept, whereby wetlands are caught between the accelerating pace of human-induced land conversion and the inexorable shifts in climate that diminish the available freshwater and alter seasonal inundation patterns (Lu & Xiao, 2024; Song, 2025). Although extensive global research has elucidated many of these trends, site-specific studies that integrate long-term meteorological data with detailed assessments of anthropogenic influence are still sparse, particularly for regions such as East Africa where ecosystems like the Walukuba-Masese wetland are exposed to rapid and compounding environmental changes (Cantonati et al., 2020; McQuaid et al., 2018).

2.3 Global Perspectives on Wetland Degradation

2.3.1 Anthropogenic Drivers of Wetland Degradation

At the most fundamental level, global degradation of wetland systems is driven by anthropogenic modifications through land use and land cover changes. The conversion of wetlands to agricultural fields, urban settlements, and industrial zones has created widespread physical losses and fragmentation of these ecologically dynamic landscapes (Cantonati et al., 2020). Agricultural expansion, driven by an ever-growing demand for arable land, has frequently resulted in the draining and filling of wetlands, thereby disrupting hydrological connectivity and reducing water retention capacities (Cantonati et al., 2020; Lázaro-Lobo & Ervin, 2021). Urban sprawl further exacerbates these effects through the proliferation of impervious surfaces that modify local runoff patterns and reduce groundwater recharge, intensifying flood risks and often leading to the chronic degradation of water quality (Cantonati et al., 2020). In numerous regions globally, the rapid pace of industrial development, notably through infrastructure projects such as dam construction and resource extraction, has compounded these issues by introducing further barriers to natural ecological flows and increasing pollutant loads in adjacent freshwater systems (Castello & Macedo, 2016). Collectively, these LULC changes have not only contributed to the dramatic reduction in wetland extent observed across continents but have also altered the regional microclimates that sustain these ecosystems.

In addition to physical modifications of the landscape, wetlands are also under severe threat from pollution and resource over-exploitation. Nutrient loading from intensive agriculture has led to rampant eutrophication in many systems, triggering excessive phytoplankton blooms that deplete dissolved oxygen and set the stage for hypoxic conditions deleterious to aquatic fauna (Cantonati et al., 2020). Chemical contaminants, arising from industrial effluents and urban runoff, further exacerbate ecosystem stress by interfering with biogeochemical cycles and directly impairing the physiological functions of sensitive aquatic species (Cantonati et al., 2020). Over-exploitation of wetland resources such as overfishing, excessive sand mining, and unsustainable vegetation harvesting further diminish the capacity of these habitats to support stable ecological communities. These extraction practices not only reduce the immediate stock of natural resources but also remove critical structural components, including plant cover and substrate, that are essential for maintaining the physical and biological integrity of wetlands (UNEP, 2021). In many parts of the world, particularly in developing regions, these pressures are amplified by weak regulatory frameworks and the misperception of water as an inexhaustible resource (Cantonati et al., 2020; UNEP, 2021). As a result, the interlinked phenomena of pollution and resource over-exploitation have emerged as major drivers of wetland degradation, contributing to not only biodiversity loss but also diminished ecosystem services upon which human communities depend.

2.3.2 Climate drivers of wetland degradation

Global climatic change has imposed a new array of challenges on wetland systems by fundamentally altering their hydrological regimes. Shifts in precipitation patterns, both in terms of overall volume and temporal distribution, coupled with rising temperatures have led to significant modifications in the frequency, duration, and intensity of inundation events (Fay et al., 2016; Ikeda-Castrillon et al., 2022). In many wetland areas, increasing temperatures have elevated evapotranspiration rates, thereby reducing the net water input even in regions that might otherwise receive adequate rainfall (Fay et al., 2016; Meng et al., 2020). These changes on a regional and global scale modify the seasonal hydroperiods that are critical for the germination, growth, and reproduction of wetland vegetation, as well as for maintaining the overall biogeochemical balance of these ecosystems (Fay et al., 2016; Joyce et al., 2016). Furthermore, the reduction of inundation frequency in some temperate wetlands has been associated with shifts in species composition as more drought-tolerant, yet biologically less diverse, communities come to dominate (Lu & Xiao, 2024; Song, 2025). Such alterations not only weaken the natural resilience of wetland systems but also make them increasingly vulnerable to additional stressors such as invasive species and further anthropogenic disturbances.

Beyond gradual shifts in baseline conditions, climate change is also associated with an increase in the frequency and severity of extreme weather events that pose immediate threats to wetland integrity. Droughts, for instance, have become more prolonged and frequent in several regions, leading to critical water shortages and causing sustained periods of desiccation in wetlands (Lu & Xiao, 2024). These conditions not only stress aquatic organisms but also undermine the stability of peatlands and other wetland types that rely on consistent moisture regimes for carbon sequestration and nutrient cycling (Lu & Xiao, 2024). Conversely, extreme flood events can rapidly alter sediment dynamics, scouring existing vegetation and depositing excessive sediments that change the physical structure of wetland basins (Joyce et al., 2016). When such rapid sediment deposition occurs repeatedly or in conjunction with other forms of anthropogenic disturbance, it can lead to irreversible morphological changes that hamper the natural regeneration processes of wetlands. In many cases, the occurrence of these extreme events creates feedback loops that intensify existing degradation patterns; for example, recurrent droughts may diminish plant cover, which in turn reduces the system's capacity to withstand subsequent flood events, thereby perpetuating a cycle of decline (Joyce et al., 2016).

2.3.3 The "Squeeze" Concept: Convergence of Human and Climate Pressures

A critical and increasingly cited phenomenon in wetland literature is the "squeeze" concept, which encapsulates the dual pressures exerted by climate change and anthropogenic land use on wetlands. On one side, climate-induced shifts, including rising sea levels, altered precipitation regimes, and increased evaporation, force wetlands to adapt by migrating inland or altering their hydroperiods (Joyce et al., 2016; Song, 2025). On the other side, rapid human development, through urban sprawl and agriculture, imposes rigid boundaries that restrict natural wetland migration and lateral expansion (Cantonati et al., 2020; Song, 2025). This combined pressure effectively "squeezes" wetlands into ever-narrower ecological niches where their ability to persist and adapt to changing environmental conditions is severely compromised. In coastal settings, for instance, the inability of wetlands to move inland in response to rising sea levels results in a net loss of habitat and a decline in the protection afforded by these ecosystems against storm surges and coastal erosion (Song, 2025). Similarly, in inland regions, the juxtaposition of intensified agricultural landscapes with shifting climatic patterns precludes the natural reorganization or expansion of wetland boundaries, a scenario that has contributed to substantial local and regional wetland losses (Cantonati et al., 2020; Lázaro-Lobo & Ervin, 2021). The squeeze phenomenon not only represents a spatial constraint but also a temporal one, as wetlands are increasingly forced to make rapid adjustments in the face of permanent infrastructural developments that are unlikely to be reversed.

The “squeeze” concept offers a particularly instructive framework for understanding these interactions. In both coastal and inland contexts, wetlands are confronted with the dual pressures of having to adjust naturally to shifting hydrological conditions while contending with the spatial constraints imposed by rapid human development (Lu & Xiao, 2024; Song, 2025). This phenomenon is especially acute in areas where urban and agricultural boundaries are rigidly fixed, thereby limiting the capacity for wetlands to migrate or expand in response to rising sea levels or altered flood patterns (Cantonati et al., 2020; Song, 2025). Such constraints not only reduce the ecological resilience of wetlands but also weaken their role as buffers against climate variability, a loss that carries significant implications for both biodiversity conservation and human well-being.

At the same time, localized case studies underscore that the impacts observed at the global level do not always translate directly to regional scales. In the case of the Walukuba-Masese wetland, for instance, direct observations have highlighted how erratic, delayed rainfall events and rising temperatures are already manifesting in changes to the local hydrological regime (Fay et al., 2016; McQuaid et al., 2018). These climatic changes, when superimposed on an already stressed landscape undergoing rapid urban and agricultural development, suggest that the mechanisms of degradation may differ substantially from those documented in more extensively studied regions (Cantonati et al., 2020; Song, 2025). The localized interaction between long-term climatic and immediate human-induced pressures creates a complex and dynamic environment that challenges conventional management approaches and underscores the urgency for integrated, site-specific research.

2.4. Climate change: evidence from global to local scales

Global-scale studies indicate that anthropogenic influences are driving rising temperatures and shifting precipitation patterns, with the IPCC projecting up to a 3°C increase by 2080 and associated changes in rainfall intensity and distribution (Acreman & McCartney, 2009; Trenberth, 2005). These global trends are linked to increased atmospheric water vapor and enhanced potential evapotranspiration, which in turn influence the frequency of heavy precipitation events and prolonged dry spells (Trenberth, 2005).

At the regional level, the Lake Victoria basin in East Africa exhibits a similar warming trend with erratic rainfall patterns, where increasing temperatures and seasonal variability have led to more extreme climatic events, including intense wet periods and prolonged droughts (Adhikari et al., 2015; Luhunga & Songoro, 2020). Local climatic influences such as sea surface temperature fluctuations and the seasonal migration of the ITCZ further complicate the precipitation regime, resulting in both bimodal and unimodal rainfall distributions (Onyutha et al., 2019; Pietroiusti et al., 2024).

The application of climate indices, notably the Standardized Precipitation Index (SPI), offers standardized measurements for quantifying droughts and wet spells; however, their use in the Ugandan context remains limited, highlighting a significant methodological gap (Adhikari et al., 2015). Climate directly affects wetland hydrology by promoting drying under reduced rainfall and elevated temperatures, while intense precipitation events lead to flooding and pollutant flushing from wetland systems (Acreman & McCartney, 2009; Trenberth, 2005).

Local studies in Uganda, particularly within the Walukuba-Masese Wetland of Lake Victoria, are sparse in integrating these global and regional climate insights with assessments of human-induced impacts on ecosystem services. There is a pressing need for targeted research employing robust climate indices and comprehensive hydrological measurements to adequately inform management strategies for these critical wetland systems.

2.4.1 Anthropogenic Pressures on Urban Wetlands

Urbanization is a dominant driver of wetland degradation in Uganda, particularly in urban and peri- urban regions such as Kampala, Jinja, and the Walukuba-Maseese area on Lake Victoria. Rapid urban expansion results in habitat fragmentation, an increase in impervious surfaces, and concentrated loads of pollutants, ultimately disrupting vital ecosystem services (Cheeseman, 2025; Matovu et al., 2024).

Land use change analyses employing Landsat satellite imagery have quantified these transformations. For instance, detailed studies on the Nsooba-Lubigi wetland system reveal significant reductions in vegetation cover alongside substantial increases in built-up areas, underscoring the adverse impacts of agricultural intensification and urban sprawl on wetland integrity (Turyahabwe et al., 2013; Twesigye et al., 2025).

Pollution in these ecosystems stems from both point-source discharges such as industrial effluents and household sewage, and non-point-source contributions like agricultural runoff. These pollutant inputs elevate water quality parameters such as BOD, COD, and nutrient loads, thereby impairing functions like water purification and flood regulation (Matovu et al., 2024; Namaalwa et al., 2013)

Despite robust evidence of urbanization and its impacts on wetland dynamics, there remains a clear literature gap regarding the combined effects of climate variability and human activities on ecosystem services in the Walukuba-Maseese wetland. This study aims to bridge that gap through integrated spatial analysis and water quality assessments.

Urban wetlands in the Walukuba-Maseese area are critically impacted by human-induced pressures that compromise both their biodiversity and essential ecosystem services. An integrated evaluation of climate and anthropogenic factors is essential to advance sustainable management practices in this unique peri-urban context.

2.4.2 Socio-ecological systems: linking ecological degradation to livelihoods

Socio-ecological systems in the Lake Victoria basin illustrate a critical interdependence between ecosystem health and community livelihoods. A range of studies demonstrates that local communities, especially poorer segments, rely heavily on wetlands for fishing, agriculture, fuelwood, and other essential resources that underpin food security and income generation (Akwetaireho & Getzner, 2010). This dependency is evident in the extensive use of wetlands to supplement subsistence activities and generate cash income, thereby sustaining household economies (Turyahabwe, Kakuru, et al., 2013).

At the same time, intensified human activities and climate have led to noticeable ecological degradation. Declines in fish stocks, reduced water quality, and a loss of vegetation cover directly compromise the ability of these ecosystems to deliver vital services, consequently impairing agricultural productivity, nutritional security, and overall health (Akwany et al., 2022; Wood et al., 2013). Such degradation not only destabilizes traditional sources of income but also triggers broader socio-economic disruptions (Turyahabwe, Kakuru, et al., 2013).

Furthermore, the literature reveals that vulnerability is unevenly distributed across communities. Marginalized groups, including low-income households, older household heads, and women, are particularly susceptible because their limited adaptive capacity reduces resilience to environmental changes (van Dam et al., 2011). Degraded ecosystem services exacerbate existing inequalities, underscoring the need for integrated management strategies that bridge ecological preservation with poverty alleviation (Wood et al., 2013).

Wetland degradation undermines both environmental integrity and human livelihoods. Strengthened sustainable management and targeted policy interventions are essential to mitigate these intertwined challenges.

2.5. Governance and Institutional Support

Governance and institutional frameworks play a critical role in supporting the adaptive capacity of communities. National and local governments, along with international organisations, are instrumental in providing policies, funding, and technical assistance to enhance adaptation efforts. Wetlands are often protected under environmental laws or international agreements like the Ramsar Convention, which promotes the sustainable use and conservation of wetlands (GRIFFIN, 2012; Ulibarri et al., 2021).

However, the success of these policies depends mainly on how well they are implemented at the local level. Involving communities in decision-making processes leads to more effective adaptation strategies, as they are more likely to align with local needs and priorities. Conversely, Studies found that weak governance or poorly enforced regulations can exacerbate the vulnerabilities of these communities, making it harder for them to adapt to climate change and wetland degradation (Ampaire et al., 2017; Mfitumukiza et al., 2020).

2.6.Technological Innovations and Adaptation Strategies

Communities are increasingly utilising technological innovations to adapt to changes in wetland health. Remote sensing technologies and advanced water management systems have been employed to monitor wetland conditions and improve water use efficiency. Communities with access to these technologies are better equipped to anticipate changes in wetland ecosystems, allowing them to implement timely and effective adaptive strategies (Mkonda, 2022; Sigopi et al., 2024).

Furthermore, some communities have adopted nature-based solutions, such as wetland restoration and conservation practices, to enhance the resilience of wetlands to climate change. These efforts help to restore essential wetland functions, such as water filtration and carbon sequestration, which in turn improve the ecosystem's capacity to support biodiversity and mitigate climate impacts (Yimer et al., 2024). However, the success of these initiatives depends on adequate funding, technical expertise, and community engagement (Erku et al., 2023).

2.7. Social Networks and Community Resilience

Social networks and community cohesion are essential for building resilience to environmental changes. Communities with strong social networks are more likely to share resources, knowledge, and support during times of environmental stress (Jennings & Bamkole, 2019). These networks facilitate collective action, such as community-based wetland management projects and cooperative strategies to address the impacts of climate change (Hodge & McNally, 2000).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study area

The Walukuba-Masese wetland is located along the northeastern shores of Lake Victoria, Africa's largest freshwater lake, within Jinja District, Uganda (Figure 2). This urban wetland covers a significant portion of the low-lying areas between the urban settlement of Walukuba and the Masese area (Namisi & Kasiko, 2009). This wetland plays a crucial role in the Lake Victoria ecosystem, providing essential ecological services such as water purification, flood control, and carbon sequestration, which are critical for the surrounding communities and regional biodiversity (Kairu, 2001). The wetland spans a combination of urban and peri-urban zones, making it highly susceptible to both natural climate variability and human activities, including urban expansion, pollution, and agricultural encroachment (Nabihamba, 2019).

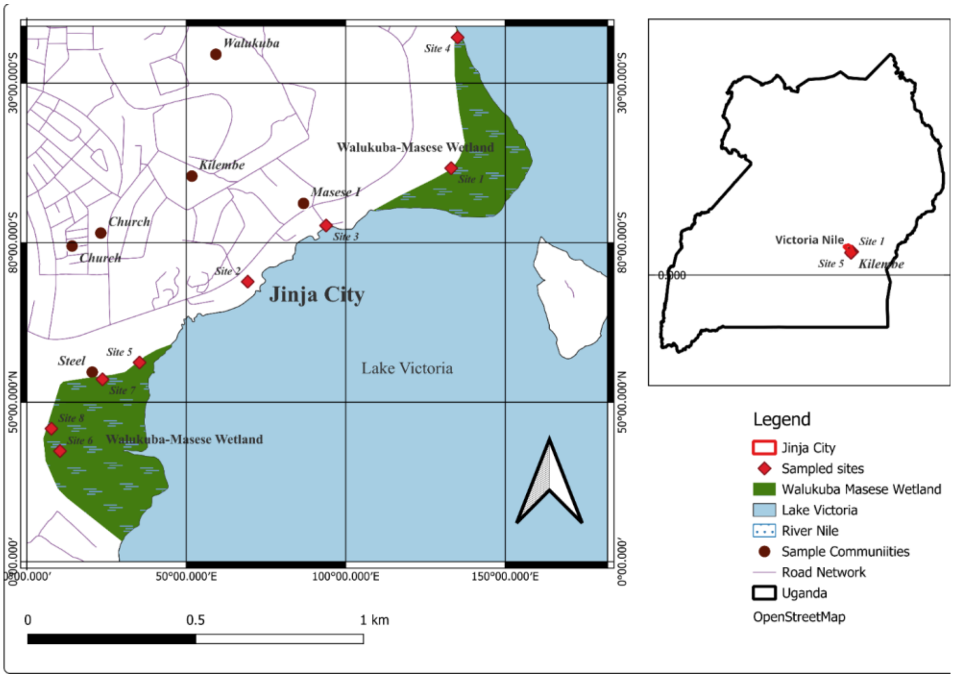

Figure 2: Location of the Masese-Walukuba wetland along Lake Victoria, Jinja, Uganda

3.1.1 Geographic and Climatic Context

Situated near the equator, the Walukuba-Masese Wetland experiences a tropical climate characterised by two primary rainy seasons: March to May and September to November (Nicholson, 2018). Lake Victoria, a large regional water body, exerts a moderating influence on the area's temperatures and raises humidity levels, creating a relatively stable microclimate in the wetland (Nyamweya et al., 2023b). Rainfall is typically abundant in the region; however, studies indicate increasing inconsistency in rainfall patterns in recent decades due to climate change, significantly affecting water levels, sedimentation rates, and the overall ecological health of the wetland (Anyah & Semazzi, 2004a; Asadullah et al., 2008; Awange et al., 2008; Nsubuga et al., 2014). This climate variability, combined with the wetland's ecological services, such as water purification, flood control, and carbon sequestration, underscores its importance to biodiversity and nearby communities (Mitsch & Gosselink, 2007a).

3.1.2 Hydrology and Water Dynamics

The Walukuba-Masese Wetland is part of the larger Lake Victoria Basin hydrological network, receiving both surface runoff and direct rainfall (Awange et al., 2008). Its position within this basin makes it an essential natural buffer for stormwater, as it filters pollutants and regulates water flow into Lake Victoria, contributing to water quality improvement for the ecosystem and surrounding communities (Olaka et al., 2019; Rowell et al., 2015; Vörösmarty et al., 2010). Furthermore, the wetland is likely instrumental in groundwater recharge, which helps sustain the local water table and provides a reliable water source during dry seasons (Cooper et al., 2015; Siegel, 1988). However, erratic rainfall patterns, coupled with urban encroachment, can disrupt these vital hydrological processes, leading to seasonal flooding and droughts that stress the ecosystem (Baig et al., 2024; Kamal et al., 2018; Kilavi et al., 2018).

3.1.3. Ecological Significance

Walukuba-Masese wetland is recognized as a biodiverse ecosystem, home to various plant species, birds, fish, and amphibians. Its vegetation primarily consists of papyrus (*Cyperus papyrus*) and Phragmites (reed beds), which are common in wetland habitats (Mitsch & Gosselink, 2007a). These wetland-adapted plants play a crucial role in filtering pollutants, storing carbon, and supporting a diverse array of wildlife. As shown in ecological surveys by Birdlife International (2018), migratory birds heavily rely on this habitat for both nesting and feeding.

However, the ecological health of the wetland is increasingly under strain due to a combination of natural and human-induced pressures. Ramsar Convention Secretariat (2013) highlights that these pressures are leading to habitat loss, declining biodiversity, and impaired ecosystem functioning in wetlands globally, which aligns with findings in Walukuba-Masese.

3.1.4. Socioeconomic Importance

The Walukuba-Masese wetland provides critical ecosystem services to local communities, including water purification, flood control, and resources such as fish, papyrus for thatching, and areas for small-scale agriculture. Wetlands are essential in maintaining water quality and providing livelihood resources to surrounding populations (Assessment (MEA), 2005b). The local population, particularly in Walukuba and Masese, relies heavily on the wetland for their livelihoods.

However, the increasing urbanization of Jinja has led to rising human pressure on the wetland. Informal settlements, land reclamation for agriculture, and industrial activities, particularly in the areas surrounding Walukuba and Masese, have intensified. According to UN-Habitat (2010), urban expansion often leads to land degradation and unsustainable land-use practices in and around wetlands, undermining their ecological functions. These human activities are directly impacting the wetland's ability to function effectively as a natural resource, a phenomenon widely observed in urbanising wetland regions.

3.2 Research Design

A mixed methods approach, involving longitudinal and cross-sectional designs, was employed to examine long-term trends in climate and anthropogenic activities, spatial and temporal changes in wetland’s ecosystem services using proxy indicators such vegetation cover, water quality, biodiversity levels and livelihoods, as well as the coping mechanisms employed by the users of the wetland. The longitudinal design involved analysing long-term rainfall and temperature data (climate variability) and satellite imagery from Landsat, used to map changes in land use (anthropogenic activities), including urban expansion, agricultural encroachment, and industrial activities, covering the period from 1984 to 2024 (Objective 1). The longitudinal design was also used to analyse temporal changes in wetland vegetation cover, which serves as one of the proxy indicators for assessing wetland ecosystem services, such as flood control and filtration (objective 2). The remaining proxy indicators of wetland ecosystem services, i.e., water quality and biodiversity levels, were assessed at a spatial scale using cross-sectional data collected through a single sampling event. The sampling sites 1-8 (Figure 1-1) were chosen based on the level of habitat degradation (see section 4.2). Adaptation strategies (Objective 4) were also evaluated using cross-sectional data collected through household surveys, which included semi-structured questionnaires, interviews, and focus group discussions.

3.3. Data Collection

Data collection was structured to address the four specific objectives of this study, employing a mixed-methods approach that integrated longitudinal and cross-sectional designs.

i. For Objective 1 (trends in climate & anthropogenic activities), longitudinal data on climate parameters and satellite imagery were used.
ii. For Objective 2 (spatial-temporal changes in ecosystem services), a combination of longitudinal satellite data (for wetland cover) and cross-sectional field surveys (for water quality, biodiversity, and livelihoods) was employed.
iii. For Objectives 3 & 4 (relationships), Data from Objectives 1 and 2 were integrated for statistical analysis.

The specific procedures for each data stream are detailed below.

3.3.1 Climate variability and anthropogenic activities

To address objective 1, data on temperature and rainfall (for assessing climate variability) and urban expansion, agricultural encroachment, and industrial activities (representing the extent of anthropogenic activities) were used. Data on rainfall and temperature spanning four decades (1984-2024) were obtained from the Global Climate Database (https://en.climate-data.org/africa/uganda/eastern-region-2584/). The Kimaka weather station was selected as the closest to the Walukuba-Masese wetland. Additionally, semi-structured interviews were conducted with local communities and environmental experts to gain qualitative insights into perceived changes in climate over the years. Data on the extent of anthropogenic activities, i.e., urban expansion, agricultural encroachment, and industrial activities, were obtained from satellite images, acquired at 10-year intervals since 1984 (i.e., 1984, 1994, 2004, 2014, and 2024). These images were obtained from Landsat and Sentinel using Google Earth.

3.3.2. Indicators of wetland ecosystem services

To address objective 2, three indicators were chosen to represent wetland ecosystem attributes, i.e., wetland vegetation cover (proxy for flood control), water quality (proxy for water purification), and floral diversity. The satellite images that were used to analyse the extent of anthropogenic activities in subsection 3.3.1 above were also used to analyse temporal changes in wetland vegetation cover. As recommended by Henrys & Jarvis (2019), a field survey was conducted to ground-truth the remote sensing data. GPS units were used to verify the satellite imagery data on-site, ensuring accuracy in the spatial analysis.

For water quality and floral diversity, a stratified sampling approach was employed using quadrat frames (Kent, 2012). Eight sites (Figure: 2) were chosen based on environmental features, such as proximity to urban areas, agricultural fields, inflow points (urban and agricultural runoff areas), mid-wetland zones, outflow points where water exits into Lake Victoria, residential runoff, biomass- processing residues, sediment inputs from sand extraction, mixed- industrial effluent zones (heavy- manufacturing discharges, engineered wastewater treatment outputs, and legacy tanning contaminants) (Table: 1). This method is recommended for capturing spatial heterogeneity in plant communities (McCune & Grace, 2002).

Within each of the eight pre-selected sites (Figure: 2), three distinct zones were identified based on visible moisture gradients and vegetation types: a permanently inundated zone, a seasonally flooded zone, and a riparian zone. A total of five 10m x 10m quadrats were randomly placed within each zone at each site, resulting in 15 quadrats per site and 120 quadrats across the entire wetland. This design was implemented to ensure adequate spatial coverage and to minimize sampling bias by capturing the unevenness within each site. In this context, "zones" represent sub-sections within the broader "sites."

Table 1: Sampling Sites and their habitat characteristics

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Site	Coordinates (Lat, Long)	Dominant Stressor	Rationale for Selection
1	0.441133, 33.249264	Domestic runoff & small-scale agriculture	Represents baseline urban–peri-urban influence; captures nutrient and pathogen inputs from residential sources.
2	0.435061, 33.238374	Charcoal assembly residues	Targets wood-processing by-products entering the wetland via surface flow; assesses organic loading and pH shifts.
3	0.438065, 33.242569	Sand extraction sediments	Evaluates sedimentation rates and turbidity impacts from aggregate mining; informs habitat smothering risk.
4	0.448128, 33.249607	Mixed industrial effluent	Situated between two metal- fabrication plants, measures heavy metals and toxicants under combined discharges.
5	0.430737, 33.232580	Manufacturing waste	Captures high-load discharges from large-scale manufacturing; critical for assessing acute contamination zones.
6	0.426001, 33.228321	Sewage treatment effluent	Assesses the efficacy of engineered wastewater treatment before re-entry into natural channels.
7	0.429836, 33.230596	Historical tannery pollutants	Evaluates persistent organic and inorganic residues (e.g., chromium) from decommissioned tannery operations.
8	0.432850, 33.235200	Agricultural runoff & encroachment	Characterizes the impact of direct conversion of wetland to crop land, focusing on nutrient loading (nitrates, phosphate)

Quadrats of standard sizes (10m x 10m for herbaceous areas and larger quadrats for woody vegetation) were randomly placed within each zone, in line with standard practices for vegetation surveys (Mueller-Dombois & Ellenberg, 1974). In each quadrat, plant species were identified, and their abundance and cover were recorded to capture species richness and vegetation composition across diverse sections of the wetland, following standard guides (Barbour et al., 1999).

For water quality, water samples were also collected from eight sites, strategically selected as shown in Figure 3-1 above. These samples were tested for pH, dissolved oxygen and associated parameters such as biological oxygen demand (BOD) and chemical oxygen demand (COD), conductivity, nutrient levels (Phosphorus, Nitrogen, nitrates and phosphates), Total Suspended Solids, Total Dissolved Solids, Total Coliforms, heavy metals, and other organic and inorganic pollutants (Fat, Oil & Grease) to assess water quality, following the established guidelines for aquatic ecosystems (Boyd, 2000; Wetzel, 2001). This strategy aimed to capture spatial variations, providing insights into pollution sources and the wetland's capacity for water filtration (Mitsch & Gosselink, 2007b).

Water sample collection followed a strict protocol to ensure integrity. Sampling was conducted between 8:00 AM and 11:00 AM over a one-week period in June 2024 to minimize diurnal variation. At each site, triplicate water samples were collected in pre-cleaned, sterile polyethylene bottles. For BOD analysis, samples were collected in dark, airtight BOD bottles. Samples for metal analysis were preserved with nitric acid to a $pH < 2$. All samples were immediately placed in a cooler at 4°C and transported to the laboratory within 6 hours of collection, following a documented chain of custody. Objective 3 relied on data collected under objectives 1 and 2.

The water quality analysis was conducted at the certified Makerere University Laboratory.

It is important to note that the data for water quality and floral biodiversity were collected through a single, comprehensive sampling event. This cross-sectional approach provides a detailed spatial assessment of conditions across the wetland but does not capture temporal changes within a given year. This study design choice was made due to resource constraints, and its limitation is explicitly acknowledged in the discussion of results.

3.4 Data Analysis

3.4.1 Climate variability and extent of anthropogenic activities

To assess the temporal inconsistency in climate, a Man-Kendall test (Kendall, 1975; Mann, 1945)was applied to the annual temperature and rainfall time series to determine the direction of the trend and whether the trend was statistically significant. Afterwards, annual temperature and rainfall data were grouped separately into five categories, representing the decadal periods since the 1980s. A Kruskal-Wallis rank sum test was performed to test the null hypothesis that there is no significant decadal variation in either temperature or rainfall. The dependent variable was temperature or rainfall, while the decadal period was set as the independent (categorical) variable with five levels (i.e., 1980s, 1990s, 2000s, 2010s, and 2020s). Where the test was significant, pairwise comparisons were performed using the Wilcoxon rank sum test, with continuity correction and p-values adjusted using the BH method. For rainfall, a standardised precipitation index (SPI), which provides a corrected measure of rainfall abundance and deficit, was used to characterise the extreme years (i.e., wet and dry years). The SPI was calculated as the standardised difference between total annual rainfall and the long-term average. The long-term average was set to represent the period from 1995 to 2024, corresponding to the last three decades, which is used for comparing climate anomalies (Ted, 2011).

To assess the extent of anthropogenic activities over time, a time series analysis of satellite images representing years from 1984 to 2024, at 10-year intervals, was conducted using classified satellite imagery in QGIS. The area covered by buildings and agricultural land was computed and presented in hectares.

3.3.2. Wetland ecosystem attributes (wetland vegetation cover, water quality, and floral diversity)

To assess temporal changes in wetland vegetation cover, the satellite data were processed using Normalised Difference Vegetation Index (NDVI) according to the formula:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

Where:

- *NIR = near-infrared reflectance values,*
- *RED = red band reflectance values.*

Changes were quantified across four major land cover categories: grassland, shrubs, forestry, and wetland, which revealed the extent of vegetation loss. The area covered under each of these vegetation types was also computed and presented in hectares.

To assess spatial differences in floral diversity, first, an ecological condition framework was developed for each site, evaluating riparian buffer quality, wetland vegetation status, agricultural encroachment, and pollution input. These variables were scored on a 0–1 scale, depending on the severity, i.e.,

- Riparian-buffer vegetation intactness (*RipCov*): 0 = none, 1 = highly degraded
- Wetland vegetation (*WetVeg*): 0 = none, 1 = intact native marsh/papyrus
- Agricultural/Other vegetation (*AgVeg*): 0 = none, 1 = intensive monocrop
- Waste pollution (*Waste*): 0 = none, 1 = high volume/toxic

These scores were then weighted using a site degradation index (SDI) for each site *i*, computed as $SDI_i = w_1(1-RipCov_i) + w_2(1\text{-}WetVeg_i) + w_3(Ag\ Veg_i) + w_4(Waste_i)$. This quantitative approach was complemented by qualitative notes and species composition data to provide a better understanding of environmental integrity. Afterwards, Shannon's Diversity Index (H), which is a combined measure of species richness and evenness, was calculated for each site according to the formula:

$$H = \sum_{i=1}^{n} p_i \cdot \ln p_i$$

Where:

$\boldsymbol{p_i} =$ Proportion of individuals belonging to species i,

These values were presented as absolute indices, given that single-event sampling was done at the site. A similar approach was used to present values of water quality parameters after laboratory analysis of water samples.

Relationship between climate and human activities and wetland ecosystem indicators

At a spatial scale, the relationship between the floral diversity index and the site degradation index (representing the extent of anthropogenic activities) was assessed using the Pearson correlation coefficient. At the temporal scale, the relationship between climate and selected wetland ecosystem indicators, was assessed using Principal Component Analysis. The same approach was used to assess the relationship between human activities on selected wetland attributes. A biplot was used to visualize the direction and relationships between land use/cover types (e.g., Grassland, Wetland, Forestry, agriculture, built-up environment), periods (e.g., 1990s, 2000s, 2010s, 2020s), rainfall (represented by median standardized index for each decade), and temperature in a reduced dimensional space (i.e., the first two principal components, PC1 and PC2).

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Long term trends in climate and anthropogenic activities

The temperature rose steadily from an average of 21.6 °C in 1984–1988 to 23.7 °C in 2019–2023. Trend analysis showed an almost perfect positive trend (tau = 0.99, $p < 0.05$), with a Sen's slope indicative of an annual increase by 0.05 °C. This confirms a robust warming trend (Y. Liu et al., 2021.). shows a gradual increase in temperature over the past five decades. The difference in median temperature between decadal periods was significant ($H_{(4)} = 38$, $p < 0.05$, n = 205), with a large effect size ($\varepsilon^2 = 0.17$). Pairwise comparisons further confirmed that each successive decade experienced statistically significant increases in minimum temperatures relative to the 1990s ($p < 0.05$).

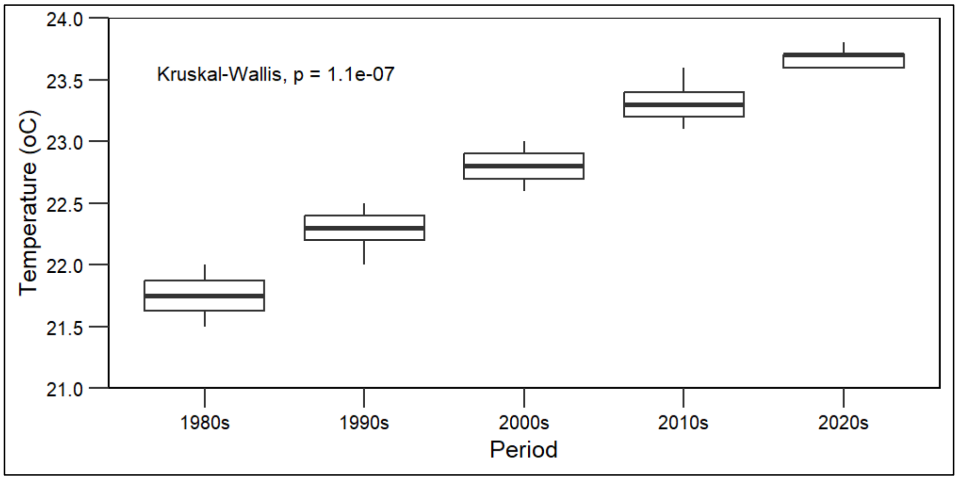

Figure 3: Decadal analysis of mean annual temperature near Walukuba-Masese wetland for the period 1984-2024

Rainfall varied between a minimum of 2,040 mm (1999–2003) and a maximum of 2,190 mm (2004–2008). A trend analysis revealed no apparent monotonic increase or decrease over the past 40 years (Mohorji et al., 2017). Although Kendall's Tau was positive (0.18), with a Sen's slope of +2.6 mm yr^{-1}, the trend was not statistically significant ($p = 0.11$).

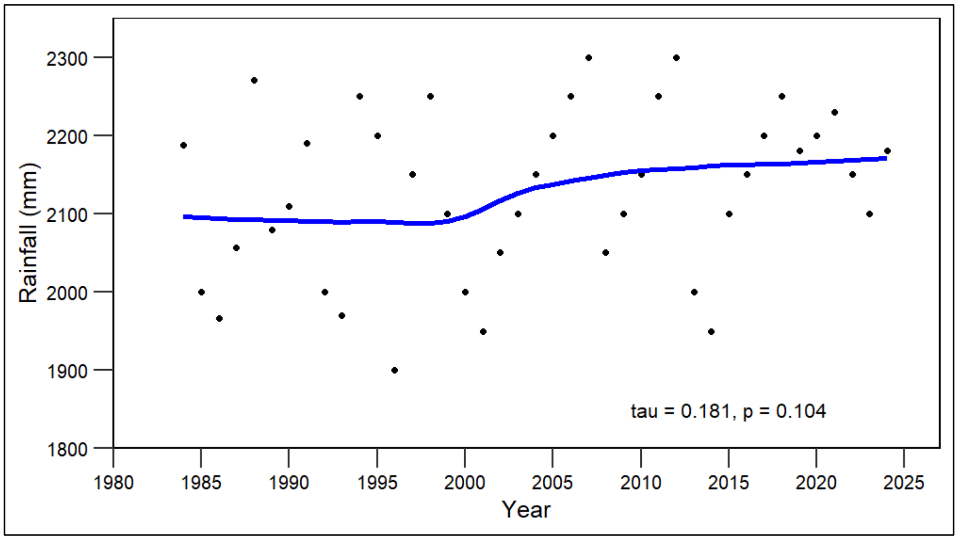

Figure 4: Annual rainfall around Walukuba-Masese wetlands for the period 1984-2024. The blue line shows the trend line fitted using the Kendal method (Kendall, 1975)

Both the statistics from trend analysis and the trend line suggest rainfall has fluctuated with a slight upward shift. This shift was confirmed from the decadal analysis (Qian et al., 2007)although the difference in median temperature between decadal periods was not significant ($H_{(4)}$ = 2.18, p > 0.05, n = 41)

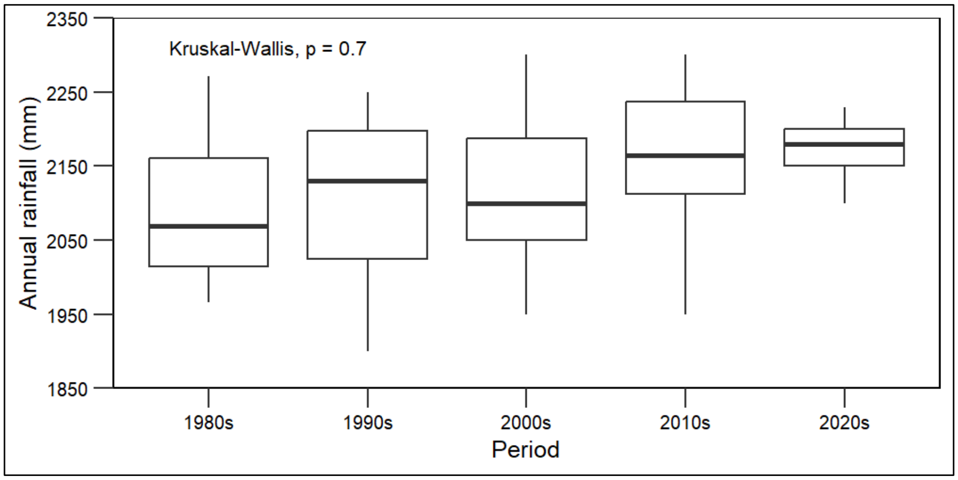

Figure 5: Decadal analysis of rainfall near Walukuba-Masese wetland for the period 1984-2024

The inter-annual variability in rainfall above was explored further using the standardised precipitation index, leading to a classification of years into extreme dry and wet years(Van Etten, 2009) Generally, the region experienced fluctuating annual rainfall, with no clear pattern. However, the years before 2004 were mostly dry, dominated by negative SPI values. Extreme anomalies were observed in 1986, 1996, 2001, and 2013, with SPI values below -1.5, indicating severe drought conditions. The last decade has generally been a wet period, with annual rainfall above the long-term average, except for 2023.

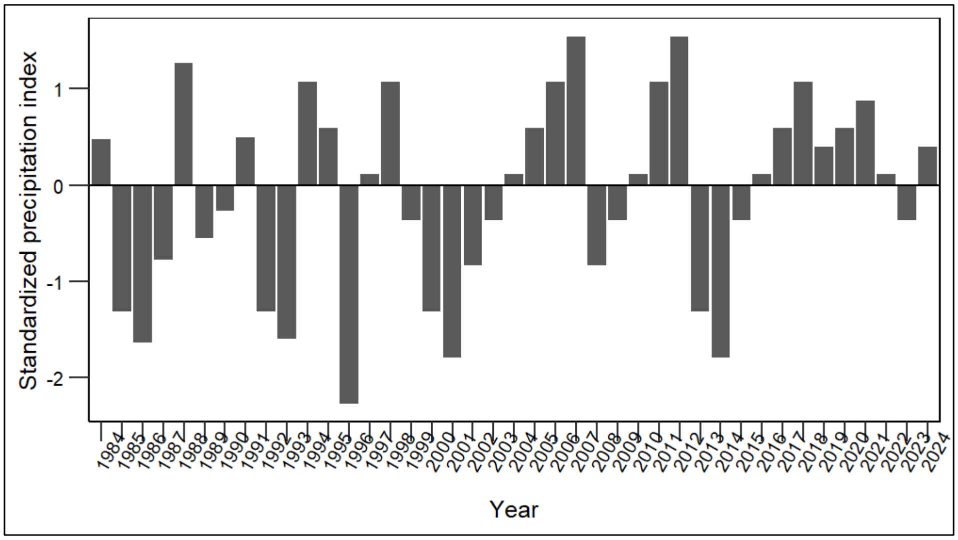

Figure 6: Standardised Precipitation index for Walukuba Masese Wetland (1984-2024).

Positive SPI values (bars above the zero line) indicate wetter-than-average years, while negative values (bars below the line) represent drier-than-average conditions. The height of each bar (regardless of the sign) indicated the magnitude of the deviation in annual rainfall from the long-term average.

4.2. Wetland ecosystem indicators (wetland vegetation cover, water quality, floral diversity)

There is a clear transition from natural to human-modified landscapes. Wetlands, once dominant, have receded steadily, replaced by urban structures and cultivated fields. The 2024 map reveals the fragmentation of wetland zones, the expansion of the lake overflow area, and the dominance of built environments around the periphery. These maps are consistent with a more than 50% reduction in wetland cover shown in Figure 7 below.

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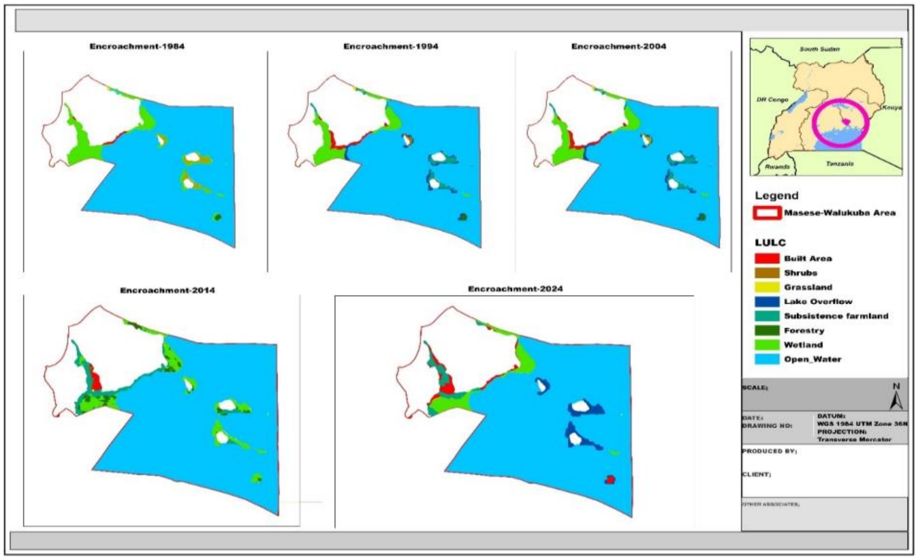

Figure 7: Land cover maps of the Walukuba–Masese wetland system (1984–2024)

The remaining proxy indicators of ecosystem services were assessed on a spatial scale. For habitat intactness, the results of the ecological condition framework, developed for each site to evaluate riparian buffer quality, wetland vegetation status, agricultural encroachment, and pollution input, are presented in Table 1. Sites 5 and 2 remained relatively intact, with riparian buffers and wetland vegetation, largely due to the presence of papyrus stands and mixed native trees. In contrast, Site 6 had degraded riparian buffers (0.1) and wetland vegetation (0.3), with invasive species like *Ricinus communis* and *water hyacinth* dominating. Moderate levels of agriculture were observed at all sites (0.3–0.6), with crops such as banana, cassava, and yams replacing native vegetation. These shifts likely contributed to altered hydrology and increased sedimentation, particularly at Site 2, located near a charcoal processing yard. Site 6 showed the highest pollution score (0.8), attributed to visible effluent discharge from a wastewater treatment facility. Site 5 also had significant plastic accumulation, further stressing aquatic habitats. These findings were supported by anecdotal evidence of fish kills and reduced insect diversity (field observations).

Table 1 also shows that plant species composition mirrored environmental degradation. Sites 5 and 3 harbored high densities of native species like papyrus (60–80) and sedges (70–75). In contrast, Sites 6 and 7 were increasingly dominated by invasive or disturbance-tolerant species, such as water hyacinth (*Eichhornia crassipes*), *Ricinus communis*, and paper mulberry (*Broussonetia papyrifera*). The presence of climbers and aquatic ferns was variable, indicating patchy habitat complexity.

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The data revealed a gradient of degradation, with Sites 5 and 3 reflecting semi-natural wetland conditions, while Sites 6 and 7 show marked anthropogenic alteration. The site degradation index (SDI) model, incorporating weighted vegetation and pollution metrics, further showed that vegetation loss and unmanaged waste are key drivers of wetland ecological decline in the Walukuba–Masese area. Site 6, for instance, had the highest SDI score (0.71), while sites 5 and 3 had the lower SDI values (0.305 and 0.370, respectively).

Table 2: Summary of the normalised environmental scores and associated observations.

Site	Riparian Cover	Wetland Vegetation	Agricultural Vegetation	Waste Pollution	Notes
5	0.7	0.8	0.5	0.3	Mixed tree row + papyrus, heavy plastics
2	0.3	0.8	0.5	0.2	Charcoal yard; some sedimentation
3	0.5	0.7	0.6	0.1	Transport hub, some invasive water hyacinth
4	0.2	0.7	0.4	0.1	Factory- built, minor papyrus remnants
7	0.4	0.2	0.3	0.1	Eucalyptus buffer; wetland cleared
6	0.1	0.3	0.4	0.8	Wastewater treatment; effluent present

To quantitatively assess the gradient of anthropogenic disturbance across the study sites, the Site Degradation Index (SDI) was calculated, as detailed in the methodology. The index components, their assigned weights, and the field-based observational justifications for these weights are presented below.

Table 3: Components, assigned weights, and field-based justifications for the Site Degradation Index (SDI) calculation.

Component	Weight	Observational Justification
Riparian-buffer Vegetation	0.25	Field observations at Walukuba-Masese showed that intact tree and shrub buffers (e.g., Eucalyptus, Albizia, pine) markedly reduced bank erosion, shaded aquatic habitats, and filtered upland runoff before it entered the wetland.
Wetland Vegetation	0.35	The transects revealed that the loss of native sedges, papyrus, and marsh plants directly corresponds with declines in both aquatic invertebrates and bird use.
Agricultural/Other Vegetation	0.20	Field surveys showed that conversion to annual crops (banana, yams, and cassava) alters inundation regimes and compacted soils.
Waste Inputs	0.20	Direct observations of plastic litter and effluent plumes at Sites 5 and 6 coincided with lower aquatic- insect diversity and fish kills.

The floral composition data presented in Table 1 reveals a clear gradient of ecological degradation across the primary assessment sites (Sites 2-7), directly supporting the SDI scores. It is important to note that Sites 1 and 8 were predominantly lacustrine, characterized by open water and submerged conditions**.** The automated quadrat sampling protocol, optimized for emergent and riparian vegetation, was technically unsuitable for these permanently inundated zones. Consequently, the data extraction for these specific sites was omitted from the floral composition analysis to prevent methodological inconsistency, with the focus retained on the terrestrial-to-wetland transition zones where the core vegetation dynamics occurred.

The data from the six sites presented show a marked decline in native, wetland-adapted species (e.g., Papyrus, Sedges) from the less degraded Sites 5 and 3 to the highly degraded Sites 6 and 7.

Conversely, the abundance of invasive and disturbance-tolerant species (e.g., Water hyacinth, *Ricinus communis*) increases along the same gradient. This inverse relationship between native and invasive species dominance provides a clear biological validation of the SDI, demonstrating that increasing anthropogenic pressure directly shifts plant community structure towards a less diverse, more disturbance-adapted state.

Table 4: Absolute species counts for key floral species across the six terrestrial and riparian assessment sites (Sites 2-7).

Species	Site 5	Site 2	Site 3	Site 4	Site 7	Site 6
Papyrus	60	50	80	45	30	20
Sedges	70	65	75	60	40	35
Water hyacinth	15	20	10	18	25	30
Water Fern	10	15	20	8	5	3
***Paspalum* spp.**	25	30	15	10	8	5
Ricinus communis	30	25	20	15	10	30
Paper mulberry	20	0	25	30	15	5
Climbers	35	20	40	25	10	8

Regarding floral diversity, Shannon diversity values ranged from 1.792 to 1.906 (Table 5). Site 6, which had the highest SDI score (0.71), showed the lowest diversity and evidence of intensive human disturbance. In contrast, Sites 5 and 3, with lower SDI values (0.305 and 0.370, respectively), maintained higher diversity and more intact ecological structure. The data support the hypothesis that habitat quality has a strong influence on biodiversity. Sites with lower degradation scores retained more complex and diverse vegetation assemblages. In contrast, highly degraded sites (e.g., Site 6) exhibited both reduced native cover and elevated dominance by invasive or disturbance-tolerant species.

Table 5: Species richness, Shannon diversity index (H′), and Site Degradation Index (SDI) for wetland assessment sites

Site	Shannon Diversity (H′)	SDI
Site 5	1.906	0.305
Site 2	1.817	0.385
Site 3	1.842	0.37
Site 4	1.884	0.405
Site 7	1.876	0.51
Site 6	1.792	0.71

The results from water quality sampling are presented in Table 6. The findings are presented alongside the NEMA effluent discharge Regulation (S.I. No 5/1999). Most parameters were within acceptable limits, indicating generally moderate to good water quality. However, several exceptions signal potential ecological stress. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) exceeded standard limits at most sites. For instance, BOD peaked at 80 mg/L and COD reached 130 mg/L, well above the thresholds of 50 mg/L and 100 mg/L, respectively, suggesting high organic pollution, likely from wastewater or agricultural runoff. Fat, oil, and grease concentrations surpassed the 10 mg/L limit at Site 7, indicating localised industrial or domestic discharges. Total coliforms exceeded the 10,000 CFU/100 mL standard at Sites 6 and 7, indicating faecal contamination and a public health risk. Other key indicators, including pH, nitrates, total nitrogen, fluoride, and conductivity, remained within permissible levels across all sites. Unexpectedly, all heavy metals tested (lead, cadmium, chromium) were undetectable or present at trace levels well below national thresholds. The water quality data reveal spatial variability, with elevated pollution at Sites 6 and 7, which is likely due to their proximity to urban discharge points.

Table 6: Water quality parameters for surveyed sites compared with The NEMA Effluent discharge regulations (S.I. No 5/1999).

Parameter	**Unit**	**Surveyed Site**							**S.I. No 5/1999**
		1	**2**	**3**	**4**	**5**	**6**	**7**	
BOD$_5$	mg/l	18.0	16.0	20.0	26.0	22.0	4	80.0	50 mg/1
Cadmium	mg/l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1 mg/1
Chlorides (Cl^-)	mg/l	250	250	30.0	40.0	35.0	30.0	40.0	500 mg/11
Chromium	mg/l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0 mg/1
COD	mg/l	26.0	30.0	42.0	44.0	48.0	120	130.0	100
Conductivity	µS/cm	420.0	404.0	425.0	398.0	418	405.0	543.0	1500
Fat, Oil & Grease	mg/l	4	3	2	2	4	6	12	10 mg/1
Fluoride (F^-)	mg/l	0.19	0.50	0.57	0.54	0.30	0.35	0.39	1.5
Lead	mg/l	0.05	0.07	0.05	0.06	0.0	0.04	0.07	0.1 mg/1
Nitrates (NO_3^-)	mg/l	22.0	20.0	24.0	32.0	30	26	30.0	20 mg/l
pH	-	7.30	7.10	7.23	7.15	7.23	7.18	7.15	6.0–8.0
Total Phosphorus	mg/l	2.40	2.39	2.47	1.98	1.74	1.0	2.20	5.0
Residual Chlorine	mg/l	0	0	0	0	0	0	0	N/S
Sulphates (SO_4^{2-})	mg/l	22.0	20.0	22.0	26.0	28.0	22.0	28.0	500 mg/1
Total Coliforms	CFU/100 ml	8000	5000	8000	6000	8000	12000	13000	10,000
Total Dissolved Solids	mg/l	314.0	309.0	340.0	320.0	329.0	364	420.0	1200 mg/1
Total Nitrogen	mg/l	5.80	5.50	5.70	5.30	5.564	4.20	4.80	10 mg/1
Total Suspended Solids	mg/l	22	12	23	28	24	34	40	100 mg/1

4.3. Relationship between climate variability, anthropogenic activities and wetland ecosystem indicators

At the spatial scale, diversity decreased with an increase in the site degradation index. The correlation between diversity and site degradation index was moderately strong and negative, but not significant ($r = -0.646$, $p > 0.05$). At a temporal scale, a significant negative correlation was observed between climate parameters (temperature and rainfall) and anthropogenic activities (built-up area and agriculture), as well as ecosystem service indicators (wetland vegetation cover) (Figure 8). Exceptions were grassland and forestry, where correlation with most climate parameters and anthropogenic activities was not significant.

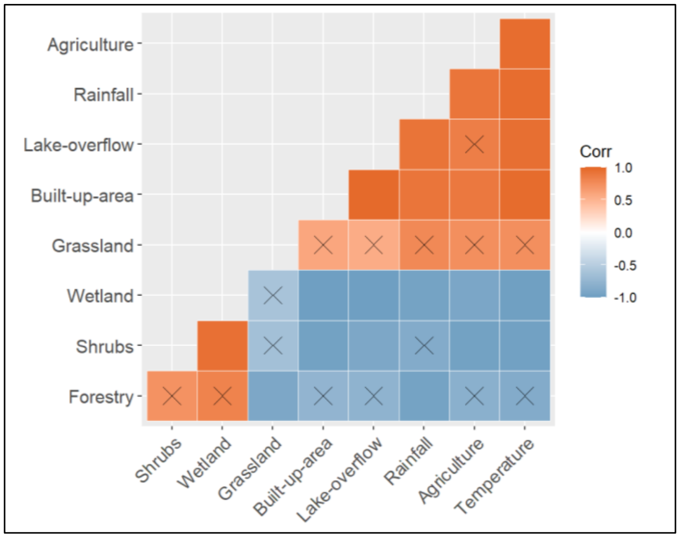

Figure 8: Multiple correlation plot between climate parameters (temperature and rainfall) and anthropogenic activities (built-up area and agriculture) and ecosystem service indicators (wetland vegetation cover).

Boxes marked with X mean that the correlation is not significantly different from zero.

Further on temporal analysis of the relationship between climate variability and anthropogenic activities and wetland ecosystem indicators, results of the Principal Component Analysis indicate a long-term shift from forested/wetland-dominated landscapes toward agricultural and built-up environment (Figure 7. For instance, wetland cover points left-up (negative PC1, slightly positive

PC2), correlating with the 1990s, indicating wetlands were more prominent earlier and have declined over time. Anthropogenic activities (agriculture and built-up environment) align with the 2010s-2020s, with arrows pointing directly opposite wetland cover, reflecting significant reduction in land cover during the recent decades with increasing anthropogenic activities. Rainfall and temperature also align with the recent decades, alongside anthropogenic activities, implying a strong negative relationship with wetland vegetation cover over time. Interestingly, climate variables (temperature and rainfall) are aligned with lake overflow (Figure 7), coinciding with high rainfall in the recent years. In absolute terms, the total area covered by lake overflow over time matches with the combined area under agriculture and built-up environment, except in 2004 where the latter was higher (see Figure 4-5), suggesting that both climate variability and anthropogenic activities have affected wetland vegetation cover.

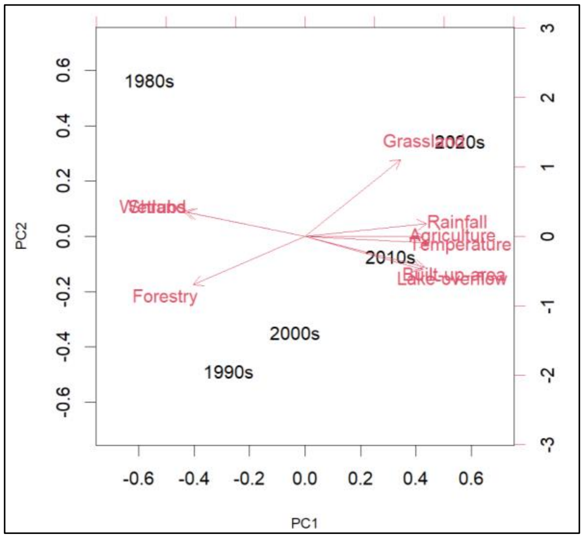

Figure 9: Biplot from principal component analysis (PCA) involving climate parameters (temperature and rainfall), anthropogenic activities (built-up area and agriculture), and ecosystem service indicators (wetland vegetation cover) over four decades

4.4. Relationship between Anthropogenic Activities and Wetland Ecosystem Indicators

Regarding the extent of anthropogenic activities, built-up areas expanded from 11.3 ha in 1984 to 57.4 ha in 2024, while agricultural land increased from 7.3 ha to 51.4 ha (Figure 8). Conversely, wetland coverage declined sharply from 264.7 ha to 128.2 ha. Shrubland and forestry areas also declined significantly, indicating a loss of vegetation.

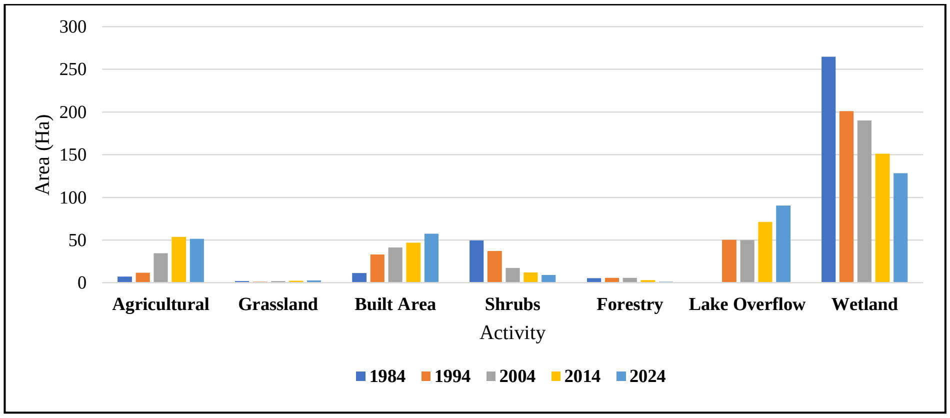

Figure 10: Clustered bar graph of land cover distribution in the Walukuba–Masese wetland system (1984–2024)

The multiple correlation analysis (Figure 8) showed significant negative correlations between anthropogenic land cover types (Built-up, Agriculture) and the wetland vegetation cover indicator. The PCA biplot (Figure 9) further illustrated this relationship, with the vectors for 'Built-up' and 'Agriculture' pointing in the direct opposite direction to the 'Wetland' vector and being strongly associated with the recent decades (2010s, 2020s).

Spatially, the correlation between the Site Degradation Index (SDI) and Shannon's Diversity Index (H′) was negative and moderately strong (r = - 0.646), indicating that sites with higher anthropogenic degradation (e.g., Site 6, SDI=0.71) supported lower floral diversity (H′=1.792) compared to less degraded sites (e.g., Site 5, SDI=0.305, H′=1.906) (Table 5). The impact of anthropogenic activities was also evident in water quality. As shown in Table 6, sites receiving significant anthropogenic inputs (notably Sites 6 and 7) exhibited the most severe degradation, with BOD, COD, and total coliform levels far exceeding national standard

4.5. DISCUSSION

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4.5.1. Impacts of observed rainfall and temperature shifts on wetland services

The mean annual temperature rose from 21.6 °C (1984–1988) to 23.7 °C (2019–2023). This warming rate (~0.05 °C yr^{-1}) is consistent with observations across the Lake Victoria basin, where surface air temperatures have increased by 0.2–0.3 °C per decade under recent climate regimes (Anyah & Semazzi, 2004b; Olaka et al., 2019).

Rising temperatures accelerate potential evapotranspiration (PET), as shown in global assessments under 1.5 °C warming scenarios, which project PET increases of up to 20%, depending on the estimation method (Bhardwaj et al., 2025; Nguvava & Abiodun, 2023; Proutsos et al., 2021; Tam et al., 2024). In wetland contexts, enhanced PET translates into reduced water residence times and lowered water tables. For example, DRAINMOD modelling at a North Carolina wetland predicts a 20% rise in evapotranspiration, leading to measurable wetland area contraction and downslope shifts in hydrologic boundaries under future warming (Moursi et al., 2022).

Furthermore, sustained temperature increase can deplete shallow groundwater storage, altering recharge–runoff partitioning and weakening hydrological resilience (Briggs et al., 2025; Zhu et al., 2020). In Walukuba–Masese, such processes likely exacerbate seasonal water deficits even without a marked decline in rainfall, undermining both aquatic habitat stability and ecosystem services such as water filtration.

The five-year mean rainfall (supplementary to the decadal analysis) displays moderate inter-period variability, peaking at 2,190 mm (2004 –2008), dipping to 2,040 mm (1999–2003), and then rising to ~2,130 mm (2019–2023) but lacks a clear monotonic trend. The Mann–Kendall analysis revealed a weak, non-significant upward trend. Regional studies, on the other hand, have shown statistically significant long-term rainfall trends over the Lake Victoria catchment, with notable year-to-year fluctuations (Tungaraza, 2012; Kisembe et al., 2019; Kiwanuka-Tondo et al., 2019; Moyers et al., 2023). However, climate projections under moderate emission scenarios (RCP 4.5) anticipate increased rainfall variability and intensity by mid-century, up to a 5% rise in annual totals, but enhanced extremes (da Rocha et al., 2014; Dallan et al., 2025; Hassan et al., 2023; Kundzewicz et al., 2010; Li et al., 2020).

Such rainfall variability particularly the prevalence of intense, short-duration events can elevate surface runoff at the expense of groundwater recharge, destabilizing wetland hydroperiods (Cook et al., 2022; Geris et al., 2022; Jumbi et al., 2024; Shagega et al., 2024). Extreme precipitation events during 2019–2020, the highest in three decades, triggered a 1.21 m surge in Lake Victoria levels and widespread flooding, illustrating the system's vulnerability to variability even when long-term trends are muted (Nyamweya et al., 2023c).

4.5.2 Implications for wetland hydrology and ecosystem services

The combination of significant warming and fluctuating rainfall absent a compensatory increase in annual precipitation poses multifaceted stress on wetland function. Accelerated evapotranspiration and lowered water tables diminish flood attenuation capacity and water-filtration efficiency (Ferreira et al., 2023b; Srivastava et al., 2023; Sun et al., 2024). They also shift plant community composition toward drought-tolerant species, thereby reducing habitat niche availability and carbon sequestration potential (Fry et al., 2021; Fuchslueger et al., 2014; Griffin-Nolan et al., 2019; Oram et al., 2025; Weiskopf et al., 2020).

In Walukuba–Masese, these hydrological shifts likely underlie the periodic die-off of hydrophilic vegetation and fish kills associated with abrupt turbidity and oxygen drops (Table:6). Thus, Objective 1's findings not only confirm regional climate trends but also foreshadow tangible declines in wetland ecosystem services central to local livelihoods.

4.5.3. Land use and land cover change in the Walukuba–Masese wetland system

Figure 4-5 shows built-up areas expanding from 11.3 ha in 1984 to 57.4 ha in 2024, mirroring rapid urban expansion observed elsewhere (Hailu et al., 2024). Agricultural land in Walukuba–Masese increased from 7.3 ha to 51.4 ha over the same period, consistent with findings that cropland adjacent to wetlands often doubles in size over three decades, intensifying nutrient and sediment runoff into wetland basins. Conversely, wetland extent halved from 264.7 ha to 128.2 ha reflecting the 75.7 % wetland loss documented around some rapidly growing cities, where urban and agricultural encroachment drove a 1,618-ha decline in three and a half decades (Assefa et al., 2021).

Spatial maps in Figure 4-6 reveal fragmentation of once-contiguous marsh blocks into isolated patches, a pattern paralleled by cellular-automaton models predicting wetland fragmentation under unplanned urban growth in the Vetch area of the Netherlands (Tendurus et al., 2013). Shrubland and forestry cover also contracted significantly, echoing global urban-wetland studies where impervious surfaces replace riparian vegetation, reducing infiltration and exacerbating surface runoff (Bitew & Kebede, 2024; Dharma et al., 2024; Dosskey et al., 2010; Olokeogun et al., 2020). Lake Overflow zones expanded into retreating marshes, indicating hydrological shifts that align with reports of altered flood regimes in urbanising wetland catchments (Wang et al., 2022; Yager et al., 2024).

4.5.4 Implications for ecosystem services and communities

The >50 % loss in wetland area undermines natural flood buffering by shortening water residence times, as built environments inhibit groundwater recharge and accelerate runoff, mechanisms shown to increase flood peaks by up to 20 % in similarly urbanised wetlands (Z. Li et al., 2022; Rojas et al., 2022). Fragmentation further isolates habitat patches, diminishing connectivity essential for species dispersal and genetic exchange; studies report that fragmented wetlands support up to 40 % fewer amphibian and bird species than contiguous systems (Athukorala et al., 2021; Bai et al., 2019; Zhang et al., 2023).

Shrinking shrub and forestry zones erode riparian buffer functions, reducing interception of sediments and nutrients by an estimated 75 % where vegetation is removed, leading to water-quality degradation documented in urban wetlands of Hangzhou and Bogotá (Garzón, 2025; Zhang et al., 2023). Agricultural expansion aggravates this by contributing diffuse nutrient loads; the U.S. CEAP study found that cropland runoff remains the leading cause of wetland nutrient pollution despite buffer best practices, a dynamic likely mirrored in Walukuba–Masese (Everard, 2016; Namaalwa et al., 2020; Raisin, 1996; Verhoeven et al., 2006).

Socio-economically, wetland contraction restricts access to fish, papyrus, and grazing resources, driving households toward alternative land uses and reinforcing the cycle of habitat loss. Global assessments of urban wetland loss link these ecological shifts to declines in local livelihoods and increased vulnerability to climate extremes (Julien et al., 2023). Thus, integrating land-use planning with participatory wetland restoration and the establishment of protective buffer zones is critical to maintaining ecosystem services, preserving biodiversity, and sustaining community well-being in the Walukuba–Masese region.

4.5.5. Impact of wetland cover change on water quality, species diversity

The water-quality survey (Table 4.3) revealed that BOD values reached 80 mg/L and COD up to 130 mg/L far exceeding the NEMA effluent discharge regulations into water or on land (S.I. No 5/1999) of 50 mg/L and 100 mg/L, respectively indicating heavy organic matter loading from wastewater effluent and agricultural runoff (Aragão et al., 2022; Fikri et al., 2023; Koch et al., 2023). These results suggest inefficient wastewater treatment by industries in the Walukuba area. Elevated BOD and COD deplete dissolved oxygen, impairing aquatic life and self-purification processes, as documented in urban wetland systems in Brazil and Poland, where untreated effluents generate similar spikes in oxygen-demand parameters (Ilyas & Masih, 2017; H. Liu et al., 2016; Saeed & Sun, 2012). The near-neutral pH at all the sampling sites indicates the high buffer capacity of the wetland (Hadad et al., 2018).

Fat, oil, and grease concentrations at Site 7 (12 mg/L) and total coliform counts above 10,000 CFU/100 mL at Sites 6–7 signal localised municipal discharges, that are loaded with faecal contamination, posing public health risks consistent with patterns observed in subtropical urban wetlands impacted by sewage inflows (Bamdadi et al., 2024; Marzec et al., 2024). Conversely, heavy metals (lead, cadmium, chromium) remained below detection limits, underscoring that organic and microbial pollutants are the principal stressors under current land-use changes (Siwiec et al., 2023).

The environmental assessment (Table 4.4) reveals a degradation gradient: Sites 5 and 2 retain robust riparian (0.7– 0.3) and wetland vegetation (0.8 each), whereas Site 6 exhibits minimal buffer cover (0.1) and high waste pollution (0.8). Riparian buffers effectively intercept sediments, nutrients, and microbial contaminants, removing up to 85 % of particulate phosphorus and reducing bacteria loads when intact benefits are markedly lost in degraded zones (Aragaw, 2021; Fortier et al., 2010; Granitto et al., 2025; Hoffmann et al., 2009; Zhou et al., 2022).

Biodiversity metrics indicate uniform species richness, but declining Shannon diversity (H′ from 1.906 at Site 5 to 1.792 at Site 6), confirming that habitat degradation reduces evenness and promotes dominance by disturbance-tolerant species an inverse relationship widely reported in freshwater wetlands under anthropogenic pressure (Bamford et al., 2017; Paz et al., 2022; Raimundo Lopes et al., 2022; Sileshi et al., 2020).

4.5,6. Ecological and socio-economic implications

The pronounced organic and microbial contamination in Sites 6–7 compromises the wetland’s natural filtration and oxygen dynamics. Without restoration of riparian buffers or implementation of constructed-wetland bioremediation, dissolved-oxygen depletion will likely intensify fish kills and loss of invertebrate biodiversity, undermining core ecosystem services such as fisheries and water purification (Davis et al., 2025; Meli et al., 2014)

Restoring multi-zone riparian buffers incorporating grasses, shrubs, and trees can intercept up to 90 % of non-point pollutants and re-establish habitat complexity, as demonstrated in North American and European studies of buffer effectiveness (Little et al., 2015; Meli et al., 2014; Wu et al., 2023). In the Walukuba–Masese context, targeted re-vegetation along Sites 6 and 7 could reduce BOD/COD loads and strengthen hydrological connectivity.

Biodiversity losses at high-SDI sites highlight the need for invasive-species control (e.g., water hyacinth, Ricinus communis). Active removal and reintroduction of native papyrus and sedge stands have been shown to restore Shannon diversity by over 20 % in degraded wetlands, thereby enhancing resilience and carbon sequestration functions (Kansiime et al., 2007; Mganga et al., 2019).

Socio-economically, diminished fish yields and crop losses erode household incomes, compelling greater reliance on external finance and information networks for adaptation. Integrating microfinance schemes, extension services, and platforms for sharing traditional ecological knowledge can bolster both ecological restoration and community livelihoods an approach validated by Ramsar and community-based adaptation programs in Asia and Africa (Barman et al., 2025).

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The analysis of 40 years of meteorological data showed no statistically significant trend in annual rainfall, indicating that precipitation totals have fluctuated within historical bounds. In contrast, mean annual temperature increased by approximately 0.05 °C yr^{-1} ($p < 0.001$), amounting to a ~2 °C rise since 1984. This pronounced warming absent a compensatory increase in rainfall likely accelerates evapotranspiration and reduces water residence time in the wetland, undermining its capacity for flood attenuation and water filtration. Thus, while precipitation variability alone may not currently pose a threat to wetland water availability, the apparent warming trend constitutes a critical stressor on wetland hydrology and function.

Land-cover classification of satellite imagery for five time points (1984, 1994, 2004, 2014, and 2024) revealed a dramatic shift from natural to human-modified landscapes. Built-up area expanded from 11.3 ha to 57.4 ha, and agricultural land from 7.3 ha to 51.4 ha, while wetland area declined from 264.7 ha to 128.2 ha, a >50% loss. This transformation correlates with both urban sprawl around Jinja and increased demand for farmland. The fragmentation and reduction of wetland cover compromise critical habitat, disrupt hydrological connectivity, and magnify the effects of rising temperatures, confirming that anthropogenic land-cover change is the primary driver of wetland loss in this system.

Wetland degradation has eroded multiple ecosystem services. Water samples from seven sites revealed excessive BOD and COD levels up to 80 mg/L and 130 mg/L, respectively indicating high organic matter pollution. Additionally, total coliforms exceeded safe limits at key discharge points. Ecological surveys demonstrated that lower-income heavily impacted sites (e.g., Site 6) had elevated Site Degradation Index ($SDI = 0.71$) and lower Shannon diversity ($H' = 1.79$), whereas less disturbed sites maintained higher diversity ($H' = 1.91$, $SDI = 0.31$).

5.2. Recommendations

Based on the specific empirical findings of this study, the following targeted recommendations are proposed to mitigate the identified degradation pathways in the Walukuba Masese wetland.

Integrate projected PET increases into wetland hydrological models to delineate and protect Climate Refugia zones, areas with higher groundwater connectivity that are more resilient to atmospheric drying, from any further anthropogenic alteration.

Implement distributed, small scale green infrastructure (e.g., retention ponds, swales) in the upland catchment to increase time of concentration, promote infiltration, and dampen the peak flow pulses that contribute to wetland scouring and lake overflow expansion.

Legislate and enforce an ecologically derived wetland boundary setback based on historical hydrologic data, prohibiting any further land conversion for agriculture or construction within this legally demarcated zone.

Adopt the SDI as a primary tool for spatial prioritization, directing intensive restoration resources (e.g., riparian replanting, pollution control) to high-SDI sites (>0.6) while enacting protective policies for low-SDI sites to maintain their high ecological function.

Biodiversity centered restoration program at high SDI sites, focusing first on the mechanical removal of invasive species (*Eichhornia crassipes*, *Ricinus communis*) followed by active re-establishment of native foundational species (*Cyperus papyrus*, sedges) to rebuild habitat complexity.

Mandate at source industrial and municipal pre treatment for organic and nutrient loads and construct targeted constructed wetland bioreactors at the inflow points of Sites 6 and 7 to augment the degraded ecosystem's natural filtration capacity.

Develop an integrated climate land use planning framework that mandates climate impact assessments for any new development project in the wetland catchment, evaluating its combined impact on both local hydrology and regional climate resilience.

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APPENDICES

Appendix 1: Data Collection Sheet used in Environment Assessment

FIELD DATA COLLECTION SHEET

PROJECT: **Impact of Climate Variability and Anthropogenic Activities on Urban Wetland Ecosystems**

STUDY AREA: Walukuba-Masese Wetland, **Lake Victoria**

Date: DD/MM/YY	**Time:** H/M	**Field Agent Name:**	**Weather Conditions:**

GPS Location Data

Site	**Coordinates** (Latitude/Longitude)	**Land Use / Activity Observed**	**Notes**

VEGETATION DATA (Quadrat Sampling)

Quadrat No.	**Species Name**	**Abundance**	**Cover (%)**	**Notes (e.g., Condition, Invasive species, etc.)**
1				
2				

WATER QUALITY DATA

Sample Point	pH	Dissolved Oxygen (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)	Other Pollutants/Observations
Inflow					
Mid-Wetland					
Outflow					

DIRECT OBSERVATIONS & NOTES

Observation Type (Vegetation Loss, Pollution, Erosion, etc.)	Location (Coordinates or Description)	Description of Observation

PHOTOGRAPHIC EVIDENCE

Photo No.	Location	Description (What is captured in the photo)

Appendix 2: Questionnaire used in the socio-economic survey

QUALITATIVE INTERVIEW DATA

PROJECT: **Impact of Climate Variability and Anthropogenic Activities on Urban Wetland Ecosystems**

STUDY AREA: Walukuba-Masese Wetland, **Lake Victoria**

Date:	**Time:**	**Field Agent Name:**	**Village:**

This questionnaire is intended to provide an overview of both individual and community-level adaptation strategies, as well as the determinants that influence these adaptive behaviors. The responses will be used to identify strengths, gaps, and areas for policy intervention to support sustainable wetland management in the Walukuba-Masese system.

INTERVIEWEE NAME	**ROLE (local resident, fisher, environmental expert, etc.)**	**OBSERVATIONS/COMMENTS ON WETLAND CONDITION**

The questionnaire is structured into several thematic sections. For each statement, please indicate your level of agreement using the following scale:

1 – **Strongly Disagree** 2 – **Disagree** 3 – **Neutral** 4 – **Agree** 5 – **Strongly Agree**

DEMOGRAPHIC INFORMATION

Variable	**Response Options**				
Age	(in years)				
Gender	Male		Female		
Education Level	None	Primary	Secondary	Tertiary	Postgraduate
Occupation					

Daily Income	< 10,000	10,000–30,000	30,000–50,000	> 50,000
Years of Experience with Wetland Use	(in years)			

SECTION I: SOCIO-ECONOMIC CONTEXT

Q No.	Statement	Response (1-5)
1	I am satisfied with my current income level derived from wetland-related activities.	
2	I have access to sufficient financial resources to invest in adaptation measures.	
3	My level of education has adequately prepared me to understand environmental challenges.	
4	I believe that my socio-economic status influences my ability to adapt to environmental changes.	

SECTION II: PERCEPTIONS OF ENVIRONMENTAL CHANGE

Q No.	STATEMENT	Response (1-5)
5	I am aware of significant changes in the wetland ecosystem over the past decade.	
6	I perceive that the frequency of extreme weather events (e.g., floods, droughts) has increased.	
7	I believe that changes in the wetland have directly impacted my livelihood.	
8	I feel confident in my understanding of the causes of environmental changes in the wetland.	

SECTION III: ADAPTATION STRATEGIES AND PRACTICES

Q No.	**Statement**	**Response (1-5)**
9	I have adopted new agricultural practices in response to changing wetland conditions.	
10	I have diversified my income sources as a means of reducing environmental risk.	
11	I actively engage in community-based adaptation projects.	
12	I have modified my use of wetland resources to ensure long-term sustainability.	
13	I participate in training programs or workshops on adaptive techniques.	

SECTION V: INSTITUTIONAL AND POLICY SUPPORT

Q No.	**Statement**	**Response (1-5)**
19	Local government policies effectively support adaptation initiatives in the wetland.	
20	I am satisfied with the level of institutional support available to wetland users.	
21	I trust that government interventions will help mitigate the adverse impacts of environmental change.	
22	I believe that current policies adequately address the risks associated with environmental variability.	

SECTION VI: BARRIERS TO ADAPTATION AND FUTURE OUTLOOK

Q No.	Statement	Response (1-5)
23	I face significant challenges in accessing the resources needed to adapt to environmental changes.	
24	Institutional corruption or inefficiency hinders the implementation of adaptation measures.	
25	I am concerned that current adaptation strategies may not be sufficient for future challenges.	
26	I feel optimistic about the future of wetland management if additional resources are allocated.	

Appendix 3: Focus Group Discussion (FGD) Guide

Study Title:

The Impact of Climate Variability and Anthropogenic Activities on Urban Wetland Ecosystem Services: A Case Study of Walukuba-Masese Wetland on Lake Victoria

Purpose of the FGD:

To gather community perspectives on observed changes in the wetland ecosystem, causes of degradation, impacts on livelihoods, and strategies used to adapt to changing environmental conditions.

Participants:

- Local residents
- Wetland resource users (e.g., farmers, fishers, papyrus harvesters)
- Women and youth group representatives
- Community leaders and elders

Group Composition:

Separate FGDs will be held for:

- Men
- Women
- Youth
- Mixed gender/community leaders

Time Required: 1–1.5 hours
Facilitator:
Note-taker:
Date:
Location:

Introduction by Facilitator (5 minutes)

- Welcome participants and introduce the team.
- Explain the purpose of the discussion.
- Emphasize that there are no right or wrong answers and that all opinions are valued.
- Ensure confidentiality and voluntary participation.
- Request permission to record (if applicable).

Discussion Themes and Questions

1. Observed Changes in the Wetland and Climate Patterns

- What changes have you observed in the Walukuba-Masese wetland over the past 10–30 years?
- Have you noticed changes in the amount or pattern of rainfall and temperature?
- How have these changes affected the wetland's water levels, vegetation, and wildlife?

2. Human Activities and Environmental Impact

- What are the common human activities taking place around the wetland (e.g., farming, fishing, and brick-making)?
- How do you think these activities have impacted the wetland?
- Are there activities that you think should be stopped or regulated?

3. Wetland Benefits and Livelihoods

- What resources or benefits do you or others in your community get from the wetland?
- Have these benefits changed over time? If yes, how and why?
- How has wetland degradation affected your household's income or food availability?

4. Coping and Adaptation Strategies

- What do people in your community do to cope with changes in the wetland (e.g., flooding, water shortages, reduced fish catches)?

- Have people changed their farming, fishing, or other practices in response to these changes?
- What has helped some people adapt better than others?

5. Support, Policies, and Community Involvement

- Are there any government or NGO programs supporting wetland conservation or adaptation?
- How are community members involved in managing or protecting the wetland?
- What kind of support (training, materials, financial) would help you manage the challenges better?

6. Recommendations

- What should be done to restore and protect the Walukuba-Masese wetland?
- What should the government or NGOs do to help your community adapt to environmental changes?

Closing (5 minutes)

- Thank participants for their time and views.
- Summarize the key points shared.
- Explain how the information will be used.
- Invite any final comments or questions.