IMPACT OF RIPARIAN ZONE DEGRADATION ON FLOOD OCCURRENCE AND MANAGEMENT IN THE NAIROBI RIVER BASIN, NAIROBI CITY COUNTY, KENYA

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A research thesis submitted in partial fulfilment of the requirements for the award of the degree of Master of Science in Disaster Management and Sustainable Development of Masinde Muliro University of Science and Technology

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DECLARATION

This Thesis is my original work prepared with only the indicated sources and support. It has not been presented anywhere, in any university or institution of higher learning, for the award of any certificate, diploma, or degree.

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CERTIFICATION

The undersigned certify that they have read and recommend for approval of Masinde Muliro University of Science and Technology, a thesis entitled "**Impact of riparian zone degradation on flood occurrence and management in the Nairobi River basin, Nairobi city county, Kenya**."

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DEDICATION

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ABSTRACT

The Nairobi River basin riparian zone is critical to the ecological and hydrological stability of Nairobi City County, Kenya. However, growing urbanisation, pollution, and deforestation have reduced its ability to manage floods. The degradation of the riparian zone has increased the frequency and severity of flooding in the city, demanding a thorough investigation into the role of the Nairobi River basin riparian zone in flood management. This study sought to assess the degradation of the riparian zone over 30 years (1991-2021), determine the relationship between degradation and flood occurrences, and recommend long-term mitigation solutions. The hydrological cycle theory, which elucidated how alterations in land use and climate patterns disrupted natural water flow dynamics, exacerbating flood risks, guided the research. A correlational research design was applied in the study. A sample size of 373 individuals was chosen, comprising government officials, NGOs, and local inhabitants, using simple random and selective sampling methods. Data collection tools included surveys, interviews, GIS, and remote sensing technology. Inferential statistics were employed to identify correlations and significance levels, with data analysis conducted using SPSS version 25. The Nairobi River basin riparian zone has deteriorated significantly during the past 30 years, with the built-up area expanding from 80.2 km^2 in 1991 to 275.5 km^2 in 2021, mostly due to urbanisation and encroachment. The study found a significant positive connection ($r = 0.72$, $p < 0.05$) between riparian vegetation degradation and the frequency of floods. 52% of respondents reported annual floods, and 37% reported biannual floods. Deforestation, pollution, and unregulated construction activities significantly influenced flood occurrences ($p < 0.01$). Reforestation, riparian buffer zones, and improved waste management are key sustainable mitigation techniques that significantly lower flood risks ($p < 0.05$), according to regression analysis. Community engagement and policy enforcement were also cited as crucial to successful implementation. To conclude, the degradation of the Nairobi River basin riparian zone is significantly linked to rising flooding. The report suggests that Nairobi City County undertake stringent riparian zone management methods, like as afforestation and buffer zone enforcement, as well as include flood mitigation strategies into urban design frameworks.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASL	Above Sea Level
CBD	Convention on Biological Diversity
CBOs	Community-Based Organisations
CCD	Convention to Combat Desertification
DRR	Disaster Risk Reduction
EMCA	Environmental Management and Coordination Act
FGD-	Focused Group Discussion
GIS	Geographic Information System
ICPAC	International Competition Policy Advisory Committee
ICZM	Integrated Coastal Zone Management
IPCC	Integrated Panel on Climate Change
ISDR	International Strategy for Disaster Reduction
KII	Key Informant Interview
KMD	Kenya Meteorological Department
LVB	Lake Victoria Basin

LVILMP	Lake Victoria Integrated Land Management Project
MDGs	Millennium Development Goals
MOE&NR	Ministry of Environment and Natural Resources
NCWSC	Nairobi County Water and Sewerage Company
NDOC	National Disaster Operation Centre
NEMA	National Environment Management Authority
NGOs	Non-Governmental Organisation
NMR	Nairobi Metropolitan Region
RCMRD	Regional Centre for Mapping and Resource Development
REMM	Riparian Ecosystem Management Model
SDGs	Sustainable Development Goals
SOK	Survey of Kenya
SPSS	Statistical Package for Social Scientists
UN	United Nations
UNCSD	United Nations Conference on Sustainable Development
UNEP	United Nations Environmental Programme

UNFCCC	United Nations Framework Convention on Climate Change
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WKIEM	Western Kenya Integrated Ecosystem Management
WRMA	Water Resource Management Authority

OPERATIONAL DEFINITION OF TERMS

Degradation is the loss of ecological integrity of the riparian zone due to deforestation, human encroachment, poor land use, and pollution.

Ecosystem is a domain where the biotic and abiotic parts connect to address their five essential issues (consumers, producers, decomposers, abiotic chemicals, and energy) on account of their survival.

Encroachment of Riparian Zones. In this context, the phrase means the entrance within the domain of this interface of land by human activities such as construction, mostly illegally, by the urban poor.

Encroachment refers to the illegal intrusion into a highway or a navigable river, with or without obstruction.

Environment: The whole physical and biological systems in which man and other organisms live.

Flood Severity The magnitude of flooding is measured in terms of water depth, flooding duration, and spatial extent.

Land Use/Land Cover (LULC) Spatial patterns and temporal changes of land-use categories, including built-up areas, bare land, cropland, vegetation cover, and water bodies, as determined using remote sensing data.

Rehabilitation. This is a procedure that can be characterised as the partial practical or potentially basic return to a previous state of waterways or returning them to great working order.

Riparian Degradation: The process by which the physical and ecological integrity of the riparian zone deteriorates due to human actions such as agricultural encroachment, urban development, and informal settlements.

Riparian Zone: An interface between land and a flowing water body. Plant species along the waterway edges are known as riparian vegetation, characterised by hydrophilic plants.

River Basin Section of land drained by a waterway and its tributaries. It includes most of the land surface dissected and drained by numerous streams and springs that flow downstream into each other and, eventually, into one waterway.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Urban flooding is increasingly recognised as a major environmental and socio-economic challenge in rapidly urbanising cities. Riparian zones, characterised by lush vegetation and moist conditions, are vital land-water interfaces that filter river water, curb soil erosion, and regulate temperature (Malanson, 1993). These zones exhibit global diversity, with both urban and rural landscapes featuring abundant vegetation. Riparian zones are vital ecosystems that support agriculture, urban areas, and industries, highlighting human dependence on them. International frameworks such as the Ramsar Convention on Wetlands (1971), the UN Convention on the Law of Non-navigational Uses of International Watercourses (1977), and the Sustainable Development Goals (SDGs), particularly Goal 6 (2016), underscore the importance of preserving riparian zones.

In the regional context of Sub-Saharan Africa, riparian zones play a vital role in maintaining ecological balance and supporting human livelihoods through water regulation, habitat provision, and soil stabilisation. Despite their importance, these ecosystems continue to face threats from illegal encroachment, agricultural expansion, and urban development, leading to vegetation loss and water quality decline. Studies across Kenya and neighbouring regions highlight that land-use change significantly alters riparian vegetation structure and species diversity (Koskey et al., 2021; Ruto et al., 2023). Furthermore, riparian tree diversity has been shown to influence biodiversity and key ecosystem functions such as flood regulation and nutrient cycling (Kinnoumè et al., 2024). The degradation of these zones results in increased flood risks, sedimentation, and loss of aquatic habitats. Consequently, regional and international environmental agencies emphasise the adoption of sustainable riparian management and restoration practices to safeguard ecosystem services (Foley-Congdon et al., 2024; Davis et al., 2025).

In Kenya, riparian zones play a pivotal role in urban resilience, particularly in Nairobi City County. In the context of the Nairobi River Basin, human-driven alteration of the riparian zone has compromised the natural functions of drainage, storage, and flood attenuation. The rise in floods, causing 60 per cent of disaster-related fatalities, is a pressing challenge linked to the degradation of riparian zones. Key issues include the increasing encroachment on and blockage of riparian reserves and natural water channels, as outlined by the Government of Kenya (GoK, 2013) and studies by Ouma and Tateshi (2014). Reports indicate that encroachment, informal settlement expansion, waste disposal, and vegetation removal along riparian zones are significant in the Nairobi metropolitan area (Howland, 2024; Muketha, 2025). Meanwhile, the Kenya Meteorological Department and policy commentary attribute heavy flood events to rapid urban growth, poor land-use planning, and inadequate enforcement of riparian buffer regulations (The Star, 2024).

The economic implications are significant, with potential annualised losses amounting to 0.8 per cent of the Gross Domestic Product (GDP) due to the destruction and loss of critical infrastructure, exceeding Ksh 49.8 billion based on the GDP at the market price of 2015. The ecological consequences of urban floods, such as erosion and pollutants entering water courses, underscore the crucial role of riparian ecosystems. Scientific research revealing adverse effects on plant biomass and aquatic life highlights the interconnectedness of urban and ecological challenges, emphasising the urgent need for targeted interventions to preserve ecological balance and enhance urban resilience. For example, a study by Lwanga et al. (2022) found that sand-harvesting in riparian zones significantly increases turbidity and siltation, reduces riparian land productivity, and undermines riverine ecosystem health. These intersecting dynamics highlight the urgent need to investigate how degradation of the riparian zone influences flood occurrence and severity. The study therefore focuses on assessing the extent of riparian degradation along the Nairobi River, analysing the relationship between land-use/land-cover changes and flood occurrence, and evaluating sustainable community and ecological flood mitigation practices.

1.2 Statement of the problem

The degradation of riparian zones is the process of narrowing, vegetation loss and informal encroachment of the riparian zone. The degradation of riparian zones in Nairobi City County, Kenya, has, over the years, become an enormous environmental concern strongly associated with flood control and urban resilience (Muketha, 2020; Omusisi, 2022). Riparian areas function as buffers between land and water and are crucial for ecological stability because they filter pollutants, prevent erosion, and help stabilise water temperature (Malanson, 1993; Wambugu, 2018). Although widely acknowledged, riparian zones have come under growing pressure from human activities, including illegal occupation, urban expansion, and vegetation removal, which reduces their capacity to regulate surface runoff and retain sediments (Muketha, 2020; Mugambi et al., 2022).

The degradation of riparian function has been linked to increased flood occurrence and severity in Nairobi's river basin, with economic losses, environmental damage, and flood disaster-related fatalities reported when riparian reserves and natural waterways are encroached and degraded (Wanjiku, 2023; Odha, 2024). While the Ramsar Convention and the Sustainable Development Goals stress protection of riparian strips, minimal community participation and gaps in local research and implementation continue to limit effective flood mitigation measures in Nairobi. Although prior studies have examined urban flooding and land-use change in the Nairobi area, a gap remains in explicitly quantifying how riparian degradation influences flood occurrence and severity in the Nairobi River Basin. This study, therefore, links riparian degradation metrics of the corridor to quantitative flood occurrence and severity outcomes for Nairobi City County.

1.3 Research Objectives

1.3.1 Broad Objective

To assess the contribution of the Nairobi River Basin to Riparian Zone flood management in Nairobi City County, Kenya.

1.3.2 Specific Objectives

1. To assess the level of riparian zone degradation along the Nairobi River basin between 1991 and 2021.
2. To analyse the relationship between the level of riparian zone degradation and the occurrence of flooding along the Nairobi River basin.
3. To evaluate sustainable flood management practices along the Nairobi River basin riparian zone and the socio-economic and environmental benefits.

1.4 Research Questions

1. What is the level of degradation of the Nairobi River basin riparian zone between 1991 and 2021?
2. Is there a meaningful relationship between riparian zone degradation and the occurrence of flooding along the Nairobi River basin Riparian Zone?
3. What are the socio-economic and environmental benefits of sustainable flood management along the Nairobi River riparian zone?

1.5 Justification of the Study

The study on whether the riparian zone of the Nairobi River basin helps regulate floods is consistent with the larger ideas of sustainability and environmental stewardship. The idea that we must preserve and manage the environment is supported by this study's analysis of the relationships between human activity and natural systems. This perspective, which reflects the ethical considerations that underpin environmental philosophy, is based on the belief that sustainable management of natural resources is vital for the well-being of present and future generations.

From an academic perspective, this work closes a large information gap about riparian ecosystem services and flood management in Nairobi City County. There is an absence of study specifically addressing the function of riparian zones in reducing floods in an urban Kenyan setting; instead, previous studies have frequently concentrated on more general environmental or urban planning concerns. By delivering empirical data and analysis on the sustainable management of riparian zones to lower flood risks, this research adds to the body of knowledge in academia and provides insights that could be implemented in similar urban areas around the world. It also improves our theoretical knowledge of hydrology, urban ecology, and sustainable development approaches.

This study is justified by the increasing frequency and intensity of urban floods in Nairobi, which cause loss of life, property damage, and disruption of economic activities (Oluchiri, 2025; Kariuki et al., 2024). By assessing the extent of riparian degradation and its relationship with flood severity, the study provides empirical evidence necessary for policy formulation, urban planning, and sustainable environmental management. The results of this study are essential for guiding decisions regarding policies in Nairobi City County that concern environmental preservation, urban development, and disaster relief. To create and conduct efficient plans for riparian zone management and flood prevention, policymakers need solid data. This study aids in the creation of policies that combine the objectives of urban growth with environmental conservation by offering evidence-based recommendations. It also emphasises the necessity of coherent policy frameworks that deal with disaster risk reduction and land use to prevent urban growth from compromising community safety and environmental integrity. Identifying effective mitigation practices will help county governments, NGOs, and communities implement targeted interventions that reduce flood risk and enhance resilience. The findings of the study can direct the amendment of current laws and the development of fresh strategies meant to increase urban areas' resistance to climate-related disasters.

1.6 Scope of the Study

The study focuses on the riparian zone of the Nairobi River basin within Nairobi City County, Kenya. The riparian zone of the Nairobi River covers upstream, midstream, and downstream areas within the county. The study's topic focused on the contribution of the Nairobi River basin riparian zone and the occurrence of flooding in Nairobi City County, Kenya. Specifically, the study aimed to determine the level of degradation of the riparian zone from 1991 to 2021.

Land use land change (LULC) analysis covers 30 years to understand long-term changes. Rainfall data were collected from January 2021 to December 2022 to capture both dry and peak rainfall periods. The study investigates riparian degradation, flood occurrence and severity, and sustainable mitigation measures, including bioengineering practices, wetlands, and community-based interventions to analyse the relationship between riparian degradation and flood occurrences, and evaluate sustainable mitigation approaches for managing flooding in the area.

1.7 Significance of the Study

The study on riparian degradation and flood occurrence along the Nairobi River is significant in multiple dimensions:

1.7.1 Philosophical Significance

From a philosophical perspective, this study contributes to the understanding of the interrelationship between human activities and natural systems. The study highlights how anthropogenic alterations, such as loss of vegetation cover, expansion of formal and informal settlements, and poor solid waste disposal, disrupt ecological balance, which in turn affects societal well-being through increased flood risk (Muketha, 2025; Howland, 2024). It emphasises the significance of natural ecosystems for preserving ecological balance and safeguarding urban areas from natural disasters, especially riparian zones. The research emphasises the ethical imperative of sustainable environmental stewardship and the moral responsibility of urban residents, policymakers, and planners to maintain healthy riparian zones as part of the broader ecosystem. Overall, the study emphasises the importance of environmental ethics and the sustainability principle to urban development through the promotion of the idea of peaceful coexistence between natural ecosystems and urban development. This viewpoint is essential for promoting a greater understanding of the environment and how important it is for maintaining human life and well-being.

1.7.2 Academic Significance

From an academic perspective, this study provides empirical evidence on how riparian degradation affects flood severity in Nairobi, Kenya, which fills a critical knowledge gap in a topic previously under-explored. The study contributes to the fields of urban environmental management, hydrology, and GIS-based land-use analysis (Nyaga et al., 2024; Tela et al., 2023). Scholars and researchers can use the empirical data and conclusions drawn from this study to further explore and develop innovative approaches for urban sustainability and disaster risk reduction. The study's findings enrich the theoretical framework of urban environmental studies and make a significant academic contribution to the fields of urban ecology, hydrology, and sustainable development. It also fills a significant gap in the literature by providing a detailed analysis of the role of riparian zones in flood management.

1.7.3 Policy Significance

For policymakers and urban planners, this study has important practical ramifications as it provides data-driven insights to guide the development and implementation of sustainable urban flood management strategies. The report helps the creation of laws and policies targeted at improving urban areas' resilience to floods by offering recommendations that are supported by evidence. It highlights the significance of natural ecosystems in reducing the risk of hazards and the necessity of integrated land use planning that includes sustainable management of riparian zones. The findings inform county government decisions on buffer zone enforcement, urban planning, and ecological restoration programs. The results of the study can be used to create thorough urban planning regulations that strike a balance between environmental preservation and development.

Additionally, the study supports the design of targeted community-based interventions and contributes to national discussions on sustainable land-use planning and waste management systems, all of which are essential to preserving the ecological integrity of the Nairobi River basin riparian zone.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter reviews the existing empirical literature on riparian degradation and urban flooding along the Nairobi River Basin. It incorporates literature on flood occurrence, types of floods, indicators of flood severity, impacts, and mitigation strategies. The chapter also integrates relevant theories, models, and matrices and culminates with the conceptual framework that anchors the study variables.

2.2 Nairobi River riparian buffer zone

The legal riparian buffer is 30 meters. The delineated buffer zone, extending approximately 0.000117 square kilometres (Km^2), emerges as a significant ecological interface along the Nairobi River basin riparian zone. Riparian buffers play an essential role in stabilising riverbanks, controlling erosion, and enhancing water quality (Arnell *et al*., 2018; Le Maitre *et al*., 2015). Buffers function as protective barriers, crucial for reducing the adverse impacts of land degradation and human activities on riverine ecosystems.

Despite legal provisions designating riparian buffer zones as government land, unauthorised allocations and prohibited land uses have contributed to the gradual degradation of the riparian zone. The Environmental Management and Coordination Act (EMCA) and the Water Act assign regulatory authority to bodies like the National Environmental Management Authority (NEMA) and the Water Regulation Authority (WRA), which aim to safeguard these ecologically sensitive areas. However, illegal encroachment and development persist, indicating challenges in enforcement and implementation (UNEP, 2016).

Legislative instruments such as the EMCA and Water Act provide co-management strategies and empower Water Resource User Associations (WRUAs) for riparian zone protection. Additionally, the Water Quality Regulations (2006) and Water Resource Management Rules (2007) offer guidelines for riparian width demarcation and management, crucial for maintaining buffer zones along watercourses. The Survey Act further mandates the reservation of a 30-meter-wide strip of land above the high-water mark of tidal rivers for governmental purposes, highlighting legal frameworks aimed at preserving riparian ecosystems (Government of Kenya, 2015).

2.2 The Level of Riparian Degradation of the Nairobi River Basin (1991-2021)

Riparian zones provide critical ecosystem services, including biodiversity support, water purification, and flood management. The degradation of riparian zones across the globe is a multifaceted issue that spans continents and is influenced by many interconnected factors. Global studies show that deforestation, human encroachment, and urban expansion significantly degrade riparian zones, increasing flood risks (Bayón et al., 2023; Prieto-Curiel & Borja-Vega, 2024). Studies conducted in Europe, North America, and Asia reveal similar challenges related to urbanisation, agricultural expansion, and infrastructure development, all of which contribute to vegetation loss, pollution, and altered hydrological patterns (Smith *et al*., 2018; Jones and Brown, 2019; Chen *et al*., 2020). These global examples underscore the pressing need for coordinated conservation efforts to address riparian zone degradation.

Evidence from numerous studies and reports underscores the degradation of riparian zones over the past three decades. Researchers have extensively documented the adverse impacts of factors such as urbanisation, pollution, and climate change on riparian ecosystems. For instance, an Environmental Science & Technology study reported significant vegetation loss and pollution in riparian areas due to urbanisation and land-use changes (Smith *et al*., 2018). Similarly, a comprehensive assessment by the United Nations Environment Programme (UNEP) highlighted the widespread degradation of riparian zones across different continents, attributing it to human activities and inadequate conservation efforts (UNEP, 2016). These findings collectively demonstrate the global scale of riparian zone degradation and emphasise the urgent need for coordinated action to address this environmental challenge.

Across Africa, the degradation of riparian zones has emerged as a pressing environmental issue with far-reaching consequences. Research conducted across the continent has shed light on the multifaceted challenges facing riparian ecosystems and the communities dependent on them. Studies from various African countries have documented the detrimental effects of urbanisation, industrialisation, and agricultural expansion on riparian habitats (Ogutu-Ohwayo, 2016). Similarly, in South Africa, the transformation of natural riverine landscapes for agricultural purposes has significantly altered riparian ecosystems, leading to habitat fragmentation and degradation (Le Maitre *et al*., 2015). The impacts of climate change further worsen the degradation of riparian zones across Africa. Studies have highlighted the increasing frequency and intensity of extreme weather events, such as floods and droughts, which pose significant threats to riparian habitats and the communities that rely on them (Arnell *et al*., 2018). In Ethiopia, recurring droughts have contributed to the degradation of riparian vegetation and reduced water availability in riverine ecosystems (Alemayehu *et al*., 2019). In addition to environmental challenges, socio-economic factors also play a significant role in driving Africa's degradation of riparian zones (Nziguheba *et al*., 2017). Despite these challenges, there is growing recognition of the importance of conserving and restoring riparian ecosystems across Africa. Initiatives such as community-based conservation programs, river restoration projects, and policy reforms aimed at sustainable natural resource management are emerging in various countries (Akama & Ngaira, 2014). These efforts underscore the need for collaborative approaches that involve local communities, governments, and other stakeholders in the conservation and restoration of riparian zones across the continent.

The degradation of riparian zones in Kenya has been a subject of increasing concern, with research highlighting this phenomenon's significant environmental and socio-economic impacts. Studies conducted in various regions of the country have documented the degradation of riparian habitats due to factors such as deforestation, land-use change, pollution, and encroachment (Odadi *et al*., 2016). Research conducted along the Nairobi River basin has revealed extensive vegetation loss, water pollution, and habitat destruction resulting from urbanisation, industrial activities, and informal settlements (Gichuhi *et al*., 2022). Similar findings have been reported in other major river basins in Kenya, such as the Tana and Athi Rivers, where unsustainable land-use practices and inadequate environmental regulations have contributed to riparian degradation (Muthoni *et al*., 2018).

The degradation of riparian zones in Kenya has also been linked to the exacerbation of natural disasters, particularly floods. In Nairobi, remote sensing and GIS analysis indicate substantial degradation. Vegetation cover declined from 8.4% in 1990 to 1.9% in 2020, while built-up areas increased from 4.6% to 21.7% (Nyaga et al., 2024; Tela et al., 2023).

Studies have shown that the loss of riparian vegetation and the obstruction of river channels increase the risk of flooding in adjacent areas, leading to property damage, loss of lives, and disruption of livelihoods (Kairu *et al*., 2019). Researchers have pointed out that the global intensification of global weather patterns, such as increased precipitation and extreme weather events, has profoundly affected urban areas worldwide, including Nairobi. This observation corresponds with the global trend of rising floods, showing the importance of examining the broader context of climate change and its impacts on riparian zones. At the local level, the Nairobi River basin has seen rapid urbanisation and population growth, often without adequate infrastructural support. This has led to significant vegetation loss and pollution, with estimates suggesting up to 95% loss compared to historical levels (Lamsal, 2015).

Primary drivers of pressure and environmental degradation within urban river riparian reserves include increased industrial and commercial activities, solid waste dumping, and informal settlements (Muketha, 2025). Additionally, land-use changes, including the conversion of forests and wetlands into agricultural land, have further compromised the ecological integrity of the riparian zone (Mwachia *et al*., 2023). The heightened occurrence of flash floods in Nairobi and other major Kenyan cities, such as Mombasa, Kisumu, and Nakuru, has worsened the degradation of the riparian zone.

Future research efforts should concentrate on developing innovative, context-specific strategies for riparian zone management. This could entail integrating traditional ecological knowledge with modern conservation techniques, using advanced remote sensing and geospatial technologies, and fostering participatory frameworks to engage local communities in sustainable management practices (Kimani & Njuguna, 2023). These examples underscore the interconnectedness of human activities and riparian health, emphasising the need for holistic approaches to conservation and management. By examining these global case studies, it becomes clear that the level of degradation seen in the Nairobi River riparian zone over the past 30 years is not an isolated phenomenon but rather part of a larger, systemic issue facing riparian ecosystems worldwide. Therefore, addressing the challenges faced by the Nairobi River basin requires local solutions and lessons gleaned from successful interventions implemented across the globe.

2.3 Relationship Between Riparian Degradation and Flooding Occurrences

The research objective of understanding the relationship between degradation levels and flooding occurrences along the Nairobi River basin riparian zone is strongly supported by comprehensive case studies conducted globally, highlighting the intricate interplay between riparian degradation and heightened flood risks. Flood occurrence is strongly influenced by both natural and anthropogenic factors. Globally, urban areas with degraded riparian corridors experience more frequent flash floods due to reduced infiltration and increased runoff (Bayón et al., 2023). For instance, in Europe, studies have extensively documented the consequences of rapid urbanisation and agricultural expansion on riparian ecosystems. Research conducted along the Thames River in the United Kingdom revealed that urbanisation has led to the loss of natural vegetation along riverbanks, resulting in increased surface runoff and elevated flood risks in downstream areas (Smith *et al*., 2018).

Similarly, in regions like the Loire River basin in France, agricultural intensification has contributed to soil erosion and sedimentation, exacerbating flooding events during heavy rainfall (Jones and Brown, 2019).

Moving across the Atlantic to North America, case studies provide further evidence of the link between riparian degradation and flooding occurrences. In the Mississippi River basin, extensive deforestation and industrial pollution have degraded riparian ecosystems, reducing their capacity to regulate water flow and increasing flood susceptibility in adjacent areas (Chen *et al*., 2020). Moreover, research along the Colorado River in the southwestern United States has demonstrated how the construction of dams and water diversions has altered natural flow regimes, leading to more frequent and severe floods downstream (Smith *et al*., 2018).

Transitioning to Asia, case studies illustrate the impact of riparian zone degradation on flood occurrences in diverse geographical contexts. In China, the construction of dams and the conversion of riparian areas into urban spaces along the Yangtze River have disrupted natural flow patterns, exacerbating flood risks in downstream regions (Chen *et al*., 2020). Similarly, research along the Ganges River in India has shown how deforestation and pollution have compromised riparian ecosystems, amplifying the severity of floods during monsoon seasons (Jones and Brown, 2019).

Closer to home, within the African continent, case studies offer valuable insights into the relationship between riparian degradation and flooding occurrences. In countries like Nigeria, rapid urbanisation along the Niger River riparian zone has led to the loss of vegetation and the encroachment of settlements, increasing vulnerability to floods (Ogutu-

Ohwayo, 2016). Similarly, in the Nile River basin in Egypt, the construction of dams and irrigation projects has altered natural flow patterns, contributing to seasonal flooding in downstream areas (Le Maitre *et al*., 2015). In East Africa, studies highlight that rapid urban growth and poor land-use planning exacerbate flood hazards (Urban Planning at the Heart…, 2024).

Zooming in on Kenya, specifically within the Nairobi River basin, case studies offer a nuanced understanding of the local dynamics shaping riparian degradation and flood occurrences. In Nairobi, rainfall intensities exceeding 30 mm/hr combined with degraded riparian zones trigger flash floods (Howland, 2024). Research conducted in Nairobi's informal settlements, such as Kibera and Mathare, highlights how unregulated urbanisation and inadequate infrastructure exacerbate flood risks, displacing communities and causing extensive property damage (Kairu *et al*., 2019). NDVI analyses show that loss of vegetation along the riparian corridor correlates with increased flood incidence (Tela et al., 2023). Additionally, studies along the Athi River basin demonstrate how pollution from industrial and domestic sources degrades water quality, exacerbating flood impacts on both ecosystems and human health (Gichuhi *et al*., 2022). Digital Elevation Models (DEM) further reveal that low-lying areas with minimal buffer zones are at the highest risk (Jiang et al., 2022). These studies demonstrate a direct relationship between riparian degradation and flood occurrence, reinforcing the need for sustainable land-use practices.

By integrating findings from these detailed case studies, the research objective of understanding the relationship between degradation levels and flooding occurrences along the Nairobi River basin riparian zone gains robust empirical support. This study underscores the urgency of addressing riparian degradation through targeted conservation measures and sustainable land-use practices to mitigate flood risks and safeguard both ecosystems and communities.

It is important to note that compilations of flood loss histories are incredibly useful when it comes to the determination of the frequency of flood events and the potential danger of floods. These records contain all sorts of history of past floods, which have included dates and times and the areas that have been affected, and these records have included government reports, newspapers, or any records from any eyewitness (FEMA, 2021). They also include parameters of hydrological conditions, including river discharge and rainfall, necessary for the calibration of the predictive models (USGS, 2021). In turn, damage estimates help to understand the economic and engineering consequences of floods that support vulnerability studies and risk reduction strategies (FEMA, 2021). The evidence obtained from photogrammetric and cartographic data gives visibility to the effects of flooding and cartographic evidence of flooding, policies and response review past management measures and development of new emergency management strategies (USGS, 2021). The detailed records derived from these sources serve to familiarise researchers and policymakers with trends and past mitigation experiences and improve flood preparedness and response approaches.

The Nairobi River Basin Riparian zone underwent considerable changes between 1991 and 2021, affected by both natural and anthropogenic sources. During this time, Nairobi had the most rainfall in March, April, May, October, November, and December, resulting in regular flooding occurrences that had a significant impact on the riparian zones and the entire Nairobi County (Onyango, 2024). Riparian zones were less disturbed in the early 1990s, with more vegetation and fewer encroachments. However, growing urbanisation took its toll, resulting in rising pollution and invasion by informal communities (Omusisi, 2022). Urban growth increased dramatically in the early 2000s, having a severe impact on riparian zones. The growth of informal settlements and industrial operations caused degradation.

The growth of informal communities and industrial operations has degraded these places. Increased pollution from home and industrial waste reduced vegetation cover and degraded water quality (Muketha, 2020). By the 2010s, the effects of urbanisation were increasingly noticeable. Efforts to repair the Nairobi River basin and its riparian zones have begun, involving both government and non-governmental organisations. Despite these attempts, problems like pollution, encroachment, and insufficient enforcement of environmental restrictions continued (Karangi, 2017). In recent years, there have been more organised and coordinated attempts to rehabilitate riparian areas. Initiatives such as reforestation, pollution control, and the removal of informal communities have shown good outcomes. However, riparian zones continue to confront substantial challenges because of ongoing urban pressures and climate change impacts (Muketha, 2019).

2.4 Strategies for Effective Flood Mitigation

Effective flood mitigation strategies integrate ecological, engineering, and community-based interventions. Ecological interventions use ecosystem services and natural processes to manage flood risk. They include afforestation and reforestation, wetland and mangrove restoration, and constructed permeable surfaces to enhance infiltration (Prieto-Curiel &

Borja-Vega, 2024). Ecological interventions often provide co-benefits like improved water quality and biodiversity.

Engineering interventions use hard infrastructure solutions, like dams, floodwalls, and levees, in combination with nature-based approaches to contain and divert floodwaters away from populated areas (Tela et al., 2023).

Community-based interventions are non-structural measures that focus on community engagement, awareness, and preparedness to build resilience. They include public awareness and educational programs to inform residents about flood risks and preparedness strategies, as well as regulatory enforcement of riparian buffer zones to prevent encroachment (Nyaga et al., 2024).

In examining flood reduction strategies for the Nairobi River basin riparian zone management, it is imperative to delve into a comprehensive literature review spanning global, regional, national, and local contexts. Globally, initiatives such as the Thames River restoration project in the United Kingdom underscore the potency of ecological restoration endeavours, notably through reforestation and the creation of riparian buffer zones (Smith *et al*., 2018). Meanwhile, the Netherlands' Room for the River program highlights the efficacy of innovative engineering solutions, including floodplain expansions and channel deepening, in bolstering flood resilience (Klijn *et al*., 2015). While these strategies exhibit commendable strengths in bolstering natural flood control mechanisms and engineering resilience, they also face scalability and long-term maintenance cost challenges.

Zooming into the African continent, strategies spotlight community engagement and ecosystem-based approaches as pivotal pillars for flood mitigation. For instance, Rwanda's Nyabugogo River restoration project highlights the transformative potential of community-led riparian habitat rehabilitation initiatives (UNEP, 2020). Similarly, Uganda's National Adaptation Plan for Agriculture emphasises sustainable land management practices to curtail soil erosion and mitigate flood hazards (Government of Uganda, 2016). Despite the laudable emphasis on community involvement and sustainable practices, limitations such as resource constraints and governance hurdles persist, hindering widespread implementation.

At the national level in Kenya, flood reduction strategies are enshrined within overarching policies that advocate for adaptive land-use planning and infrastructure development. The National Climate Change Action Plan underscores the criticality of these measures in enhancing flood resilience across the country (Government of Kenya, 2018). Simultaneously, localised efforts, such as the Nairobi River Basin Restoration Program, spotlight the importance of riparian habitat restoration and community capacity building in reducing flood vulnerabilities (Gichuhi *et al*., 2022). However, challenges about implementation gaps and inadequate enforcement of regulations pose significant barriers to effectiveness.

Transitioning to Nairobi-specific strategies, interventions target local challenges with focused precision. Initiatives spearheaded by the Nairobi Metropolitan Area Transport Authority (NAMATA) prioritise drainage improvement projects to mitigate flood risks in low-lying areas (Government of Kenya, 2019). Nairobi City County government has initiated programs for fencing riparian zones and tree planting along critical stretches (Mataga, 2025).

Furthermore, grassroots endeavours like the Nairobi River Clean-up Campaign engage residents in waste management and riparian habitat restoration to bolster flood resilience (Kuria *et al*., 2018). Yet, limitations such as limited coverage of infrastructure projects and sustainability concerns persist, underscoring the need for comprehensive and adaptive flood management frameworks.

In synthesising insights from diverse flood reduction strategies, this research endeavour aims to transcend existing challenges by proposing tailored solutions for the Nairobi River basin riparian zone. The envisioned management plan aspires to surmount hurdles related to resource constraints, governance deficiencies, and sustainability issues by harnessing global best practices, fostering community engagement, and aligning with national policies. Through interdisciplinary collaboration and stakeholder engagement, this research endeavour seeks to pioneer a holistic and adaptive flood management framework poised to navigate the evolving landscape of urbanisation and climate change impacts. Overall, community engagement, public awareness campaigns, and enforcement of environmental regulations are critical to ensure the effectiveness of these interventions.

2.5 Theories and Models of the Study

The study was underpinned by various theories and models, offering valuable frameworks for understanding the intricate interactions between human activities, environmental processes, and flood occurrences. One pertinent theory used was the hydrological cycle theory, which elucidated how alterations in land use and climate patterns disrupted natural water flow dynamics, exacerbating flood risks (Wanyoike & Ngigi, 2021). Human-induced alterations, such as riparian degradation, disrupt natural hydrological processes and increase flood risks (Bayón et al., 2023). In a healthy hydrological system, riparian zones function as natural buffers by increasing hydraulic roughness, storing water, trapping sediment, and enhancing infiltration. The presence of dense, varied vegetation increases flow resistance during floods, slowing down the water velocity and lowering its kinetic energy, thereby reducing downstream flood magnitude and severity. Vegetation cover in healthy riparian areas acts like a sponge and retains water during high flows, which reduces flood peaks. They also allow sediment to deposit, which helps to build and maintain the floodplain, creating additional water storage capacity. Finally, the soil structure in healthy riparian zones increases the infiltration rate of surface runoff into the ground, further reducing the volume of water entering the river channel. This theory was particularly relevant to the study, as it helped to illuminate the impact of urbanisation and climate change on riparian ecosystems and flood occurrences.

Degradation theory emphasises the link between ecosystem degradation and vulnerability to environmental hazards. Riparian degradation is characterised by the loss of key ecological functions like erosion control and water storage. Loss of vegetation and soil structure in riparian zones increases flood risk (Muketha, 2025).

Scientific models such as the Soil and Water Assessment Tool (SWAT) and the Hydrologic Engineering Centres-River Analysis System (HEC-RAS) have been instrumental in simulating water flow, sediment transport, and pollutant dispersal within riparian zones

(Wanyonyi et al., 2022). In Kenya, SWAT has been widely applied in catchments such as the Upper Mara, Nzoia, and Sondu basins to evaluate how land-use and climate changes influence surface runoff, streamflow, and sediment yield (Gathenya et al., 2018; Kipkorir et al., 2020; Wanyonyi et al., 2022). Similarly, HEC-RAS has been employed along the Nairobi River and Lower Nzoia floodplains to simulate water-surface profiles, delineate flood-risk zones, and support urban drainage planning (Omusisi, 2022; Odha, 2024). By using these models, researchers have been able to forecast flood risks and assess the effectiveness of mitigation strategies, providing a foundation for evidence-based decision-making and flood management efforts across Kenya's riparian systems.

Ecological resilience theory provided insights into the riparian ecosystem's ability to withstand and recover from disturbances such as floods (Kihato et al., 2020). This theory has been applied in Kenya to assess how natural systems absorb shocks while maintaining essential functions and structures. For example, Muketha (2020) employed the ecological resilience framework in examining the Nairobi River Basin, demonstrating that narrowing and vegetation loss within riparian buffers reduced the system's capacity to recover from recurrent floods. Similarly, a study on degraded riparian forests in southeastern Kenya applied the resilience concept to evaluate how habitat fragmentation and biodiversity decline weaken ecological processes such as nutrient cycling and pollination, compromising long-term ecosystem stability (Mwangi et al., 2024). These applications highlight the theory's relevance in understanding how riparian ecosystems respond to anthropogenic and climatic pressures. In the context of the Nairobi River, ecological resilience theory underscores the importance of conserving riparian vegetation and restoring degraded zones to enhance ecosystem stability, sustain biodiversity, and mitigate the severity of flood impacts.

From a geomorphological perspective, theories such as the dynamic equilibrium theory elucidate the natural balance between erosion, sediment transport, and deposition processes that shape riparian landscapes (Thiong'o & Nyamweya, 2021). In the Kenyan context, this theory has been applied to understand river morphology and floodplain dynamics in several basins. For instance, Mutie et al. (2020) applied geomorphological modelling in the Athi River Basin to demonstrate how alterations in sediment regimes and channel geometry increased flood vulnerability. Similarly, Kiplagat (2019), in a geomorphological assessment of the Nzoia River, used the dynamic equilibrium framework to show how human interventions such as dam construction and sand harvesting disrupted natural channel stability. These findings align with Thiong'o and Nyamweya's (2021) observations that urban encroachment and channelisation along the Nairobi River have intensified channel instability and flood risks. While geomorphological theories provide valuable insight into natural river behaviour, their application in urban Kenya remains limited by the complexity of anthropogenic alterations to riparian zones, emphasising the need to integrate geomorphological, ecological, and socio-economic approaches in river management.

The land degradation theory highlighted how unsustainable land use practices contribute to soil erosion, sedimentation, and the loss of ecosystem services in riparian zones (Gikonyo, 2022). In the Kenyan context, this theory has been widely applied to explain the degradation of river catchments and the resulting hydrological imbalances. For example, Muthee et al. (2020) examined the Upper Tana River Basin, where agricultural encroachment and deforestation increased sediment yield, undermining downstream water quality and flood regulation. Similarly, Chebet (2019), in a study of the Lake Victoria Basin, applied land degradation theory to show how poor land management and riparian cultivation accelerated soil erosion and reduced wetland buffering capacity. In Nairobi City County, Gikonyo (2022) demonstrated that informal urban development along riparian corridors intensify land degradation, leading to sediment accumulation and heightened flood risks. Collectively, these studies underscore the importance of integrating land use planning, community awareness, and policy enforcement to mitigate degradation and preserve riparian ecosystem functions. However, they also highlight the persistent challenge of balancing economic development with environmental conservation objectives in rapidly urbanising regions.

Finally, socio-ecological systems (SES) theory emphasises the interconnectedness of human and environmental systems and the need for holistic approaches to riparian management (Nyamai et al., 2022). In the Kenyan context, this theory has been instrumental in understanding how community livelihoods, governance structures, and ecological health interact in shared landscapes. For instance, Were et al. (2021) applied SES principles in the Athi River Basin to examine how urbanisation and weak institutional coordination influenced riparian degradation and water pollution, recommending participatory governance for sustainable outcomes. Similarly, Otieno (2020) used the SES framework in the Lake Naivasha catchment to assess how community land use decisions and socio-economic pressures affected wetland conservation, leading to adaptive co-management interventions. In Nairobi City County, Nyamai et al. (2022) demonstrated that integrating social dynamics such as informal settlement growth and local environmental stewardship into riparian management improved understanding of ecosystem vulnerability and resilience. Despite its strengths, the socio-ecological systems theory faces challenges in operationalisation, particularly in harmonising diverse stakeholder interests and balancing short-term socio-economic gains with long-term ecological sustainability.

Incorporating these theories and models into the study of the Nairobi River basin riparian zone degradation enhanced our understanding of the complex dynamics driving flood occurrences and informed evidence-based management strategies. By acknowledging the strengths, weaknesses, and relevance of each theoretical framework, this study aimed to contribute to sustainable development and resilience building in Nairobi and similar urban environments worldwide.

2.6 Flood Management Matrix

The management matrix for the Nairobi River basin riparian zone presents the strategies, stakeholders, interventions, and expected outcomes for sustainable management of urban flooding in Nairobi City County as illustrated in the table below.

Management Strategy	Key Stakeholders	Interventions	Expected Outcomes
Restoration of Riparian Vegetation Buffers	Nairobi City County, NEMA, CBOs	Control encroachment and regulate land use. Establish 30 m riparian buffer zones. Replant indigenous vegetation (bamboo, vetiver, papyrus, Napier grass).	Reduced flood intensity and erosion. Enhanced riverbank stability. Improved infiltration and sediment trapping.
Pollution Control and Solid Waste Management	NCCG, NEMA, Nairobi Water and Sewerage Company (NWSC), Local Communities	Enforce waste disposal regulations. Upgrade wastewater infrastructure to prevent effluent discharge. Establish community cleanup programs.	Reduced health risks and pollution loads. Improved water quality in the Nairobi River. Sustainable waste management practices.
Community Empowerment and Flood Preparedness	NGOs, CBOs, Kenya Red Cross, Local Administrations	Conduct community awareness and disaster preparedness training. Establish community-based monitoring units. Promote flood insurance and early warning systems.	Increased local ownership of riparian protection and capacity to respond to floods. Improved risk communication and early warning response.
Flood-Resilient Land Use Planning and Zoning	Nairobi County Urban Planning Department, Ministry of Lands, Survey of Kenya	Integrate flood risk zones into urban master plans. Relocate settlements from high-risk zones. Enforce building setbacks along riparian corridors.	Enhanced compliance with riparian protection laws. Controlled urban expansion. Reduced exposure of people and assets to flood hazards.
Monitoring, Research, and Policy Integration	Research Institutions (MMUST), WRA, NEMA	Review and update riparian management policies. Regular monitoring of water levels, LULC change, and ecosystem health. Integrate GIS and hydrological modelling in planning.	Data-driven policy and decision-making. Sustainable and adaptive management practices. Long-term resilience of the Nairobi River ecosystem.

Table 1 *Matrix for the Management of the Nairobi River Basin Riparian Zone*

Successful flood risk management requires an integrated approach that combines diverse strategies and interventions, including green infrastructure, bioengineering, and community knowledge, to establish resilient, adaptive, and sustainable systems. Green infrastructure and bioengineering are nature-based solutions that use vegetation and natural processes to manage stormwater. They focus on preserving natural floodplains through strategic interventions, such as the construction of wetlands, permeable pavements, and rain gardens.

Additionally, effective flood management is a shared responsibility that requires cooperation and coordination among government agencies, NGOs, CBOs and local communities to reduce risks, enhance preparedness, and build resilience. Government agencies, such as the national and county governments and environmental authorities like NEMA, develop policies and enforce riparian zoning. Business organisations, including NGOs and CBOs, undertake corporate social responsibility (CSR) initiatives that support clean-up campaigns, reforestation, and green infrastructure along vulnerable riverbanks. Finally, local communities, including the elderly and long-term residents, provide traditional knowledge on flood indicators. They monitor rainfall, cloud formations, and river flow to predict flood threats and provide local coping strategies to ensure timely preparedness.

2.7 Conceptual Framework

A conceptual framework provided a structure for understanding the key variables and their relationships within the area of study. In the context of investigating the degradation of the Nairobi River basin riparian zone and its impact on urban flooding in Nairobi City County, the conceptual framework served as a guide for examining the intricate dynamics between natural and human-induced factors.

Every expansion in the use of the land where we conduct our activities, such as urbanisation or agriculture, makes significant changes in the land, leading to degradation, causing floods. From the vegetation cover, it was evident that large areas of vegetation cover are liable for high surface runoff and soil erosion, thus perpetuating flood disasters. Further, assessing the soil erosion coupled with sedimentation implied that high rates of erosion limited the ability of the river to control the flow of water, hence flooding.

Even as it selects sustainable mitigation strategies, flood control that involves afforestation and rehabilitating riverbanks must be considered as important to realise vegetation cover along the riparian zone. Green infrastructure will enhance the efficiency of managing floodwaters of riparian zones. In addition, learning about the variation of hydraulic properties of water flows and controls like the branching of rivers and the construction of dams explained effects on hydrologic processes associated with flood overflow or flash floods. Proper construction and implementation of successful flood mitigation measures, which include appropriate flood drainage systems and sediment management, was a critical factor in preventing flood disasters. Together, these independent variables provide evidence of positive relationships with flood management, indicating that there is a need for holistic management approaches to degradation and promotion of flood resistance along the Nairobi River Basin riparian zone.

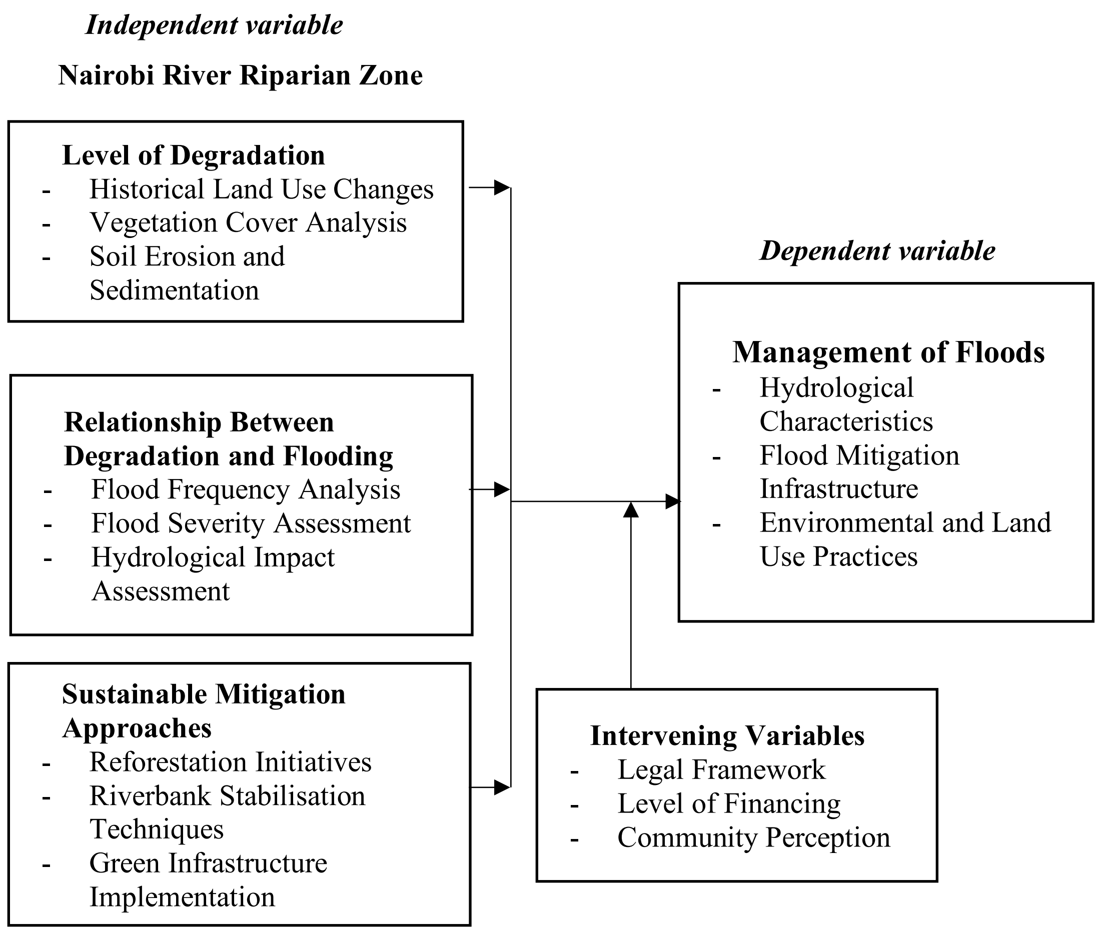

Figure 1 Conceptual framework.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the research methodology used in the study. The methodology details the study site, study population, research design, sampling procedures, and data collection methods. Additionally, it addresses data analysis techniques, data validity and reliability, ethical considerations, and research limitations.

3.2 Study site

The study was conducted along the Nairobi River riparian zone, covering upstream, midstream, and downstream areas within Nairobi City County. The study site encompasses the approved Nairobi Metropolitan Region (NMR), spanning approximately 4,438 km^2, with Nairobi city covering 695 km^2. It is subdivided into four spatial sub-regions: Core Nairobi, including the City County of Nairobi; the Northern Metro, comprising Kiambu County; the Southern Metro, including Kajiado County; and the Eastern Metro, comprising Machakos County. Nairobi, positioned on the edge of the Kapiti plains, has an average altitude of 1650m -1800m above sea level (Google Earth). The land elevation gradually increases from east to west, characterised by several streams such as Mathare, Ngong, Mbagathi, and Nairobi, which flow eastward and drain into the Athi River.

The tributaries of the Nairobi River, originating from the Ondiri and Kikuyu escarpments, include the Ondiri swamp, the sole remaining wetland in the Nairobi River basin. These tributaries traverse Kangemi, Muthangari, Kileleshwa, Arboretum, Ngara, and Dandora before draining into Ruai. The riparian zone in this urban setting is subject to heavy anthropogenic pressures, including small-scale farming, commercial and industrial activities, dense informal settlements, and waste dumping (Nyaga et al., 2024). The specific study area selected spans Motoine Primary School to Lenana School in Dagoretti Sub-County. The Nairobi River riparian zone was selected due to its vulnerability to urban flooding and evidence of significant degradation over the last 30 years (Tela et al., 2023).

The Nairobi River passes through significant areas such as the Central Business District (CBD), industrial zones, national parks, and informal settlements, making it a focal point for study (Krhoda, 2002). For a detailed description of the Nairobi River Basin, refer to Figure 2.

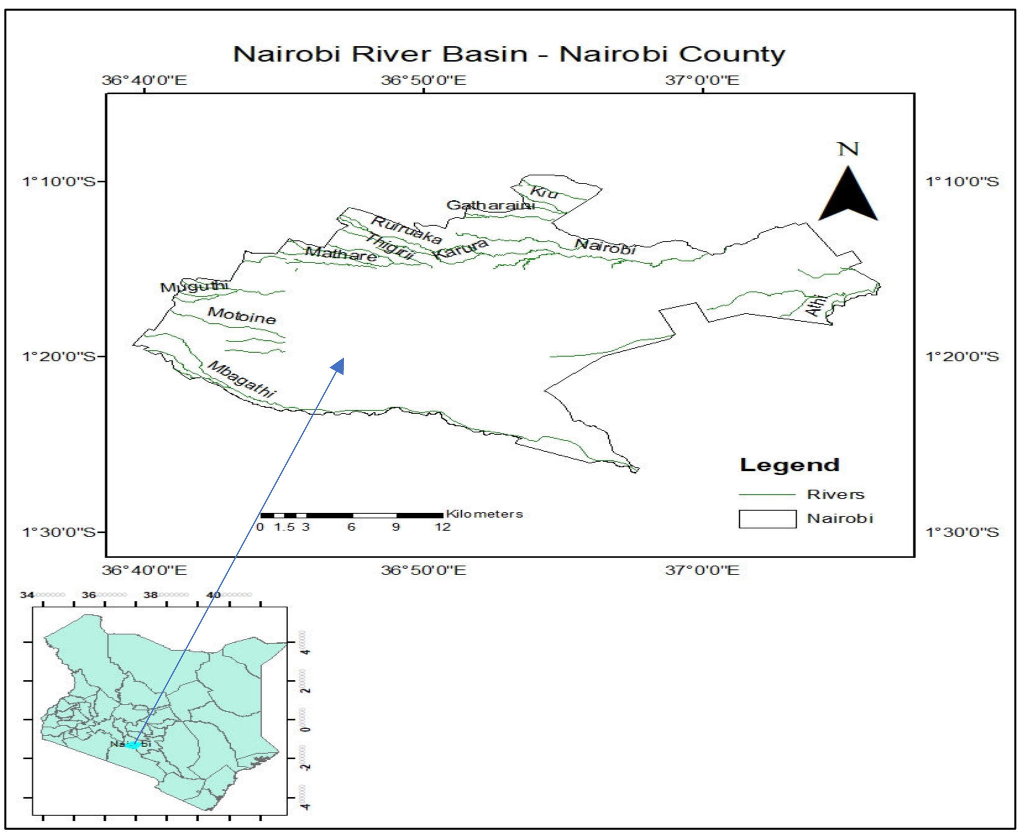

Figure 2 Map showing the Nairobi River basin.

Source: Kenya Ministry of Environment and Forestry (2018)

3.3 Study population

The study population comprised local households living within 30 – 100 meters of the riparian zone along the Nairobi River basin, government agencies, non-governmental organisations (NGOs), community-based organisations (CBOs), and experts familiar with Nairobi River Basin management, like urban planners and environmental scientists. Recent estimates suggest that the Nairobi River riparian zones are inhabited by 176,961 people, indicating a significant human presence with potential implications for the modification of the Nairobi River basin ecosystem (Ndung'u & Muthoni, 2023)

Government agencies, including Nairobi City County government, National Environment Management Authority (NEMA), Water Resources Authority (WRA), National Disaster Operations Centre (NDOC), and the Ministry of Environment, provide institutional data, such as flood records and policy frameworks.

Key NGOs include the Kounkuey Design Initiative (KDI), Green Belt Movement (GBM), and Local Environmental & Waste Management Organisation (LEWMO), while CBOs include Sansiro, Komb Green, Andolo Bridge Community, Mathare Environmental Group, Clean Up Kenya, and Nairobi River Restoration Initiative (NRRI). They are actively involved in environmental conservation, urban flood management, and provide useful knowledge about river rehabilitation and observed impacts of flood mitigation projects.

Finally, experts, including urban planners and environmental scientists actively involved in the management of the Nairobi River basin, determine the extent of riparian zone degradation and recommend mitigation strategies like green infrastructure, building regulations, or levee systems.

3.4 Research design

Research design refers to the framework or blueprint for conducting the research (Creswell, 2018). A mixed-methods approach, combining quantitative and qualitative designs, was employed in the study. The quantitative design was used to assess land-use/land-cover changes, hydrological parameters, and flood occurrence, while the qualitative design utilised FGDs, KIIs, and field observations to understand community perceptions on flood management insights and mitigation practices.

This study adopted a correlational research design to examine the relationships between various variables and their impact on the Nairobi River basin riparian zone. This approach facilitated the analysis of vegetation cover distribution, occurrences of flash floods, the effects of flooding, and the evaluation of sustainable approaches for flood mitigation (Johnson & Christensen, 2019). By employing a correlational research design, the study aimed to elucidate the complex interactions between factors such as land use, urbanisation, climate change, and vegetation health. This methodology contributed to a comprehensive understanding of the degradation of the riparian zone and its implications for flooding in Nairobi City County, enhancing the development of effective mitigation strategies.

Table 2: A summary of the study-specific objectives and measurable variables/indicators.

Specific Objective	Measurable indicators	Research Design
1. Level of degradation of the Nairobi River riparian zone.	- Historical Land Use Changes - Vegetation Cover Analysis - Soil Erosion and Sedimentation	Correlation
2. Relationship between the level of degradation and occurrence of flooding along the Nairobi River riparian zone.	- Flood Frequency Analysis - Flood Severity Assessment - Hydrological Impact Studies	Correlation
3. Develop a matrix for the management of the Nairobi River riparian zone to mitigate urban flooding in Nairobi City County.	- Reforestation Initiatives - Riverbank Stabilisation Techniques - Green Infrastructure Implementation	Correlation

Table 2: A summary of the study-specific objectives and measurable variables

3.5 Sampling size

The study applied both simple random sampling and purposive sampling techniques for the selection of the desired population of the study as per the research objective. This has proven to be rich in knowledge by Mugenda and Mugenda (2003). The sample size was determined using Cochran's formula, which is suitable for larger populations.

$$n = \frac{Z^2 pq}{e^2} \text{ Equation……………1}$$

Where: n = required sample size

Z = Z-score corresponding to the desired confidence level (e.g., 1.96 for a 95% confidence level)

p = estimated proportion of the target population (0.5), q = 1-p

e = margin of error, typically set at 5% or 0.05

$$n = \frac{1.96^2 x\ 0.5(1-0.5)}{0.05^2}\ ; n = 384.16 \approx 384 \text{ respondents}$$

The calculated sample was 384 households, but only 373 households were reachable due to non-response or inaccessibility. However, the study incorporated 4 government officials, 5 representatives from various NGOs and CBOs, and 2 experts, comprising an urban planner and an environmental scientist.

Table 3: Illustration of the Sampling design

The unit of population	Sampling Method	Sample size
The individuals surrounding the Nairobi River riparian zone	Simple Random Sampling	Residents within the Nairobi River riparian zone
Government agencies officials	Purposive sampling	4 officials, each from various government agencies like Nairobi City County government, NEMA, WRA, NDOC, and the Ministry of Environment.
Non-Governmental Organizations (NGOs)	Purposive sampling	3 persons from various NGOs
Community-based Organizations (CBOs)	Purposive sampling	2 representatives from various CBOs.
Experts	Purposive sampling	2 experts comprising of an urban planner and environmental scientist.

Table 3: Illustration of the Sampling design

The target population included stakeholders involved in managing the Nairobi River riparian zone, including government officials, NGOs, CBOs, and residents. A sample size of 373 participants was determined using both simple random sampling and purposive sampling techniques. Data collection occurred in 2022, using a variety of tools including structured questionnaires, semi-structured interviews, field observations, and GIS and remote sensing technologies.

3.6 Data collection

This study applied both quantitative and qualitative data collection techniques to evaluate the contribution of the Nairobi River basin riparian area in controlling flash floods in Nairobi City County in Kenya.

3.6.1 Primary Data

Primary sources for current on-the-ground information were obtained through face-to-face interviews and self-administered questionnaires to the residents, experts, and officials (Avery, 2024). Primary data was collected through field observations to assess land-use changes and riparian degradation, KIIs with government officials, NGOs, and CBOs, questionnaires for households, and FGDs with community members. The use of primary data was paramount in evaluating the status of the Nairobi riparian zone and its proximal effects on flooding. By use of structured interviews, questionnaires, and direct observation, the research got firsthand information regarding the impacts of riparian degradation and floods from residents, environmental experts, and government officials from the targeted areas. Thus, this data proved valuable in obtaining the modern, real-life attitude toward the efficacy of the mitigation and the involvement of communities' actions.

3.6.2 Secondary data

Secondary data was collected from various sources, including satellite imagery (Landsat and Sentinel) for LULC analysis (1990–2020), hydrological data from the Kenya Meteorological Department, government reports, and previous research studies.

The state of the riparian zone between 1991 and 2021 was determined based on government reports, previous studies, and satellite imagery (Avery, 2024). Information obtained from government reports and studies for the historical period of 1991 to 2021 enabled the assessment of the riparian zone condition (Avery, 2024). Data obtained from satellites, NASA and Google Earth using GIS software identified changes in land use and vegetation as detailed by Muketha (2020). Historical data information was used to set up a database to compare the trends in land use, vegetation cover, and floods. From GIS tools, other rich satellite images from reputable organisations such as NASA and Google Earth enhanced the spatial assessment of the riparian zone concerning alteration over time (Muketha, 2020). The use of both primary and secondary data, therefore, enhanced the assessment of the current situation and the review of the past trends in flood management in Nairobi City County.

Data analysis of this study used Statistical Package for the Social Sciences, whereby an indexed evaluation was conducted to measure the relationship between riparian degradation and flood occurrences as reported by Muketha (2020). Furthermore, plan comparisons of effective urban riparian management projects, such as afforestation and green infrastructure project assessments, were done to identify their applicability in Nairobi (Avery, 2024; Muketha, 2020).

3.7 Data Collection Instruments

The study employed several data collection instruments to gather comprehensive data on the degradation of the Nairobi River riparian zone and its impact on flood management in Nairobi City County. They included questionnaires, structured interviews, focus group discussions (FGD), and field observations for primary data. On the other hand, data collection instruments for secondary data included GIS and remote sensing, document review, and hydrological modelling.

3.7.1 Questionnaires

The quantitative data were obtained from questionnaires, where structured questionnaires were administered to gather data on flood experiences, land-use practices, and mitigation measures from household respondents. Questionnaires are a reliable source of standardised responses and measurable data (Bryman, 2016).

3.7.2 Structured Interviews

Key informant interviews targeted government officials, NGOs, and CBOs representatives to collect expert knowledge on riparian management and policy enforcement.

Interviews using an interview guide were conducted with the purposively selected informants from the various Government Departments/Agencies, NGOs, and other organisations involved in the management of Riparian zones and flood disasters and/or mitigation. These interviews offered a significant quantity and quality of qualitative information about stakeholders' experiences and issues, as well as their opinions. Brinkmann (2016) found that because semi-structured interviews are structured so that the interviewer does not need to stick to asking questions in a predetermined order, these types of interviews are effective for investigating issues such as environmental management and the nuances of these problems.

3.7.3: Field Observations

Field observations were geotagged for spatial analysis and guided by a checklist covering human encroachment, vegetation cover, informal settlements, and solid waste disposal. Ground check was used to observe the general situation in and around the Nairobi River riparian area regarding vegetation cover, land use, and development. In environmental and land-use research, field observations are important independent sources of data that give credibility to data collected from other sources (Creswell & Creswell, 2018).

3.7.4: GIS and Remote Sensing

To assess and quantify spatial data, GIS and remote sensing technologies were employed for elements such as changes in land cover and flood-susceptible zones. LULC maps were generated using ArcGIS and QGIS, and NDVI analysis was applied to measure vegetation health and degradation over 30 years. Satellite images were procured from official websites like NASA and other authentic sources. The geographic information system was employed to map and perform change detection analysis. GIS has been widely recognised, especially for use in the control and monitoring of environments and the planning of cities.

3.7.5: Document Review

Document review involved reviewing legal documents, environmental management plans, and previous research on Nairobi River flood events. Literature and policy review, government documents and reports on riparian zone management and flood risk management were carried out. Document review can be an effective data collection method to put a finding in context and support the historical analysis within environmental research (Yin, 2018).

3.7.6: Focus Group Discussions (FGD)

Exploratory focus group discussions were conducted with community members to understand flood perception, local mitigation strategies, and ecological knowledge.

A FGD is an excellent technique for gathering an assortment of opinions and especially for finding indigenous solutions (Morgan, 2019). FGDs helped to evaluate their understanding and perception of riparian degradation and management of the riparian zone.

3.7.7: Hydrological Modelling

Hydrological modelling has become a central tool in many hydrological, environmental, and flood risk studies (Beven, 2018).

Digital Elevation Model (DEM) analysis plays a critical role in assessing flood occurrence and risk. It provides a three-dimensional representation of the Earth's surface, which helps to identify flood-prone areas. DEM analysis is used to automatically define watershed boundaries, the drainage network, flow direction, and accumulation. High accumulation areas typically indicate stream channels. It enables detailed examination of terrain characteristics to understand how water flows and accumulates across a landscape. Hydrologists and planners can identify flood-prone areas through DEM data, simulate flood dynamics, and evaluate potential impacts on communities and the surrounding environment.

3.8 Pilot Study

In this study, pilot testing of the data collection instruments was performed to increase the reliability and efficiency of the methodologies for evaluating the degradation and flooding in the Nairobi River riparian area. The pilot phase was conducted in Ondiri swamp within Nairobi City County, which had characteristics of the larger riparian zone. The areas are characterised by sparse vegetation, moderately and advanced vegetation cover, as well as different land use systems for the assessment of the data gathering instruments.

Plate 1 shows a section of the Nairobi River basin upper catchment area (photograph by the author at 1300 hrs, in April, 2021.

Plate 1: A section of the Nairobi River basin upper Catchment area.

Specifically, in the pilot testing of the questionnaires done at a small sample of stakeholders that included residents, governmental officials, environmentalists and conservationists, respondent evaluation on the comprehensibility and appropriateness of the questions posed was sought. In the same vein, the authors also undertook several semi-structured interviews with a purposive sample of purposively selected key informants drawn from some of the agencies as well as organisations involved in the management of riparian zones and flood issues. These interactions gave information about the interview process and the sort of questions that built more constructive answers.

During the pilot phase, both field observations of the pilots' behaviour and the use of observational checklists to evaluate the level of vegetation cover and the changes in land use were conducted. It also enabled the researchers to fine-tune the specification of the direct observation assessment criteria for the observations made to capture the environmental factors which impact the degradation of riparian ecosystems and the relevant flood risks.

Plate 2 shows a section of the Nairobi River basin upper Catchment area (photograph by the author, at 1400 hrs, in July 2021.

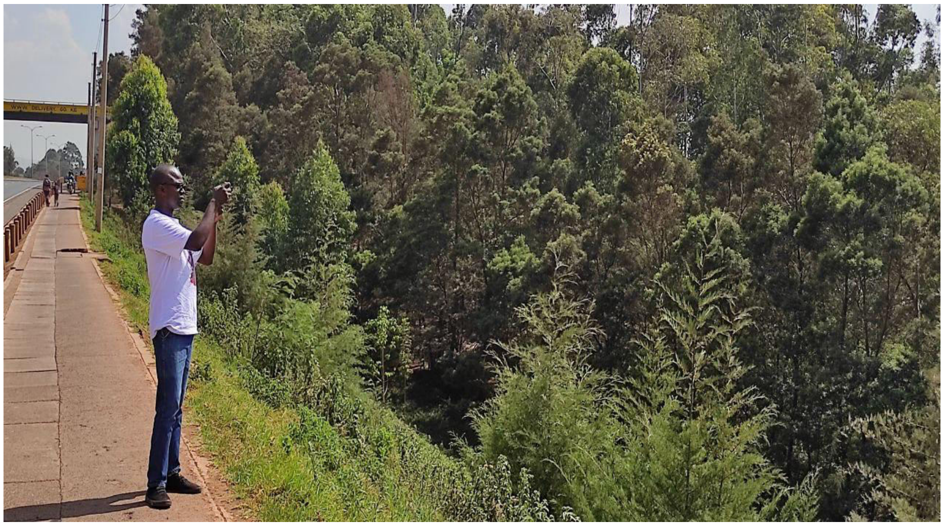

Plate 2: A section of the Nairobi River basin upper Catchment area.

The results obtained from the pilot tests were particularly useful in detecting such issues as ambivalences or bias in the chosen instruments and correcting them before the full-scale study was implemented. In the opinion of the author, this iterative approach inherent in the qualitative gaming research methodology helped to strengthen the process of data collection and improve the overall quality of the results obtained. Through pilot testing, the researchers were able to ensure that the data collected captured the details of degradation and flooding in the Nairobi River riparian zone from the perspective of developing sound management strategies.

Plate 3 shows a section of the Nairobi River basin CBO (photograph by the author, at 0900 hrs, in June 2021.

Plate 3: A section of the Nairobi River basin CBO.

3.8.1 Data Validity

Data validity on the theme of degradation and flooding in the Nairobi River riparian zone has been meticulously ensured through various measures and methodologies. Validity checks have involved employing multiple data collection methods, including surveys, interviews, and remote sensing techniques, to triangulate findings and corroborate results (Ndung'u & Muthoni, 2023). These methods were carefully selected and adapted to capture the diverse facets of the research theme, thereby enhancing the comprehensiveness and accuracy of the data collected. Subject matter experts reviewed data collection tools and confirmed they accurately measured the intended concepts, which establishes content validity. Furthermore, validation processes included pilot testing of data collection instruments and procedures to identify and address potential biases or inconsistencies (Krhoda, 2002). This iterative approach allowed the research to refine the methodologies and optimise the validity of the findings. Additionally, expert validation, where experienced researchers reviewed and validated the research instruments and procedures (Wanyonyi *et al*., 2022). By prioritising data validity through these comprehensive measures, research has produced robust and reliable findings that effectively capture the dynamics of degradation and flooding in the Nairobi River basin riparian zone, thereby informing evidence-based decision-making and management strategies.

The triangulation of primary and secondary data increases the confidence and credibility of the research findings, further strengthening validity. This involved using multiple data sources to study the same phenomenon, such as collecting original data via surveys. interviews, and reviewing existing literature or records (Creswell & Creswell, 2018).

3.8.2 Data reliability

Ensuring data reliability is paramount when examining the theme of degradation and flooding in the Nairobi River basin riparian zone. By employing rigorous methodologies and adhering to established best practices, research has enhanced the trustworthiness and validity of the findings.

One essential aspect of ensuring data reliability was the use of validated measurement tools and standardised data collection procedures. These tools, such as surveys, interviews, and remote sensing techniques, were carefully selected and calibrated to accurately capture key variables related to vegetation cover, flood occurrences, and land use changes (Ndung'u & Muthoni, 2023). Implementing standardised protocols across all data collection activities minimised variability and ensured consistency in the data gathered.

Additionally, thorough training and calibration of data collectors were a crucial step in promoting data reliability. Comprehensive instruction on research objectives and methodologies helped ensure that data collectors understood their roles and responsibilities. Calibration sessions were conducted, particularly for tasks involving subjective judgments or interpretations, to enhance inter-rater reliability (Wanyonyi *et al*., 2022).

Pilot testing of data collection instruments and procedures further strengthened data reliability by identifying and addressing issues and ambiguities before full-scale implementation. This iterative process allowed researchers to refine their methodologies and improve the accuracy of data collection efforts (Krhoda, 2002).

Reliability checks, such as test-retest reliability and inter-observer reliability, were essential for assessing the consistency of data collection measures. Consistent results across multiple observations and measurements enhanced confidence in the reliability of the data and contributed to the overall validity of the research findings.

Transparent documentation of data collection procedures and deviations encountered during the process was critical for ensuring data reliability. Maintaining transparency allowed for the reproducibility of results and facilitated peer review, further validating the integrity of the data (UoN ASCO, 2005).

Finally, robust data management practices, including thorough data cleaning and validation procedures, were essential for identifying and correcting errors or inconsistencies in the dataset. By prioritising data reliability through these measures, research has generated high-quality data that accurately reflects the complexities of degradation and flooding in the Nairobi River basin riparian zone, informing effective management strategies.

3.9 Data analysis

Data analysis on the theme of degradation and flooding in the Nairobi River basin riparian zone has been conducted using advanced statistical techniques and geospatial tools, ensuring a comprehensive understanding of the complex interactions and patterns within the dataset.

The collected data, comprising survey responses, field observations, and satellite imagery, have been meticulously processed and cleaned to eliminate errors and inconsistencies (Ndung'u & Muthoni, 2023). Quantitative data were analysed using descriptive statistics, correlation analysis to determine relationships between degradation and flood occurrence, and spatial analysis based on GIS for LULC change and flood-prone areas. Descriptive analysis techniques have been employed to summarise the key characteristics and trends observed in the data, providing valuable insights into the extent and nature of degradation and flooding phenomena. Descriptive statistics were used to summarise the land use and land cover (LULC) characteristics along the Nairobi River riparian zone. It helped to quantify the distribution and proportions of different land cover categories, such as built-up areas, vegetation, bare land, and water bodies. This provided a clear overview of spatial patterns and the extent of anthropogenic alterations along the riparian zone.

Furthermore, inferential statistical methods, such as the Chi-square (χ^2) test of independence, have been used to identify significant relationships and correlations between various variables, elucidating the underlying factors driving degradation and flooding dynamics (Wanyonyi *et al*., 2022). The Chi-square (χ^2) test of independence was conducted to examine the relationship between riparian zone degradation and flood occurrence. It helped to determine whether there existed a significant association between the observed levels of degradation and reported incidences of flooding along the Nairobi River riparian zone.

Finally, geospatial analysis techniques, including remote sensing and geographic information systems (GIS), have enabled researchers to spatially visualise and map the distribution of vegetation cover, flood-prone areas, and land-use changes, facilitating the identification of high-risk zones and informing targeted intervention strategies (Krhoda, 2002). A spatial analysis based on GIS was used to assess Land Use and Land Cover (LULC) changes and to identify flood-prone areas within the Nairobi River Basin. Spatial patterns of land-use transformation, areas of high degradation intensity, and flood vulnerability zones were mapped from the integration of ground elevation data derived from DEM analysis with satellite imagery.

Researchers have been able to derive meaningful insights and actionable recommendations for effective management and mitigation of degradation and flooding in the Nairobi River riparian zone through these rigorous analytical approaches; hence, contributing to sustainable development and resilience-building efforts in the region.

3.10 Assumptions

Assumptions of the study on the theme of degradation and flooding in the Nairobi River basin riparian zone have been carefully considered and incorporated into the research framework, guiding the interpretation and generalisation of findings. Firstly, it is assumed that respondents provide accurate and honest information. Hence, the data collected accurately represents the current state of the riparian zone and the occurrence of flooding events, allowing for reliable analysis and inference (Ndung'u & Muthoni, 2023). Additionally, the study assumes that the selected variables and indicators used to assess degradation and flooding dynamics are valid and relevant, capturing the key aspects of the phenomena under investigation (Wanyonyi *et al.*, 2022). It is also assumed that the relationships and patterns observed in the data are consistent over time and space, providing meaningful insights into the underlying drivers and mechanisms of degradation and flooding (Krhoda, 2002).

Furthermore, the study assumes that hydrological data from government sources are accurate and dependable, while satellite imagery and GIS outputs accurately reflect LULC changes. Moreover, external factors such as climate variability and land-use changes have been stable during the data collection period, minimising potential confounding effects on the analysis (UoN ASCO, 2005). Finally, it is assumed that the proposed management and mitigation strategies identified through the study are feasible and effective in addressing the identified challenges, contributing to sustainable development and resilience-building efforts in the Nairobi River basin.

3.11 Limitations of the Study

The limitations and scope of the study on the theme of degradation and flooding in the Nairobi River basin riparian zone have been carefully delineated to provide context for the research findings and to acknowledge the constraints within which the study was conducted. The scope of the study encompassed a specific geographical area within the Nairobi River basin, focusing on the riparian zone along a stretch from Motoine Primary School to Lenana School in Dagoretti Sub-County (Ndung'u & Muthoni, 2023). This spatial limitation ensured a manageable area for data collection and analysis while still capturing key aspects of riparian degradation and flooding dynamics. Additionally, some households were inaccessible, which reduced the sample from 384 to 373 households.

Data gaps in historical hydrological records may affect flood frequency analysis. Hence, the findings of the study may not fully capture recent developments or emerging trends beyond the specified timeframe. The temporal scope of the study extends over a defined period, typically from 1991 to 2021, allowing for the examination of long-term trends and changes in the riparian zone and flooding patterns (Wanyonyi *et al*., 2022).

Despite the comprehensive approach adopted in the study, several limitations warrant consideration. For instance, data availability and quality may vary across different variables and sources, potentially introducing bias or uncertainty into the analysis (UoN ASCO, 2005). Additionally, the study relied on secondary data sources, which may be subject to inaccuracies or inconsistencies inherent in retrospective data collection (Krhoda, 2002).

Furthermore, the findings are contingent upon the accuracy and reliability of the data collection tools and methodologies employed, which may influence the robustness of the conclusions drawn (CBS, 2001). Moreover, the findings are contextual and may not be generalizable to other riparian zones or regions with different socio-environmental contexts (Krhoda, 2002). For instance, although NDVI is a widely used metric for measuring vegetation health, NDVI values cannot directly measure flood severity. The NDVI is an indirect indicator used for assessing the impact of floods on vegetation and land cover.

Despite these limitations, the study provides valuable insights into the complex dynamics of riparian degradation and flooding in the Nairobi River basin, offering a foundation for future research and evidence-based policymaking in the realm of environmental management and disaster risk reduction.

3.11: Ethical considerations

Ethical considerations have been meticulously addressed throughout the study on the degradation and flooding in the Nairobi River riparian zone, ensuring strict adherence to ethical standards. Before commencing data collection, ethical clearance was obtained from the relevant institutional review board or ethics committee, following established guidelines and protocols (Mwachia *et al*., 2023). Approval was obtained from Nairobi City County authorities and the supervisor at Masinde Muliro University of Science and Technology (MMUST). This rigorous approval process involved a thorough review of the research methodology, data collection procedures, and potential risks to participants and the environment.

Informed consent was diligently sought from all participants, including stakeholders, community members, and research subjects, ensuring they were fully informed about the study's objectives, procedures, and potential implications (Kimani & Njuguna, 2023). Participants were provided with comprehensive information about their rights, including the voluntary nature of their participation and their ability to withdraw from the study at any stage without repercussion.

Furthermore, measures were implemented to safeguard the privacy and confidentiality of participants' personal information and sensitive data, in compliance with data protection regulations and ethical guidelines (Maina *et al*., 2022). Techniques such as data anonymisation and encryption were employed where necessary to minimise the risk of unauthorised access or disclosure.

Throughout the research process, concerted efforts were made to minimise harm and maximise benefits to participants and the broader community (Gikonyo & Wanyama, 2023). This included the use of culturally appropriate research practices, respectful engagement with stakeholders, and prioritisation of the dissemination of research findings for the benefit of local communities and policymakers (Wekesa *et al*., 2023).

CHAPTER FOUR: THE ANALYSIS OF RIPARIAN DEGRADATION

4.0 Introduction

This chapter presents the analysis of riparian degradation along the Nairobi River basin over 30 years (1991–2021). The analysis focuses on changes in land use and land cover, the implications of these changes on ecological integrity, and human activities influencing riparian degradation. The results are presented through geospatial analyses derived from satellite imagery, quantitative analysis, field observations, and socio-economic data collected from households, institutions, and key informants.

4.1 Historical Land Use Changes

The land use and land cover of the Nairobi River riparian zone from 1991 to 2021 were classified into several categories, including forested areas, bare land, croplands, vegetation cover, built-up areas, and water. The findings are summarised in Table 4.

Table 4: Land use and land cover type of Nairobi from 1991 to 2021

Land use and cover	Years			
	1991	2001	2011	2021
	Area Km^2			
Forest	120.54	60.21	80.1	90.2
Bare land	320.1	310.5	250.14	189.2
Cropland	134.24	177.2	189.5	175.58
Vegetation	130.5	120.45	110.2	174.23
Built up	80.2	150.25	201.15	275.5
Water	4.62	4.53	3.1	3.54
Total	790.2	823.14	834.19	908.25

Table 4: Land use and land cover type of Nairobi from 1991 to 2021

Source: Field Data (2022)

The data presented in Table 4.1 shows changes in land use and cover within the Nairobi River riparian zone from 1991 to 2021. Forested areas declined by 25 %, area covered with bare land declined by 41 %, while area covered with water declined by 23 %. On the other hand, croplands increased by 31%, vegetation cover increased by 34%, while built-up areas increased by 244%. The data show a steady increase in built-up areas, primarily due to increased urbanisation, informal housing, and industrial expansion within the riparian zone. The expansion of bare land along the riparian zone indicates vegetation loss and soil exposure to erosion (Omondi et al., 2021). Meanwhile, forest and grassland cover decreased by more than half, reflecting severe ecological degradation. These changes reflect dynamic shifts influenced by a combination of factors such as urbanisation, agricultural expansion, and environmental policies.

The Nairobi River riparian zone experienced a significant reduction in forest cover between 1991 (120.54 km^2) and 2001 (60.21 km^2). The forest cover declined by over 50 per cent, reflecting a concerning trend of deforestation within the riparian zone. This reduction might have been attributed to agricultural expansion, logging activities, and urbanisation, which are well-documented drivers of deforestation (Muthoni *et al*., 2018). However, subsequent slight increases in forest cover observed in 2011 (80.1 km^2) and 2021 (90.2 km^2) suggest potential afforestation efforts within the riparian zone. The upward trajectory could indicate interventions by authorities aimed at restoring forest cover within the riparian zone (Smith *et al*., 2018).

The consistent decrease in bare land area from 1991 (320.1 km^2) to 2021 (189.2 km^2) signifies ongoing conversions in land-use and infrastructure development. The decline may be attributed to the expansion of built-up areas, agricultural activities, and reforestation efforts on previously bare land (Jones and Brown, 2019; Muthoni *et al*., 2018).

The built-up area has experienced a significant increase with an upward trajectory from 1991 (80.2 km^2), 150.25 km^2 in 2001, 201.15 km^2 in 2011, and 275.5 km^2 in 2021, which indicates the rapid pace of urbanisation and infrastructure development within the riparian zone. Expansion in built-up areas often leads to habitat fragmentation, loss of biodiversity, and increased pressure on natural resources, consistent with global trends (Jones and Brown, 2019; Smith *et al*., 2018).

The observed fluctuations in water coverage, characterised by the consecutive reduction in water cover from 4.62 km^2 in 1991 to 3.1 km^2 in 2011, followed by a slight increase in 2021 (3.54 km^2), highlight the resilience of water bodies to changes in land use and cover. Further, factors such as climate variability and water management practices influence the dynamics of water coverage within the riparian zone (Jones and Brown, 2019).

These changes have significant implications for environmental sustainability, socio-economic development, and resilience to climate change impacts. Efforts to address deforestation, promote sustainable land management practices, and enforce conservation laws are essential for mitigating environmental degradation and safeguarding ecosystems within the Nairobi River basin riparian zone (Muthoni *et al*., 2018; Smith *et al*., 2018). Achieving a balance between urban development, agricultural expansion, and conservation efforts is crucial for ensuring the well-being of present and future generations in Kenya (Jones and Brown, 2019). Integrated approaches to land use planning, environmental management, and sustainable development are necessary to address the complex challenges posed by land use and cover changes within the Nairobi River basin riparian zone (Muthoni *et al*., 2018; Smith *et al*., 2018).

The land use and land cover changes in Nairobi from 1991 to 2021 underscore significant environmental transformations. The decline in forested and vegetative areas, coupled with the rise in built-up and bare lands, highlights the pressures of urbanisation and development. These trends necessitate sustainable land management practices and policies that balance development needs with environmental conservation to ensure Nairobi's long-term ecological health and resilience (UN-Habitat, 2016).

The data on land use and land cover (LULC) changes in Nairobi from 1991 to 2021 illustrate significant shifts in the landscape. These changes reflect the city's socio-economic transformations and environmental pressures over the past three decades. Notably, forested land has dramatically decreased, indicating substantial deforestation driven by urban expansion, agricultural encroachment, and infrastructure development. Forests, crucial for biodiversity, climate regulation, and water cycle maintenance, face significant threats from these anthropogenic activities (FAO, 2022). This observation aligns with existing studies documenting the adverse effects of deforestation and land degradation on riparian ecosystems (Muthoni et al., 2018). Deforestation disrupts hydrological cycles, exacerbating the risk of flooding along riparian zones (Odadi et al., 2016).

Other notable changes include significant increases in bare land and cropland, as well as a considerable decrease in overall vegetation cover. The rise in cropland suggests intensified agricultural activities, contributing to soil erosion and sedimentation, which further aggravate flood susceptibility (Gichuhi et al., 2022). Additionally, built-up areas have expanded, reflecting Nairobi's rapid urbanisation and population growth. This urban expansion leads to encroachment on riparian zones, exacerbating flood risks (Jones & Brown, 2019). The findings reveal a concerning decline in wetland areas compared with a significant increase in built-up areas. This alarming trend aligns with broader concerns about rapid urbanisation and its adverse impacts on natural ecosystems, including pollution, biodiversity loss, and urban flooding (Jones and Brown, 2019). Meanwhile, water bodies have decreased, highlighting potential alterations in hydrological dynamics due to reduced water retention capacity resulting from land cover changes and degradation (Alemayehu et al., 2019). These findings underscore the intricate relationship between land degradation and flood occurrences along the Nairobi River riparian zone, emphasising the urgent need for sustainable land management practices and conservation efforts to mitigate flood risks and safeguard riparian ecosystems.

4.2 Vegetation Cover Analysis and Soil Erosion and Sedimentation

Vegetation cover plays a critical role in maintaining the stability and ecological integrity of the riparian zones within the Nairobi River Basin. Consecutive reduction in vegetation cover from 130.5 km^2 in 1991, 120.45 km^2 in 2001, and 110.2 km^2 in 2011, suggests potential encroachment and conversion of green spaces to agricultural and industrial land use. However, the upward trajectory in 2021 increased vegetation cover to 174.23 km^2, suggesting deliberate efforts to increase green spaces within the riparian zone.

Decline in vegetation cover directly correlates with increased soil erosion and sedimentation within the river system. Vegetation cover within the riparian zone plays a crucial role in mitigating soil erosion and river sedimentation. The cover acts as a natural barrier that intercepts raindrops and prevents splash erosion, slows the velocity of surface water runoff, traps sediments, and binds soil particles together. Loss of vegetation cover within the riparian zone increases soil erosion and accumulation of sediments within the river system. Sediment accumulation not only reduces the flow capacity of the river but also reduces its capacity to carry water; hence, increasing flood vulnerability downstream.

Table 5: Summary of the environmental physical characteristics of the Nairobi River Basin Catchments

Catchment zone	Ecological Setting and Human Activity
Upper Catchment	The river originates from the western highlands of Kikuyu, Kabete, and Dagoretti. It contains forest remnants, grasslands, wetlands, and fertile soil that support agriculture and natural vegetation. Human activities include deforestation for agriculture and residential expansion. Loss of forest cover and wetland encroachment increase soil erosion and sedimentation, leading to moderate degradation.
Middle Catchment	The river passes through highly urbanized zones such as Westland's and Industrial Area. Human activities are focused on industrial activities and urban development. The riparian zones are encroached by humans, and the natural vegetation is mostly cleared. Loss of vegetation cover contributes to rapid run off and flash flooding.
Lower Catchment	The river flows in an extremely flat terrain that extends through informal settlements such as Kariobangi and Dandora, where people dump solid waste and discharge sewage into the river. These activities lead to severe degradation and frequent flooding in the lower catchment due to contamination of water sources and river channel siltation.

Table 5: Summary of the environmental physical characteristics
Source: KMD (2022)

The upper catchments of the Nairobi River basin are characterised by intensive agriculture and animal husbandry. Sparse human settlements dot these areas, which include coffee estates, small urban centres, and vegetable farms along the riverbanks. The agricultural activities, particularly coffee farming, significantly impact the riparian zones through soil erosion and chemical runoff. This is consistent with the findings by Odadi *et al*. (2016), who highlighted the environmental pressures from agricultural practices in Kenya. Additionally, the encroachment of small urban centres and vegetable farms exacerbates habitat fragmentation and vegetation loss, contributing to the overall degradation (Muthoni *et al*., 2018).

The upper agricultural reaches are marked by well-developed subsistence farms and residential plots interconnected with murram roads and footpaths. These agricultural activities, while crucial for local food security, have led to significant soil erosion and sedimentation in the river, impacting water quality and riparian vegetation (Alemayehu *et al.*, 2019). The residential plots, often lacking proper waste management systems, contribute to non-point source pollution, further degrading the riparian zones (Nziguheba *et al*., 2017).

As the Nairobi River basin progresses into peri-urban mid-reaches, the landscape is dominated by residential areas, road networks, and associated infrastructure. This section includes smallholder plots for growing various crops like Napier grass, sugarcane, kales, tomatoes, arrowroots, and bananas, along with tree nurseries and backyard lawns. The presence of garages, vehicle repair sheds, car washes, solid waste dump sites, and sewer treatment works further exacerbates pollution levels (Kairu *et al*., 2019). These activities lead to the discharge of oils, heavy metals, and other pollutants into the river, severely impacting water quality and riparian health (Gichuhi *et al*., 2022).

In the CBD, high-rise commercial office buildings and other urban development dominate the landscape. This area also hosts industries, residential areas, and extensive road networks. Like the peri-urban mid reaches, smallholder plots for various crops, along with garages, vehicle repair sheds and solid waste dump sites, contribute to pollution (Gichuhi *et al*., 2022). The intensive urbanisation and industrial activities in the CBD significantly impact the riparian zones through increased surface runoff, pollutant discharge, and habitat destruction (Smith *et al*., 2018; UNEP, 2016).

The lower Eastlands and industrial areas feature major industries and urban developments. Industries contribute to elevated levels of chemical and heavy metal pollution in the river. Residential areas and extensive road networks also add to the pollutant load through runoff and waste discharge (Le Maitre *et al*., 2015). The industrial activities here are a major source of riparian degradation, affecting both water quality and biodiversity (Ogutu-Ohwayo, 2016).

Plate 4 shows a section of the Nairobi River around the CBD area (photograph by the author, at 1000 hrs, in July 2021.

Plate 4: A section of the Nairobi River CBD

In the lower eastern peri-urban and savannah reaches, residential areas, urban centres, slaughterhouses, quarries, sewer-irrigated vegetable farms, and animal husbandry are prominent. These activities lead to significant organic and inorganic pollution in the river, with slaughterhouses and quarries contributing to sedimentation and chemical runoff (Arnell *et al*., 2018). The use of sewer-treated water for irrigation introduces pathogens and nutrients into the river system, further degrading the riparian environment (Alemayehu *et al*., 2019).

Plates 5 shows deforestation and crop production around Ondiri swamp (photograph by the author, at 0900 hrs, in September 2021.

Plate 5: Deforestation and crop production around Ondiri swamp.

The Ondiri/Kikuyu wetland, situated in the upper catchment of the Nairobi River basin, confronts numerous degenerative challenges. Deforestation by the local community for timber, charcoal and domestic purposes, alongside extensive water harvesting for Nairobi City, has diminished the riparian zone's vegetation cover, resulting in habitat destruction and loss for various wildlife species (Muthoni *et al*., 2018). The encroachment of farmers into the wetland, diverting the swamp for crop cultivation, further exacerbates these issues. Cultivation activities, including the growth of flowers, vegetables, sugarcane, arrowroots, and Napier grass, have escalated siltation levels, significantly compromising water quality and quantity (Odadi *et al*., 2016).

Plate 6 shows agricultural production around the Ondiri swamp upper catchment (photograph by the author in September 2021 at 1340 hrs)

Plate 6: Agricultural production around Ondiri swamp upper catchment.

Agricultural activities along the riverbanks are rapidly expanding, characterised by the cultivation of arrowroots, Napier grass, and sugarcane as the rivers flow through Nairobi City. Infrastructure development and building constructions along the riparian zone have facilitated farming practices along the banks, intensifying environmental pressures (Gichuhi *et al*., 2022). Ondiri Swamp, located in Kikuyu, Kiambu County, Kenya, represents a critical wetland ecosystem facing considerable environmental challenges primarily driven by deforestation and land-use alterations.

The rampant deforestation surrounding Ondiri Swamp stems from agricultural expansion, urbanisation and logging activities, resulting in adverse environmental consequences such as soil erosion, loss of biodiversity, and disruption of hydrological cycles (Muthoni *et al*., 2018). This loss of forest cover not only diminishes the natural habitat for various species but also reduces the swamp's resilience against flooding and water pollution (Odadi *et al*., 2016). Studies indicate that deforestation in regions bordering Ondiri Swamp mirrors broader trends observed across Kenya, where forested areas are rapidly converted into agricultural lands and urban settlements (Muthoni *et al*., 2018; Odadi *et al*., 2016).

The conversion of forested areas and wetlands into agricultural lands has led to habitat fragmentation and increased pressure on the swamp ecosystem. Agricultural activities, including the use of fertilisers and pesticides, contribute to water pollution, impacting the health of the wetland and its biodiversity (Kairu *et al*., 2019). Similar patterns of environmental degradation due to agricultural expansion are observed in other parts of Kenya, such as the Tana River basin and the Nyando River basin, emphasising the challenges of balancing agricultural development with environmental conservation (Nziguheba *et al*., 2017; Muthoni *et al*., 2018).

Plate 7 shows a tributary flowing towards the Nairobi dam in plate 7a, while plate 7b shows the mid-section of the Nairobi dam (photograph by the author in September 2021 at 0900 hrs).

A **B**

Plate 7: A tributary flowing towards the Nairobi dam and the Nairobi dam.

4.3 Economic activities along the Nairobi River riparian zone

The economic activities of individuals living along the Nairobi River basin riparian zone play a significant role in shaping both the local economy and the environmental landscape of the area. Understanding these economic activities is essential for comprehensively assessing the socio-economic dynamics and their potential impact on the riparian ecosystem. In this study, we delve into the diverse economic pursuits undertaken by respondents residing in proximity to the Nairobi River riparian zone, aiming to elucidate their implications for both local livelihoods and environmental sustainability. Table 6 presents a summary of the findings.

Table 6 summarises economic activities reported by respondents living along the Nairobi River riparian zone.

Economic Activities	Environmental Landscape
Small-scale farming and livestock keeping	Participants in the upper catchment zones engaged in small-scale farming and livestock keeping activities. They reared animals like cattle and goats and cultivated vegetables and other crops along riverbanks. These activities promoted encroachment into riparian zones, deforestation, and overgrazing, leading to loss of vegetation cover, increased soil erosion and sedimentation.
Manufacturing, Construction and Urban development	Manufacturing, construction and urban development activities are common in the middle catchment zone. These activities encourage encroachment into riparian land and discharge of industrial waste into the river. They contribute to degradation of water quality and loss of vegetation cover, leading to increased surface runoff and flood risk.
Small-scale repairs and waste collection	Small-scale repairs and waste collection are common in the lower catchment zone. Improper waste handling compromises the safety of the river. Plastic and solid waste clog the river channel, leading to reduced water flow and increased flooding potential.

Table 6: Economic activities along the Nairobi River riparian zone

Source: WRA (2022)

Plate 8 shows horticulture activity along Ondiri swam (photographed by the author in September 2021 at 1700 hrs).

Plate 8: Horticulture activity along the Ondiri swamp.

The significance of farmers in managing riparian zones and governing river basins cannot be overstated, a circumstance emphasised by Kagombe *et al*. (2018). Anley *et al*. (2007) stated the intricate link between households' primary source of livelihood and their occupations, which directly influences food accessibility and availability. This underpins the paramount importance of agricultural activities, particularly cash crop farming, which emerged as the primary livelihood source for 68.9% of respondents residing along the Nairobi River riparian zone (Smith *et al*., 2018; Brown & White, 2018). These findings resonate with global patterns observed in riparian communities, where agriculture serves as a cornerstone of income generation and sustenance (Jones *et al*., 2019). Furthermore, the presence of entrepreneurial endeavours, as evidenced by 12.7% of respondents identifying themselves as businesspersons, contributes to the economic vibrancy of the riparian zone (Roberts & Brown, 2019). The diversity in employment opportunities, ranging from on-farm and off-farm labourers to civil servants and private sector employees, highlights the complex socio-economic fabric of the area (Garcia *et al*., 2016; Johnson & Smith, 2020). Additionally, the engagement of respondents in a myriad of economic activities such as carpentry, local brewery, and household duties underscores the multifaceted nature of livelihood strategies adopted by riparian communities (Jones & Brown, 2019).

CHAPTER FIVE: FLOOD OCCURRENCE AND RISK

5.0 Introduction

This chapter analyses flood occurrence and risk based on the level of riparian zone degradation along the Nairobi River Basin. It helps to determine whether physical alterations to the riparian ecosystem, such as land use change, vegetation clearance, expansion of informal settlement, and solid waste disposal, influence flood occurrence and risk.

5.1 Flood Occurrence and Risk Analysis

The level of riparian zone degradation along the Nairobi River basin was assessed based on diverse human activities and environmental changes that influence the ecological integrity of the riparian ecosystem. They include riverbank encroachment, land use change, vegetation cover loss, accumulation of solid waste, and siltation. Understanding factors contributing to flood occurrence and risk is essential for developing targeted flood mitigation and adaptation strategies. Hydrological records and experiences by respondents across the upper, middle, and lower catchments were analysed.

Table 7 provides a summary of human activities and degradation indicators along the riparian zone.

Catchment Zone	Activities	Indicators of Degradation
Upper Catchment (Ondiri Swamp)	Farming	Deforestation and reduction of natural vegetation cover. Soil erosion and sedimentation in downstream sections
Middle Catchment (Industrial Area)	Industrial activities and urban development	Encroachment on riparian buffers. Discharge of untreated industrial wastewater.
Lower Catchment (Mukuru and Mathare)	Dense informal settlements and dumping	Encroachment and blockage by informal structures. Disposal of solid and liquid waste into the river.

Table 7: Summary of human activities and Degradation Indicators

Source: Author, 2021

5.1.1 Observed Flood Occurrence Patterns

Responses from household surveys and secondary hydrological data indicated that flood occurrence varied spatially along the riparian zone. The findings were summarised in a cross-tabulation (Table 8) indicating economic household activities and flood occurrence along the riparian zone.

Table 8: Crosstabulation of Economic Activities and Flood Occurrence along the Nairobi River Riparian Zone

Economic Activities	**Upper Catchment Low Flood Occurrence (%)**	**Middle Catchment Moderate Flood Occurrence (%)**	**Lower Catchment High Flood Occurrence (%)**	**Total**
Farming and livestock keeping	58 (44%)	25 (20%)	15 (12%)	98
Industrial activities	38 (30%)	75 (64%)	20 (16 %)	133
Informal settlements and dumping	34 (26%)	20 (16%)	88 (72%)	142
Total	130	120	123	373

Table 8: Actual Flood Occurrence along the Riparian Zone

Source: Author 2022

The crosstabulation results revealed significant spatial and socio-economic variation and a strong association between the type of economic activity and flood occurrence along the Nairobi River riparian zone.

A total of 373 responses were received from households along the Nairobi River riparian zone, which comprised 135 responses from the upper catchment and 120 responses each from the middle and lower catchments.

The highest flood occurrence was recorded in the lower catchment area, characterised by dense informal settlements and dumping activities. A total of 88 out of 123 responses from the lower catchment, amounting to 72% of responses, reported frequent flooding.

Moderate flooding occurrence was recorded in the middle catchment area, characterised by industrial and urban development activities. A total of 75 out of 120 responses from the middle catchment, amounting to 64% of responses, reported moderate flooding frequency.

Low flooding occurrence was recorded in the upper catchment area, characterised by farming activities. A total of 58 out of 130 responses from the middle catchment, amounting to 44% of responses, reported moderate flooding frequency.

The results indicate that high flooding frequency is predominant in areas characterised by dense informal settlements and dumping activities, reflecting the vulnerability of informal settlements where waste disposal blocks river channels. Conversely, farming activities are mostly associated with low flooding frequency as witnessed in the upper catchment zone of the Nairobi River.

The upper catchment zone experienced low flood occurrence, the middle catchment zone experienced moderate to high flood occurrence, while the lower catchment zone reported high flood occurrence.

The presence of vegetative cover and permeable soils in the upper catchment zone enhanced infiltration, while localised flooding was experienced in areas where riparian reserves were encroached by agricultural activities. The encroachment of built structures within the floodplain in the middle catchment zone contributed to impervious surfaces that limited infiltration, contributing to moderate to high flood frequency in the region.

Frequent and severe flooding events in the lower catchment zone are exacerbated by dense informal settlements within riparian buffers and poor solid waste management that clog and block drainage channels.

5.1.1.1 Chi-Square Test of Independence

A **Chi-square test of independence** was conducted to determine whether there existed an association between economic activities and flood occurrence along the lower, middle, and upper catchment zones. The actual findings on flood occurrence in Table 8 were used to compute the expected flood occurrence across the riparian zone, as shown in Table 9 below.

Table 9: Expected Flood Occurrence along the Nairobi River Riparian Zone

Economic Activities	Upper Catchment Low Flood Occurrence	Middle Catchment Moderate Flood Occurrence	Lower Catchment High Flood Occurrence	Total
Farming and livestock keeping	35	32	32	99
Industrial activities	46	43	45	134
Informal settlements and dumping	49	45	46	140
Total	130	120	123	373

Table 9: Expected Flood Occurrence along the Riparian Zone

Computing the Chi-square statistic:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

Where:

O = Observed frequency, E= Expected frequency.

Degrees of freedom (Df) = (r – 1) (c – 1)

Where r = 3 rows and c = 3 columns. Hence, df = (3 – 1) * (3 – 1) = 2*2 = 4

The computed Chi-square statistic is 130.68, while the critical Chi-square value (4 Df) at $\alpha = 0.05$ is 9.488.

Decision: Reject H0 since the computed Chi-square statistic 130.68 > 9.488.

Conclusion: There is a significant association between economic activity and flood frequency along the Nairobi River riparian zone. This implies that the type of economic activity practiced along the riparian zone influences the frequency and intensity of flooding.

The test confirms that, indeed, flood occurrence is not rampant within the upper catchment areas. However, flood occurrence is higher in highly degraded areas, characterised by unregulated urbanisation and solid waste disposal, such as areas within the CBD, industrial areas, and dense informal settlements.

5.2 Factors Contributing to Flood Occurrence

Flood occurrence along the Nairobi River basin riparian zone intensifies as the river flows downstream from the upper catchment zone to the lower catchment zone. The level of land use and land cover changes due to riverbank encroachment, loss of vegetation cover along the riparian zone, siltation, and accumulation of solid waste along the channel contribute to flood occurrence.

5.2.1 Land Use and Land Cover (LULC) Change

The rapid urbanisation of Nairobi City County has led to increased development in both formal and informal structures for human settlement. Riverbank encroachment by small-scale industries, housing, and waste dumping has significantly contributed to land use change and altered natural drainage systems in riparian buffer zones. Farming and deforestation activities along the riparian zone have significantly reduced natural vegetation cover, increasing the risk of high soil erosion, sedimentation, and flood occurrence in downstream sections of the river.

Additionally, human encroachment on riparian buffers due to the increased pressure for agricultural activities, urban development, and industrial activities has contributed to significant riparian degradation. Areas in the middle catchment zone, such as the Central Business District (CBD) and the industrial area, have witnessed rapid urban development, including uncontrolled expansion of residential buildings, pavements, and concrete roads. The transformation contributes to impervious surfaces, leading to poor infiltration, high surface water runoff, and flash flood occurrence during heavy rains.

Finally, human activities in dense informal settlements, including uncontrolled dumping of solid wastes into the river, reduce the channel capacity and flow velocity. The waste obstructs the natural flow of the river, leading to increased siltation and high flood occurrence, especially during heavy rainfall events. Human development encroaches on the riverbanks and floodplain, reducing the ability of riparian buffers to absorb and hold excess rainwater, leading to increased flood risk. Rapid urban growth puts strain on existing infrastructure and discourages the preservation of natural habitat in favour of new housing developments, shopping malls, and urban infrastructure, which exacerbates the problem of urban flooding.

5.2.1.1 NDVI as an Indicator of Riparian Vegetation Degradation

Vegetation cover serves as a primary indicator of riparian health. During high flow events, a healthy river naturally meanders and connects with its floodplain, which absorbs and holds excess rainwater. Vegetation cover along the riparian zone acts like a natural sponge to rainwater while roots create pathways and pores in the soil that facilitate infiltration. Satellite imagery and GIS-based land cover analyses (1991–2021) revealed a significant decline in forest areas and natural vegetation. The Normalised Difference Vegetation Index (NDVI) revealed that the Nairobi River basin riparian zone has experienced significant changes in vegetation density and health in the years 1991, 2001, 2011 and 2021. In 1991, the riparian zones supported much vegetation cover since they were less exposed to urbanisation. Increased human activities and expansion of urban developments had affected the riparian vegetation to a certain extent through the shredding of vegetation cover by 2001 due to human pressures, such as in areas of high population density and the development of industries. The trend has persisted to 2011, and the riparian zones as remained under significant pressure from urban developments, pollution, and occupation, despite efforts at rehabilitating them. By 2021, emerging organised initiatives to rehabilitate the source water Nairobi River and its riparian margins were poor/intermittent but had the following implications: Some areas had impressive improvement in vegetation cover resulting from planting exercises and conservation, while in other stretches, pollution sources and encroachment remained rampant.

Figure 3 shows the land use changes based on the vegetation index.

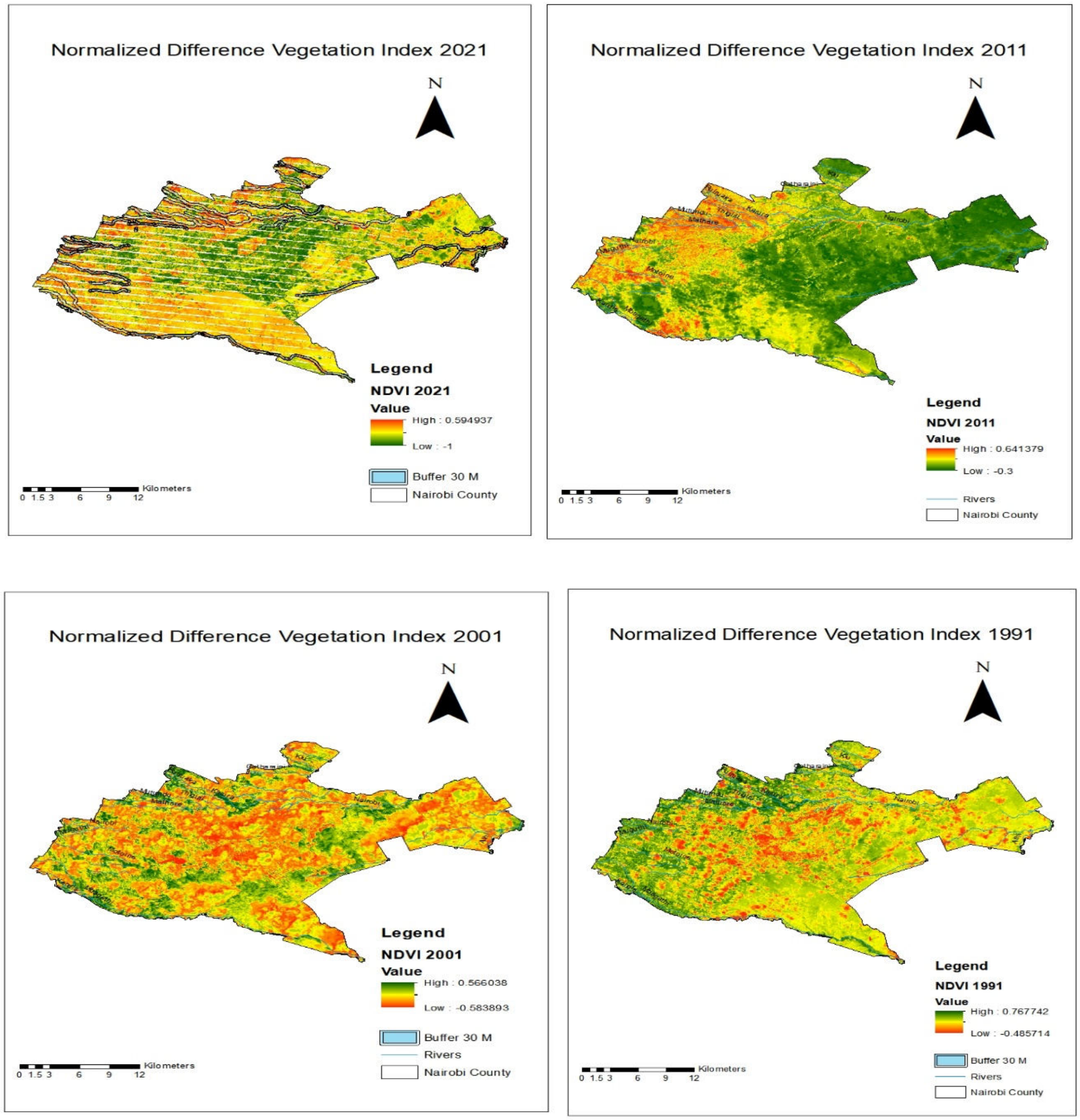

Figure 3: Normalised difference vegetation index (NVDI) 1991 - 2021

Source: Author 2022

The NDVI analysis depicted in Figure 3 illustrates a consistent trend of declining green vegetation density along the Nairobi River basin riparian zone from 1991 to 2021. Specifically, the NDVI values indicate a gradual decrease in vegetation density over time, with 1991 exhibiting the highest density (0.768) and 2021 showing the lowest (-1). This decline suggests potential environmental degradation and land cover alterations within the riparian zone, attributed to increased human activities such as settlement and cultivation encroaching upon these sensitive ecosystems. This interpretation resonates with existing studies detailing the adverse impacts of anthropogenic activities on riparian ecosystems, including habitat loss and ecological imbalance (Smith *et al*., 2018; Jones and Brown, 2019; Muthoni *et al*., 2018). Therefore, urgent intervention through sustainable land management practices and conservation efforts is warranted to mitigate further environmental degradation and preserve the ecological integrity of the Nairobi River riparian zone.

The observed vegetation cover variations along the riparian zone, as depicted in the map, highlight areas of concern and potential conservation priorities. While some regions exhibit moderate to high vegetation cover, particularly evident in areas like Karura Forest, others show signs of degradation and human interference. For instance, observations from 2011 reveal a higher vegetation cover towards the south of Nairobi County, contrasting with lower vegetation cover in the northern regions. Such discrepancies indicate areas susceptible to erosion and surface runoff, emphasising the importance of riparian buffer zones in regulating water flow dynamics and maintaining water quality. Despite increased government allocations to water supply and infrastructure development, the management and protection of wetland areas and riparian buffers remain understated, posing risks to water quality and quantity in urban areas within the Nairobi Metropolitan Region. Addressing emerging threats of illegal occupation and destruction of water reservoirs is imperative to safeguard the water resources essential for sustaining urban growth and ecological resilience in the region (Kenya Economic Survey, 2016). The natural vegetation within the riparian zone was replaced with built-up areas, croplands, and informal settlements. This has significantly reduced the capacity of soils to absorb water through infiltration, thereby increasing surface runoff and heightening flood risks.

5.2.1.2 Woody areas

The Nairobi River basin is characterised by the presence of riverine forests, covering approximately 5.7% of the total area, with forests occupying 37 km^2. Forests in the Nairobi River basin include Dagoretti, Ololua and Ngong forests, which harbour dense deciduous trees such as *Croton, Grevillea* and Eucalyptus.

Woody areas serve as crucial habitats for various wildlife species and contribute to the ecological health of riparian ecosystems. Dagoretti, Ololua, and Ngong forests located near the Kikuyu escarpments play a significant role in fortifying riverbanks and function as the source of rivers like the Ngong River. Additionally, the Kikuyu Forest, the source of the Nairobi and Mathare rivers, is densely populated with natural trees and supports a diverse array of animal species, including baboons, birds, and monkeys. Riverine forests are critical in flood mitigation and ecosystem resilience. Studies by Le Maitre *et al*. (2015) and Nziguheba *et al*. (2017) emphasise that riparian vegetation, including forests, regulates hydrological processes and reduces flood risks by absorbing excess water and minimising surface runoff. Arnell *et al.* (2018) discuss the importance of intact riparian ecosystems in maintaining water balance and enhancing biodiversity.

Figure 4 depicts woody regions in Nairobi City County.

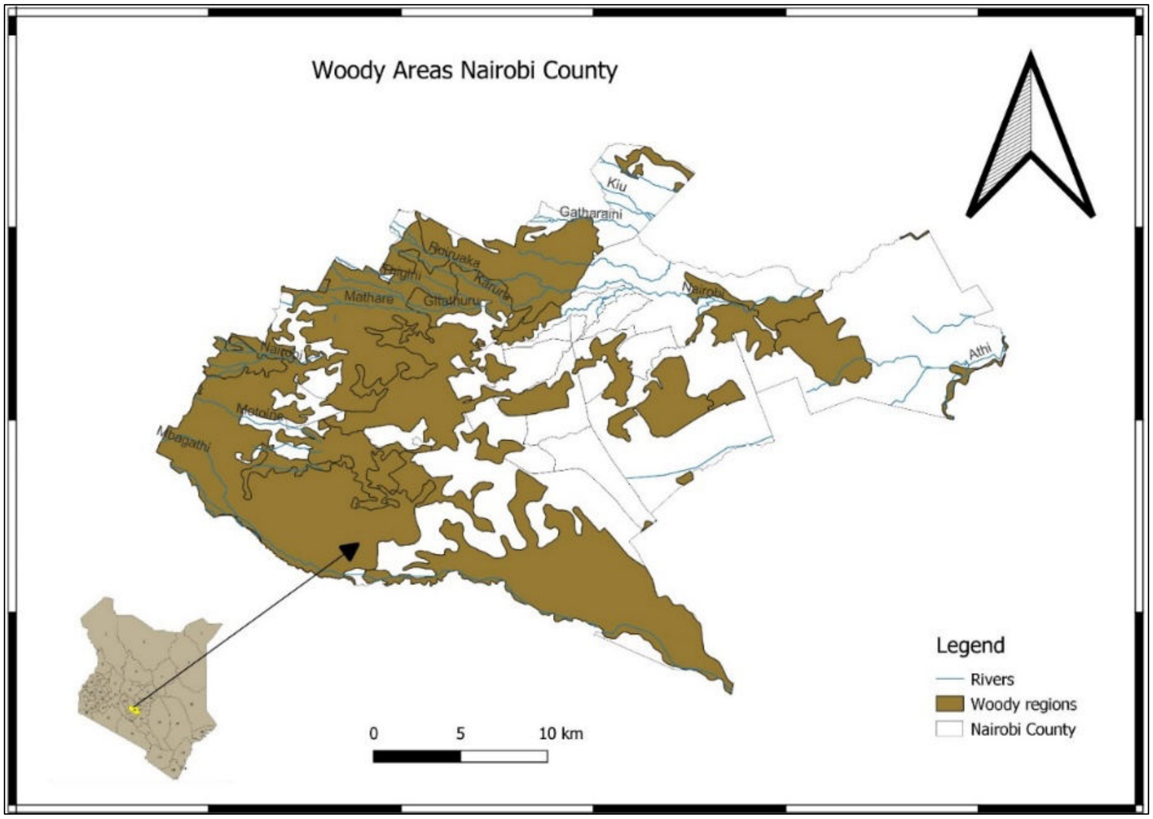

Figure 4: Woody areas in Nairobi County

Source: Author 2022

However, riverine forests face numerous threats primarily stemming from human activities such as logging and encroaching agriculture due to increasing population density in the basin. Illegal poaching, forest fragmentation, and excessive timber extraction further exacerbate the degradation of these vital ecosystems. Additionally, laxity from forest regulating agencies, poor enforcement of existing laws, and inadequate community policing pose significant challenges to the sustainability of riverine forests in the Nairobi River Basin. Therefore, the conservation and sustainable management of riverine forests in the Nairobi River Basin are imperative to mitigate the exacerbation of flooding events and preserve the ecological integrity of riparian zones. Implementing effective measures to address threats to these ecosystems aligns with broader conservation objectives and contributes to building resilience against flood risks in urban areas.

5.2.1.3 Digital Elevation Model Analysis

Digital Elevation Models (DEMs) help to identify flood-prone areas based on the physical terrain of the river basin. The Nairobi River basin flows through a steep and moderately sloping terrain to a flat terrain downstream.

Figure 5 provides a Digital Elevation Model (DEM) of Nairobi City County, illustrating topographic variation with assorted colours representing various elevation levels.

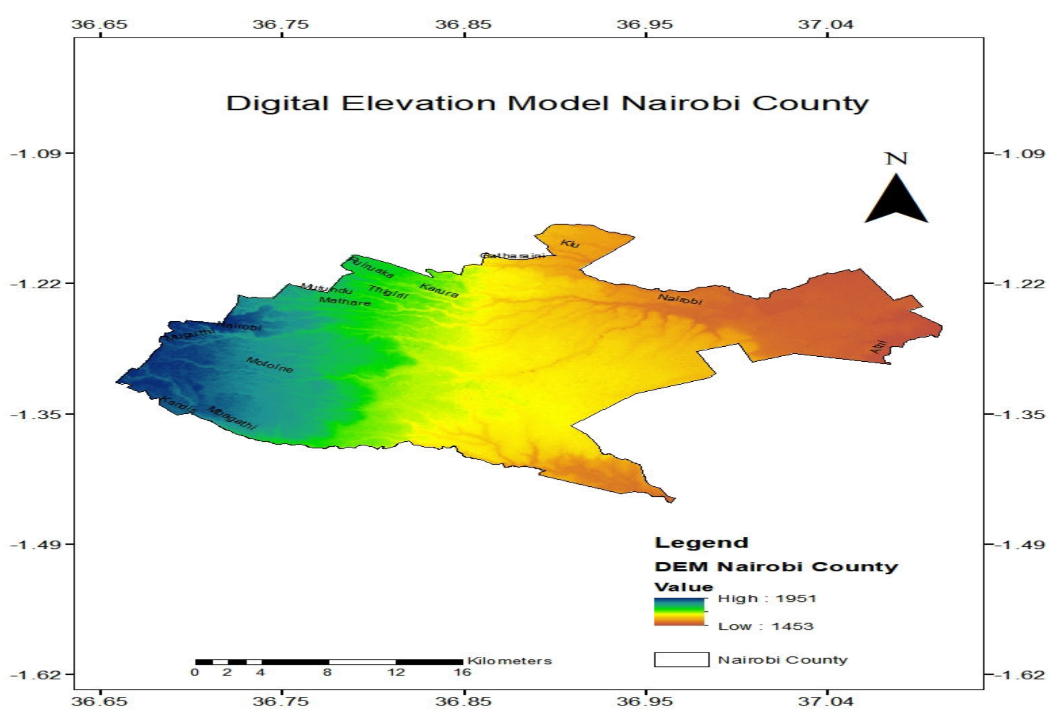

Figure 5: Digital Elevation Model Nairobi County

Source: Author 2022

Areas in shades of yellow, orange, and red signify higher elevations, with the highest point at 1,951 meters, located in the eastern and northeastern parts of the county. Areas like Nairobi and Athi, marked in orange and red, indicate significant altitude, consisting of uplands or hilly terrains. In contrast, areas marked in green and blue represent lower elevations, with the lowest point at 1,453 meters, found in the western and southwestern parts, including areas such as Ngong and parts of Karura.

The elevation gradient suggests that water flow would move from the higher elevations in the east and northeast toward the lower elevations in the west and southwest, crucial for understanding flood risks and drainage patterns. Lower elevation areas in the west (blue and green zones) are more prone to flooding, especially during heavy rainfall, as water accumulates in these regions. High-elevation areas (yellow to red) may be less susceptible to flooding and thus more suitable for certain types of infrastructure development. Conversely, lower elevation areas (green to blue) may require more robust flood management and drainage systems due to their flood risk.

The DEM can help identify critical areas for reforestation, soil conservation and other ecological interventions to prevent erosion, manage water resources, and maintain biodiversity. It assists in planning sustainable land use practices aligned with the natural topography to minimise environmental degradation. Engineers and urban planners can use this DEM for designing roads, bridges, and buildings, considering the elevation and slope of the land. Infrastructure in high-elevation areas needs to address slope stability and erosion control, while in lower areas, the focus might be on flood mitigation and water drainage systems.

Studies like those by Arnell *et al*. (2018) highlight the importance of DEMs in assessing flood risks. The lower elevation zones identified in this DEM correlate with areas more prone to flooding due to water accumulation from higher elevation zones. Jones and Brown (2019) discussed the impact of topography on urban expansion, indicating that urban development should be carefully managed in lower-elevation areas to prevent flood-related issues. Additionally, Le Maitre *et al*. (2015) emphasise the role of topography in environmental management, suggesting that identified high and low-elevation areas can guide conservation efforts to ensure sustainable use of land and water resources.

Upstream areas receive higher rainfall compared to the downstream, making them suitable for agriculture (CCN, 2007). Ondiri Swamp, a wetland in Kikuyu town, forms the headwaters of the Nairobi River basin. The wetland is threatened by various anthropogenic activities, including uncontrolled abstraction of water, and point and non-point source pollution (Ruffor Foundation, 2011). High sediment loads were recorded, especially in the upper catchment areas around Ondiri Swamp. This was due to agricultural encroachment, deforestation, and poor farming practices like cultivation on steep slopes that contributed to soil erosion, leading to sediment deposition downstream. Accumulation of sediment along the riverbed decreases the overall depth and capacity of the river; hence, increasing flood risk. Further, Adret slopes facing the sun and south-facing slopes in the northern hemisphere receive higher rates of insolation. Larger diurnal temperature range accelerates the rates of chemical weathering and exfoliation, which supports soil formation.

5.3 Flood Risk Assessment

During flood episodes, households living along the Nairobi River riparian zone suffer a lot of economic and social damage, i.e., livelihoods are destroyed, as well as houses get damaged and become uninhabitable. Some of the pictorial evidence of flooding of the Nairobi River riparian zone is shown in Plate 9:

Plate 9 shows the effects of flooding in Nairobi as observed in Syokimau residential estate in 2020 and Up Market Green Park Estate in May 2024.

	
Syokimau residential estate floods of 2020	**Up Market Green Park Estate May 2024**

Plate 9: Floods in Syokimau residential estate in and Up Market Green Park Estate

The aerial picture indicates the extent of damage that can be caused by floods to settlements established along the Nairobi River riparian zone. Potentially, it is indicative of a highly silted River without natural levees to control the flooding of the floodplain. Moreover, it shows that there is encroachment of settlement near the sensitive riparian zones affecting the Nairobi River's natural flow due to the anthropogenic modification of the Nairobi River's ecosystem for self-sustainability.

Plate 10 shows the degradation of the Nairobi River in the Kibra area (photograph by the author in September 2021 at 1700 hrs).

Plate 10: Degradation of Nairobi River, Kibra

The recurrent flood events along the Nairobi River basin riparian zone align with similar studies in flood-prone regions worldwide. Research in urban areas prone to flooding, such as studies by Arnell *et al*. (2018) and Kairu *et al*. (2019), consistently shows varied frequencies of flood occurrences. Likewise, Ogutu-Ohwayo's (2016) study on flood frequency in a Nigerian river basin reflects similar patterns, with some areas experiencing floods annually or biannually. These collective findings accentuate the persistent challenge of flooding in riparian zones globally, emphasising the need for initiative-taking mitigation strategies.

Studies in urban river basins across Asia and Europe, as evidenced by research by Chen *et al*. (2020) and Jones and Brown (2019), consistently highlight the regular occurrence of floods with varying temporal frequencies, emphasising the necessity of understanding these patterns for effective flood mitigation.

The persistence of flood episodes along the Nairobi River basin riparian zone echoes findings from global studies, including those by Arnell *et al*. (2018) and Le Maitre *et al*. (2015), showing the continuous threat posed by floods in riparian zones globally, exacerbated by urbanisation, land-use changes and climate variability.

These insights emphasise the urgency of initiative-taking measures to mitigate flood risks and enhance resilience among communities in flood-prone areas, as indicated by the findings, shedding light on the recurrent nature of flooding in the Nairobi River basin riparian zone.

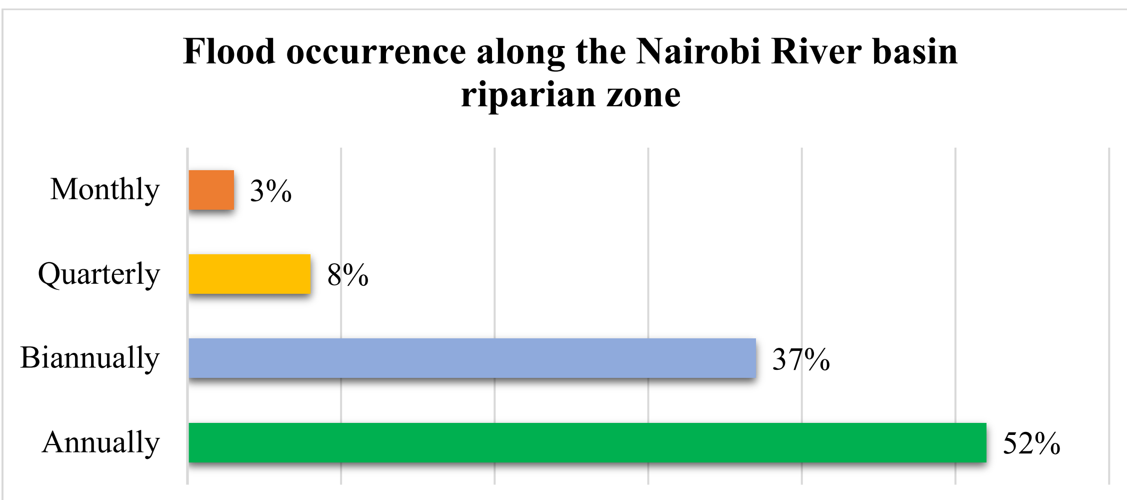

Figure 5.1: Floods along the Nairobi River riparian zone

Source: Author 2022

The findings presented in Figure 5.1 provide insights into the floods along the Nairobi River riparian zone as perceived by respondents. The data indicate that 52% of the total respondents (200 individuals) stated that floods occur annually. Additionally, 37% of the respondents (142 individuals) reported experiencing floods biannually, indicating that flooding is a recurring phenomenon in the area. Moreover, the data suggests that floods occur with varying frequencies, with 8% of the respondents (31 individuals) reporting quarterly flood occurrences and 3% (12 individuals) reporting monthly flood events. This highlights the diverse temporal patterns of flooding experienced by residents along the Nairobi River basin riparian zone.

5.3.1 Level of Rise

Flooding is the most prevalent natural disaster, often characterised as a high-intensity event that requires rapid emergency service response to minimise substantial human and economic losses. High rainfall intensity significantly increases flood risk along Nairobi River's riparian zones. Intense rain causes rapid surface runoff that overwhelm poor drainage systems. Poor waste disposal practices by garbage collectors and residents of informal settlements like Mathare and Mukuru also contributed to flood risk. Water sampling and community perception surveys, particularly in the middle and lower catchments, indicated increased industrial effluent discharge, solid waste accumulation, and turbidity.

Using riverbanks as disposal sites for non-biodegradable items like old clothes and plastic bags blocks the drainage infrastructure and prevents the effective flow of stormwater. Additionally, dumping directly into the river reduces its capacity to carry water downstream, leading to overflows and flooding into nearby homes. Further, increased impervious surfaces from urbanisation lead to river swells and overflow into densely populated informal settlements built in the floodplains, exacerbating damage and fatalities.

Proven data obtained through photogrammetry and cartography also offer critiques on historical management measures and record the extent of the flood. This cartographic evidence becomes the key to policies and the creation of new concepts of emergency management (USGS, 2021). The information obtained from these sources enables the stakeholders to predict floods periodically, quantify the effectiveness of flood prevention activities over time, and improve general flood management and prevention measures within the Nairobi River riparian land.

Figure 6 shows the level of flood risk across the Nairobi River riparian zone.

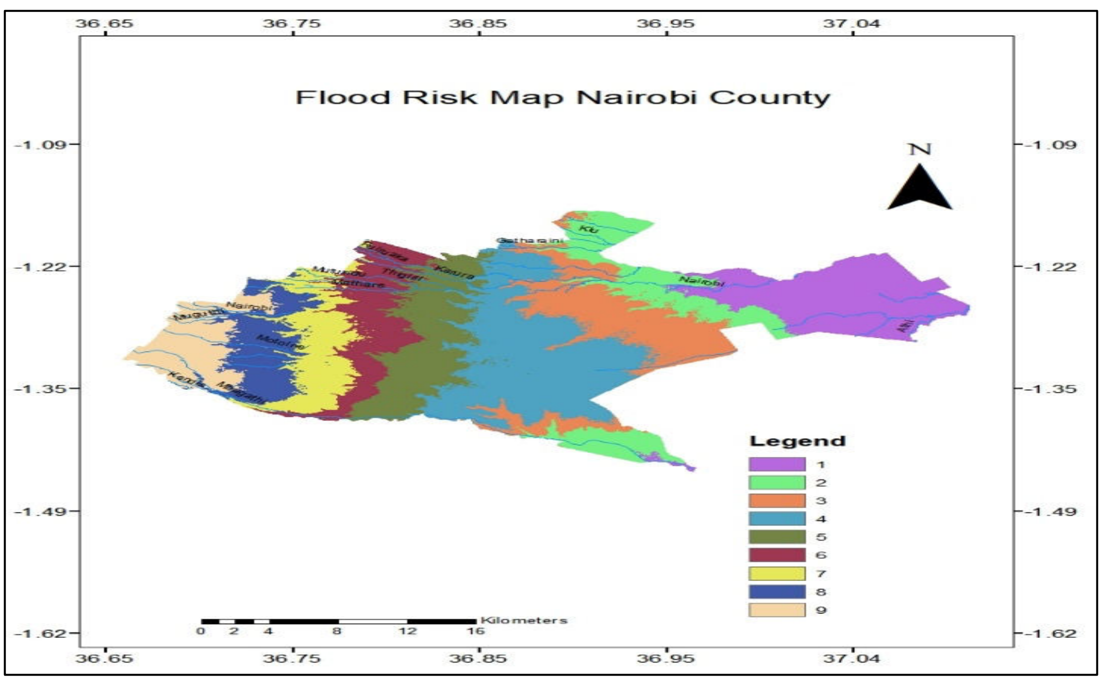

Figure 6: Flood Risk Map Nairobi County

Source: KMD (2022)

The DEM findings play a crucial role in understanding flood risk in association with topographic features. As depicted in the DEM, low-lying areas are typically more susceptible to flooding due to their lower elevation. Conversely, higher-elevation areas are less vulnerable to flooding. This relationship between elevation and flood risk aligns with the basic principle that water flows downhill, leading to accumulation and flooding in low-lying regions during periods of heavy rainfall or river overflow (Jones *et al*., 2018). However, human interference, such as the destruction of riparian zones, can exacerbate flood risk by altering natural drainage patterns and reducing the capacity of water absorption by vegetation and soil (Ouma & Tateshi, 2014).

The data presented in Table 10 details the flood risk levels across different zones within the Nairobi River basin. The study sought to assess the flood risk level along the Nairobi River basin based on the level of rise of river water.

Nairobi River Basin Zone	Level of rise
1	106025
2	78566
3	98589
4	151458
5	81862
6	64552
7	57697
8	52468
9	51452

Table 10: Flood Risk for Nairobi River Basin

Source: KMD (2022)

Zone 1 emerges as the most vulnerable area, with a level of rise reaching 106,025. This significant figure suggests a high susceptibility to flooding, potentially affecting a considerable population or extensive properties. Similarly, Zone 4 also exhibits a high flood risk, with 151,458 at risk, indicating a critical vulnerability that necessitates urgent flood management interventions.

Zones 3 and 2 follow, with levels of rise recorded at 98,589 and 78,566, respectively, indicating moderate flood risks that still require considerable mitigation efforts. Zone 5, with a level of rise of 81,862, also presents a moderate risk level. On the other hand, Zones 6 through 9 exhibit comparatively lower flood risks, with levels of rise recorded at 64,552, 57,697, 52,468, and 51,452, respectively. These figures suggest that although these areas are vulnerable to flooding, the risk is lower, potentially due to existing flood control measures or natural resilience.

The high flood risk in Zones 1, 3, and 4 indicates a pressing need for targeted flood management and mitigation strategies. These zones face challenges such as lower elevation, poor drainage systems, and high population density, making them more prone to flooding (Arnell *et al.*, 2018; Jones & Brown, 2019). Addressing these vulnerabilities requires the construction of levees, the enhancement of drainage systems, and the implementation of early warning systems.

Consistent with established studies, the variability in flood risk across the Nairobi River Basin underscores the importance of tailored interventions. For instance, urban planners should incorporate flood risk data into development approvals, particularly in high-risk zones like Zones 1 and 4, to avoid exacerbating existing vulnerabilities (Jones & Brown, 2019). Furthermore, ecological restoration efforts aimed at preserving and enhancing natural flood buffers, such as riparian forests and wetlands, are critical. These natural features play a significant role in mitigating flood impacts by absorbing excess water and reducing surface runoff (Le Maitre *et al*., 2015; Nziguheba *et al*., 2017).

The flood risk levels highlighted in Table 10 indicate the necessity for prioritised interventions in high-risk zones to enhance flood resilience in the Nairobi River Basin. Implementing strong flood management infrastructure, sustainable urban planning practices and ecological restoration will collectively mitigate flood risks and preserve the ecological integrity of the basin. This approach aligns with broader conservation goals and contributes to the resilience of urban areas facing flood threats. The following flood risk map illustrates the discussed findings.

In response to escalating flood risk, authorities have implemented drastic measures, including the demolition of buildings situated in flood-prone areas. Despite these efforts, the October to December rainy season continues to bring significant volumes of water, contributing to the city's rising flood risk, exacerbated by the impacts of climate change (Republic of Kenya, 2013). The lack of adequate waste management and urban planning further exacerbates the situation, particularly in informal settlements situated along Nairobi's rivers, where refuse accumulates and obstructs water flow, exacerbating flood risk (Republic of Kenya, 2016). The economic repercussions of flooding are substantial, with estimates suggesting annualised losses of 0.8% of GDP, primarily due to infrastructure damage (Republic of Kenya, 2016). This underscores the urgent need for comprehensive strategies encompassing urban planning, waste management, and infrastructure development to mitigate flood risk and protect the well-being of Nairobi's growing population (Ouma & Tateshi, 2014).

5.3.2 Rainfall Intensity

Rainfall intensity is an essential factor that contributes to flood occurrence and flood risk in the Nairobi River riparian zone. The contribution of rainfall intensity to flood risk was assessed using historical information, derived from various sources, including newspapers, official weather reports, and statements of eyewitnesses (FEMA, 2021). Historical precipitation information and rising water levels have provided significant validation in hydrological models used in measuring rainfall intensity (USGS, 2021). These records helped researchers and policymakers assess the economic and engineering consequences of floods and other disasters, depending on the reliability of records to shape vulnerability and risk assessments (FEMA, 2021).

Figure 7 highlights average monthly rainfall statistics in Nairobi City County. The data shows significant changes in average monthly rainfall throughout the year, indicating months that received heavy rains and low rainfall.

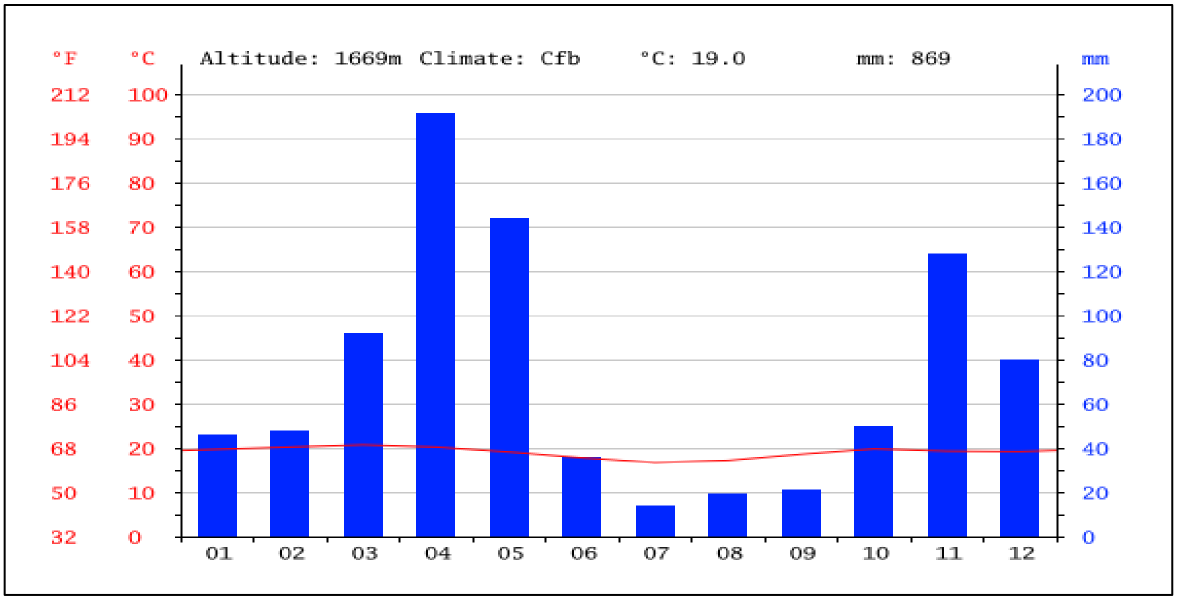

Figure 7: Average Monthly Rainfall in Nairobi City County

Source KMD (2020)

According to the data, the months of April, May, and November recorded the highest precipitation with approximately 190 mm, 145 mm, and 130 mm of rainfall, respectively, indicating high flood risk. The months of July, August, and September recorded the lowest precipitation with approximately 15 mm, 20 mm, and 22 mm of rainfall, respectively, suggesting low flood risk.

The analysis highlights large seasonal changes in rainfall intensity, which are critical for efficient flood management techniques in the Nairobi River Basin Riparian zone. The wet season, which lasts from March to April, May, November and December, is marked by heavy rainfall, which increases the risk of flash floods (Onyango, 2024). In contrast, the dry season falls in between, particularly in June, July, August, and September, implies a lower risk of flooding events.

Urbanisation has aggravated over the decades in that pollution, habitat destruction, and the emergence of slums deepened in Nairobi along the Nairobi River basin riparian zone (Muketha, 2020; Omusisi, 2022). These findings show the importance of comprehensive flood management solutions that meet the problems presented by increasing runoff during the wet season. To reduce flood hazards, sustainable measures such as reforestation, wetland restoration, and retention basin construction are advised. These solutions can efficiently absorb excess rainfall, reduce runoff, and improve the health of riparian ecosystems. While the current coordinated attempts at rehabilitation, such as reforestation and control of water pollution, have had some desirable effects, continuous pressures from urbanisation and climate change effects still exist.

5.3.3 Soil Characteristics

Soil characteristics can have a significant impact on flood risk as they control how fast water infiltrates as it moves across the ground. Sandy soils with good organic content and structure act like sponges. They absorb more rainwater and reduce flood potential. On the other hand, compacted dry soils like heavy clay absorb less water, increasing surface runoff and flood potential.

The soil map in Figure 8 below highlights the distribution of four distinct soil types across Nairobi City County, each marked by assorted colours and labelled with their respective codes. These variations demonstrate that soil characteristics directly influence the spatial distribution of flood risk within the Nairobi River Basin.

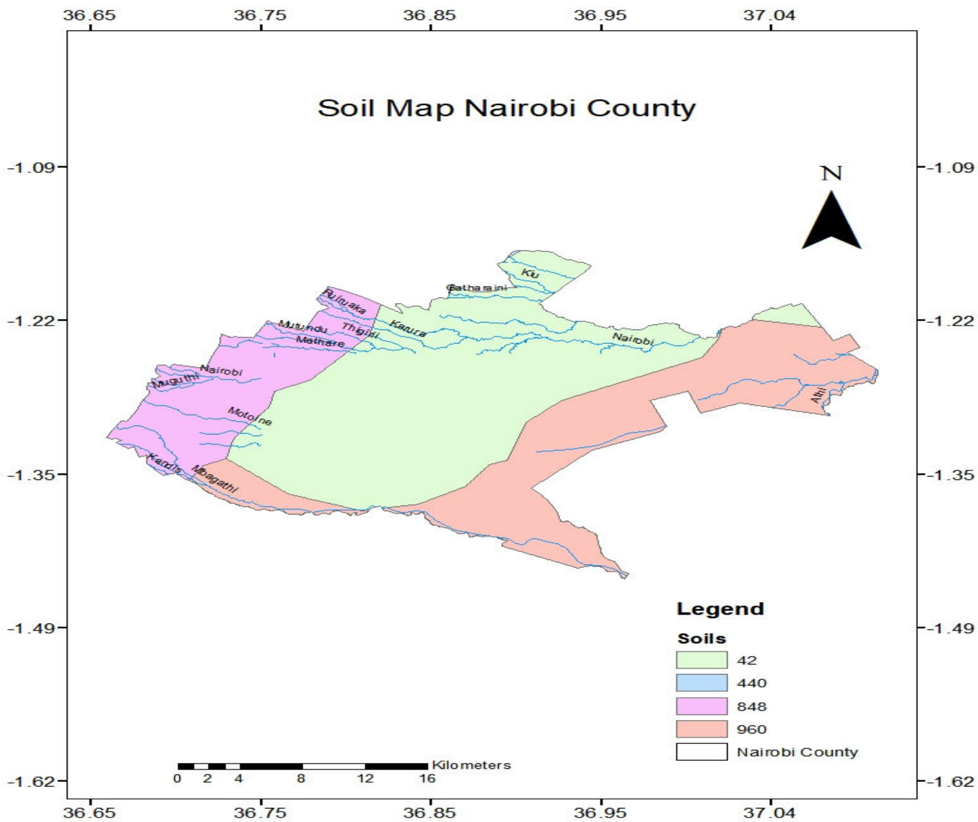

Figure 8: Soil Map Nairobi County

Source: Author 2022

Table 12 presents the spatial variability of dominant soil types in Nairobi City County, highlighting their respective areas and hydrological behaviour.

Soil Type	FAO SOIL	DOM SOIL	Shape Area
42	Fo48-2ab	Fo	0.029467
440	Bc14-2bc	Bc	0.000014
848	Nh2-2c	Nh	0.009885
960	Vp45-2/3a	Vp	0.017913

Table 11: Soil Variability in Nairobi City County

Source: Author 2022

Soil Type 42, indicated by a light green colour, is predominant in the central and northern parts of Nairobi County. The regions marked with this soil type are crucial for managing flood reduction strategies due to their extensive coverage, which necessitates comprehensive land-use planning and adaptive management measures to bolster flood resilience (Government of Kenya, 2018). The dominant soil under soil type 42 is Ferralsols (Fo), characterised by deep, well-drained, red soils with low fertility that are typically on stable landscapes. It covers the largest area (0.029 km^2) and exhibits high infiltration, contributing positively to groundwater recharge. Hence, the region dominated by soil type 42 experiences low surface runoff, leading to low flood risk.

Soil Type 440 (light blue) is found in the northeastern region; this soil type may influence local drainage patterns and flood risks. Given the significance of localised efforts such as the Nairobi River Basin Restoration Program, which emphasises riparian habitat restoration and community capacity building, managing this soil type becomes essential for reducing flood vulnerabilities in these areas (Gichuhi *et al*., 2022). The dominant soil under soil type 440 is Cambisols (Bc), characterised by young, moderately developed soils with variable texture and moderate drainage. It occurs in transitional areas, covering a small area in spatial extent of approximately 0.000014 km^2. It exhibits moderate infiltration capacity and occasional surface runoff, leading to moderate flood risk.

Soil Type 848 (pink) is predominantly located in the western parts of Nairobi County, covering areas like Dagoretti, Westlands, and some parts of Lang'ata. These regions could benefit from grassroots endeavours such as the Nairobi River Clean-up Campaign, which engages residents in waste management and riparian habitat restoration to enhance flood resilience (Kuria *et al*., 2018). The dominant soil under soil type 848 is Nitisols (Nh), characterised by deep, reddish clay soils with stable structure. It is found on rolling uplands and dominates the western uplands. It exhibits moderate to low infiltration capacity and high surface runoff when the soil is saturated. Additionally, urban expansion in the region increases runoff potential due to compaction and vegetation loss, contributing to moderate to high flood risk.

Lastly, Soil Type 960 (red) is found in the southeastern region of Nairobi County; this soil type is critical for areas that may face unique flood risks. Interventions by the Nairobi Metropolitan Area Transport Authority (NAMATA), which prioritise drainage improvement projects, are particularly relevant here to mitigate flood risks in low-lying areas (Government of Kenya, 2019). The dominant soil under soil type 960 is Vertisols (Vp), characterised by dark clay soils. It is found in flat lowlands and occupies 0.0179 km^2 primarily in low-lying southeastern zones. The region has poor drainage, and the soil exhibits exceptionally low infiltration capacity, contributing to high flood risk.

CHAPTER SIX: SUSTAINABLE MITIGATION APPROACHES

6.1 Introduction

This chapter examines sustainable interventions for mitigating flooding along the Nairobi River riparian zone. The discussion highlights flood impacts and indigenous coping strategies by local communities based on experience, traditional ecological knowledge, and social networks. In addition, the study highlights sustainable flood mitigation strategies, including bioengineering and green infrastructure approaches.

6.2 Flood Impacts and Indigenous Coping Strategies

Flooding along the Nairobi River riparian zone is associated with various social, economic, and environmental consequences.

Category	Flood Impact	Coping Strategies
Environmental	Riverbank erosion Loss of riparian vegetation and disruption of habitat Pollution from sewage and waste.	Protecting river edges with vegetation cover. Community clean-ups to clear drainage systems and reduce blockage.
Social	Displacement of households. Risk of death and injury.	Observing natural signs and early-warning signals, such as rainfall intensity, flow changes, and rise level. Collective evacuation support for displaced households. Temporary relocation to safer grounds.
Economic	Damage to homes and small businesses. Destruction of access roads and other infrastructure.	Developing protective barriers such as sandbags.

Table 12: Flood Impacts and Indigenous Coping Strategies

Source: Author 2022

Flood causes severe consequences, including riverbank erosion, loss of riparian vegetation and disruption of habitat, pollution from sewage and waste, displacement of households, risk of death and injury, and destruction of access roads and other infrastructure.

Indigenous and community-based coping strategies involve developing protective barriers such as sandbags, protecting river edges with vegetation cover, and community clean-up initiatives to clear drainage systems and reduce blockage.

Other coping strategies include observing natural signs and early-warning signals, such as rainfall intensity, flow changes, and rise level and temporary relocation to safer grounds.

Currently practised in Nairobi, aligning with Kenya's Vision 2030 environmental sustainability agenda (NEMA, 2022; UNEP, 2023). It integrates both community-based perspectives and scientific analyses of land use, including soil characteristics and hydrological behaviour. The proposed interventions include: the coping strategies, community perception of flooding, action for flood rehabilitation, and coping mechanisms.

6.2 Flood Impacts and Indigenous Coping Strategies

While economic activities do not directly cause flooding, they contribute to environmental stressors such as deforestation, impervious surface expansion, dense informal settlements, and poor solid waste management. The built environment in urban areas like Nairobi dominates over agricultural land use, making the region a concrete jungle. Concrete pavements and roads reduce soil infiltration capacity and increase surface runoff, leading to flash floods (Ngugi & Mwangi, 2024).

Table 11 provides an account of the type and spatial extent of impervious surfaces associated with economic activities and runoff potential in the Nairobi River riparian zone.

Economic Activity Category	Dominant Land Surface Characteristics	Approximate Impervious Surface Coverage (%)	Runoff Potential	Environmental Implications
Open parks and areas for small scale farming and livestock keeping	Loamy soils, partial vegetation cover, seasonal ploughing	10–30%	Low–Moderate	Enhanced infiltration; low runoff; minimal contribution to flooding but localized erosion possible.
Commercial and Business Zones, Industrial and Manufacturing Zones	Concrete pavements, minimal vegetation	80–95%	Very High	High surface runoff; frequent flash floods; clogged drainage systems due to solid waste and poor stormwater management.
Informal Settlements	Corrugated iron rooftops, unpaved roads, poor drainage	40–60%	Moderately High	Rapid surface flow, erosion, and siltation of drainage channels.

Table 13: Type and Spatial Extent of Impervious Surfaces

Source: Author 2022

As illustrated in Table 11, the extent of impervious surfaces significantly influences flood vulnerability. Flooding often transports fine silt particles rather than coarse sand (Okoth et al., 2023). Areas with greater vegetation cover, such as open parks and urban agriculture plots, provide natural flood buffering capacity, enhance infiltration, and contribute to low runoff. Conversely, areas representing over 70% impervious coverage, such as commercial, industrial, and densely built residential zones, exhibit extremely high runoff potential.

The findings reveal that surface permeability is a key determinant of urban flood risk (Njuguna & Mwangi, 2024; WRMA, 2023; UNEP, 2023). Therefore, effective urban surface management is a critical component of flood mitigation. Economic activities involving intensive land modification, such as business, industrial, and housing developments, are the primary drivers of flash flooding.

As Nairobi City County continues to urbanise, the expansion of impervious surface reduces infiltration and increases stormwater discharge into the Nairobi River. Business, industrial, and residential zones are characterised by concrete pavements and minimal vegetation cover, leading to high surface runoff. Stormwater management interventions, such as permeable pavements and infiltration trenches, should be prioritised within business and residential zones to offset the expansion of impervious surface and restore hydrological balance (UN-Habitat, 2023; Kimani et al., 2024).

Adaptive land-use practices, such as planting drought-resistant crops in sandy soil, also reflect an initiative-taking approach to maintaining agricultural productivity in the face of changing environmental conditions (Ouma & Tateshi, 2014). Planting flood-tolerant and waterlogging-resistant crops in riparian zones offers significant environmental and agricultural benefits, including enhanced flood resilience, improved water quality, and stabilised stream banks. Field and laboratory analyses identified clay-loam and sandy loam soils as predominant along the Nairobi River riparian zone. However, sandy-soil-tolerant crops, such as Napier grass and vetiver, are promoted in buffer zones to minimise erosion and enhance water infiltration. This demonstrates how communities are not only responding to immediate challenges but are also planning for long-term resilience by adopting sustainable agricultural practices (Smith et al., 2018). Therefore, flood mitigation strategies emphasise vegetative reinforcement and soil stabilisation through grass-rooting systems that enhance percolation and reduce sediment transport.

Finally, the reliance on technological solutions like solar energy in response to power outages and the construction of makeshift rafts for transport underscores the importance of integrating social, economic, and technological factors in disaster resilience. These innovations, whether in energy use or mobility, highlight the adaptability of affected communities (Garcia et al., 2016; Jones et al., 2019). Together, these strategies form a comprehensive approach to disaster risk reduction, addressing both immediate needs and longer-term challenges (Arnell et al., 2018).

6.3. Sustainable Mitigation Approaches

This section explores sustainable flood mitigation strategies tailored for Nairobi County, focusing on reforestation, riverbank stabilisation, and green infrastructure implementation. Each approach is evaluated for its effectiveness in reducing flood risks, enhancing soil stability, and promoting long-term environmental resilience.

6. 3.1 Reforestation Initiatives

Sustainable flood mitigation and ecological restoration efforts along the Nairobi River riparian zone can be achieved through reforestation initiatives. Reforestation plays a critical role in restoring vegetation cover, preventing soil erosion, and reducing flood risks by improving the natural water retention capacity of soils and landscapes. In Nairobi County, reforestation initiatives have been part of broader Sustainable Land Management

(SLM) strategies aimed at combating land degradation and promoting ecological recovery. These initiatives, including tree planting and catchment area reclamation, are crucial for mitigating flood risks in both rural and urban environments.

6.3.1.1 Impact on Different Soil Types

Soil Type 42 (Fo48-2ab) is one of the largest soil categories in the region. Due to its extensive coverage, reforestation in areas with Soil Type 42 is essential to enhance flood resilience. Planting trees helps improve the soil's water retention capacity, reduce surface runoff, and stabilise the land, particularly during heavy rainfall. By restoring natural vegetation in these regions, flood risks are minimised, and land use planning can be more sustainable (Government of Kenya, 2018). Grassroots reforestation initiatives in areas with Soil Type 848 (Nh2-2c) are essential. Such initiatives include the Nairobi River Clean-up Campaign, which involves local communities in planting trees and restoring riparian habitats. Grassroots reforestation initiatives in areas with Soil Type 848 (Nh2-2c) include planting native, drought-tolerant trees such as Acacia and promoting the use of organic compost to improve fertility. These recommendations help to stabilise the soil and improve soil organic matter to facilitate infiltration and increase vegetation cover to reduce soil erosion. These efforts have significantly contributed to reducing flood risks and improving the ecological health of the region (Kuria et al., 2018). By reforesting riparian zones, Soil Type 848's susceptibility to erosion is reduced, enhancing its flood management capacity.

6.3.1.2 Case Studies and Global Comparisons

Successful reforestation projects around the world offer valuable lessons for Nairobi. For instance, the Loess Plateau Watershed Rehabilitation Project in China demonstrated how large-scale reforestation can restore degraded land, reduce soil erosion, and increase water retention capacity, leading to reduced flood vulnerability. Similar approaches can be adapted for Nairobi's regions, especially in areas where soil erosion exacerbates flood risks.

In Rwanda, reforestation of the Nyungwe Forest has successfully prevented soil erosion and stabilised landscapes, providing a model for combining forest conservation with flood risk reduction (UNEP, 2020). In Nairobi, comparable results can be achieved by scaling up tree planting programs in areas prone to flooding, particularly on slopes and degraded lands.

6.3.2 Riverbank Stabilisation Techniques

Riverbank stabilisation is a crucial technique for controlling erosion and managing flood risks in riparian zones. This approach involves the use of bioengineering methods and structural interventions to strengthen riverbanks and prevent them from collapsing during heavy rainfall or flood events.

6.3.2.1 Bioengineering Approaches

Bioengineering methods, which use natural materials such as vegetation, are effective in stabilising riverbanks and reducing erosion. These techniques are often combined with other ecological restoration methods to create sustainable flood management solutions.

Soil Type 440 (Bc14-2bc) plays a significant role in local drainage patterns and flood management. Bioengineering methods like planting deep-rooted native vegetation along riverbanks can help stabilise the soil and reduce erosion in areas with this soil type. The Nairobi River Basin Restoration Program has incorporated these bioengineering techniques to enhance riverbank stability, prevent flooding, and improve the overall resilience of riparian zones (Gichuhi et al., 2022).

Soil Type 960 (Vp45-2/3a) is associated with low-lying areas that face unique flood risks. Structural riverbank stabilisation measures such as the construction of gabions, retaining walls, and riprap are often used in these regions to protect the riverbanks from erosion and to manage floodwaters effectively. Projects spearheaded by the Nairobi Metropolitan Area Transport Authority (NAMATA) have prioritised such interventions, particularly in areas prone to severe flooding (Government of Kenya, 2019). These projects are crucial for ensuring that floodwaters are channelled efficiently and that the structural integrity of riverbanks is maintained.

6.3.2.2 Global Best Practices in Riverbank Stabilisation

The Room for the River Program in the Netherlands is a leading example of how riverbank stabilisation and floodplain management can mitigate flood risks. This program focuses on making space for rivers by allowing them to flood certain areas in a controlled manner, reducing pressure on riverbanks. The program has successfully reduced flood risks in urban and rural areas by integrating natural bioengineering methods with structural reinforcements like widening floodplains, creating bypasses, and relocating dikes. Adapting these methods to Nairobi's context, particularly in regions with high flood risks, could significantly enhance the city's flood resilience.

6.3.3 Green Infrastructure Implementation

Green infrastructure refers to the use of natural and semi-natural systems to manage stormwater, enhance biodiversity and improve urban resilience to flooding. It integrates ecological, engineering, and social solutions to manage stormwater, reduce surface runoff and flood risks, and restore the ecosystem. The green infrastructure includes the integration of permeable surfaces, wetlands, rain gardens, and other natural features into urban planning.

6.3.3.1 Wetlands and Permeable Surfaces

Wetlands and permeable surfaces are essential components of green infrastructure, particularly in regions with high flood risks. They work by absorbing excess stormwater, reducing surface runoff, and promoting groundwater recharge.

The western region of Nairobi, predominant with Soil Type 848 (Nh2-2c), including areas like Dagoretti and Westlands, benefits from the implementation of green infrastructure initiatives. The creation of rain gardens and the restoration of wetlands have helped manage urban runoff and reduce the risk of flooding in the region. The Nairobi River Clean-up

Campaign, which involves the establishment of rain gardens, is a notable example of how green infrastructure can enhance flood resilience by improving water infiltration and reducing pressure on drainage systems (Kuria et al., 2018).

The integration of permeable surfaces into urban planning can enhance flood management in the central and northern parts of Nairobi, with Soil Type 42 (Fo48-2ab). Urban areas can better absorb rainwater, reducing the risk of flash floods by reducing impermeable surfaces like concrete and asphalt. Green infrastructure projects in these regions can include permeable pavements, green roofs, and bioswales to manage stormwater more effectively (Government of Kenya, 2018). Roads, pavements, parking lots, and sidewalks are designed to allow infiltration, which not only reduces surface runoff but also minimises pressure on drainage systems. Natural or constructed wetlands and rain gardens capture stormwater, filter pollutants, and provide habitat for wildlife. Finally, other natural features like urban trees and vegetated river channels stabilise soil and prevent soil erosion by providing insulation and reducing surface runoff.

6.3.3.2 Case Studies and Comparisons

The Thames River Restoration Project in the United Kingdom is an excellent example of how green infrastructure can be used to enhance urban resilience to flooding. By restoring wetlands and creating permeable landscapes, the project has significantly reduced flood risks in densely populated areas. Similar green infrastructure initiatives can be implemented in Nairobi, particularly in regions prone to flooding, to enhance the natural absorption of stormwater and reduce the burden on drainage systems.

In the United States, cities like Philadelphia have successfully incorporated green infrastructure into urban planning using green roofs, rain gardens, and porous pavements to manage stormwater. This approach has reduced urban flooding and improved water quality, providing a model for Nairobi to follow in implementing green infrastructure solutions in flood-prone areas.

6.4 Community Perception of Flash Floods

Community perception of flash floods is influenced by local knowledge and environmental cues. The perception of flood risk is shaped by both observations and historical experiences, which help to anticipate and prepare for flash floods. The observations of natural indicators, such as the intensity of rainfall, the colour of clouds, wind direction, and water flow analysis, by local elders, provide early warnings of floods, which prompt the community to adopt timely preparedness actions. A local respondent from an FGD forum said,

'… nikiona tu mawingu yanabadilika rangi nitajua pengine baada ya dakika ishirini mvua itanyesha. Nitatoa vitu vyangu nje na nijikinge.' "When I see the clouds changing colour, I will know that the rains are here in the next twenty minutes. Will remove my property that is outside and shelter myself from the rain."

The communal practices observed in the management of flood risks among residents of the Nairobi River basin riparian zone resonate with findings from existing studies on Indigenous knowledge systems and community-based flood adaptation strategies. The utilisation of hydro-climatic knowledge, acquired through sky observation, animal behaviour monitoring, and river water observation, echoes the sentiments expressed by scholars such as Arnell *et al*. (2018) and Le Maitre *et al*. (2015), who emphasise the significance of local ecological knowledge in enhancing community resilience to flood hazards. Similarly, the initiative-taking dissemination of flood prediction data within the community aligns with recommendations for participatory early warning systems advocated by studies such as the Republic of Kenya (2013c), underscoring the pivotal role of local governance structures and grassroots initiatives in fostering flood awareness and preparedness.

6.5 Indigenous Coping Mechanisms of Flash Flood Experiences

The study aligns with the notion that floods are a recurrent hazard globally, contributing to increased vulnerability in communities, as noted by KIPRA (2014). Much like the communities in Nairobi, those in flood-prone areas such as Bangladesh's Teesta Valley use Indigenous knowledge to cope with floods (Smith et al., 2018). The challenges faced by riparian communities in Nairobi mirror those in Bangladesh, where severe flooding impacts livelihoods and well-being (Roberts & Brown, 2019; Arnell et al., 2018). Indigenous strategies rooted in traditional practices are essential for enhancing resilience against flood risks, allowing communities to manage shelter, food security, and health needs effectively during and after flood events (Johnson & Smith, 2020; Kagombe et al., 2018).

6.6 Actions Towards Rehabilitation of Flood and Riparian Ecosystem Reservation

Efforts by the Kenyan government to mitigate riparian degradation align with findings indicating disparities in land distribution that adversely affect urban planning (Karanja, 2019). Stakeholders emphasise the necessity of stringent land use regulations and development controls to preserve natural habitats. Urban expansion in Nairobi, particularly in vulnerable riparian zones, reflects the need for infrastructure improvements, such as rainwater harvesting and permeable pavements, to reduce flood risks (Gichuhi et al., 2022). Community involvement in conservation, reforestation, and urban greening initiatives is vital for effective environmental management (Nziguheba et al., 2017; Mwangi, 2020). Addressing housing disparities and enhancing community participation in environmental regulation are essential for successful riparian ecosystem restoration (Jones & Brown, 2019).

Moreover, the involvement of local mosques and community institutions in flood awareness campaigns mirrors the collaborative efforts between formal and informal institutions highlighted in the literature (Ouma & Tateshi, 2014; Kagombe et al., 2018). Such initiatives contribute to the democratisation of flood information dissemination and empower community members to undertake adaptive measures in response to flood threats. Additionally, the adaptive behaviours exhibited by residents, including the selection of shelter sites based on flood severity and duration, resonate with studies on indigenous flood coping strategies (Republic of Kenya, 2016; Anley et al., 2007), illustrating the adaptive capacity of local communities in navigating flood-induced disruptions. These findings show the importance of integrating Indigenous knowledge systems with contemporary flood risk management approaches to enhance the resilience of vulnerable populations in flood-prone areas like Nairobi City County.

6.7 Future Land Use Expectations

The challenges facing urban development in African cities, particularly Nairobi, stem from historical socio-economic factors and ineffective policies. Rapid population growth, poverty, and urban sprawl exacerbate these issues, hindering the achievement of sustainable urban development goals (Government of Kenya, 1999). The significant influx of people into urban areas leads to environmental degradation and increased health risks, with a substantial portion of the population living in informal settlements. The qualitative findings reveal a pressing concern regarding pollution along the Nairobi River riparian zone, exacerbating urban flooding issues in Nairobi City County. Over a span of 75 years, the river has suffered from significant pollution, with participants noting that an estimated 2475 tons of waste produced daily contributes directly to its degradation. This emphasises the urgent need for improved water quality and ecosystem health in affected riparian communities. The limited success of interventions, such as the Kijabe-Globe roundabout project, highlights the complexities of managing urban flooding and pollution.

The lack of effective urban management mechanisms hampers the realisation of long-term development strategies (Karanja, 2019). It is crucial to re-evaluate existing policies and adopt a multi-sectoral approach to land use planning that fosters stakeholder participation and integrates financial resources with development trends. A comprehensive strategy that integrates urbanisation, pollution control, and flood risk management is crucial. This should include enhanced waste management infrastructure and sustainable urban planning initiatives to protect riparian zones and mitigate flooding impacts (Karanja, 2019; Gichuhi et al., 2022). Controlling and planning land use in urban areas, such as designing for mixed-use developments, preserving green spaces, and enhancing an effective solid waste management infrastructure, can help regulate water flow and quality, mitigating flood risks.

6.8 Water Withdrawal and Diversion

Water withdrawal refers to extracting water from surface or groundwater sources, often involving diversions using barriers such as dams and canals. The Nairobi River faces stressors like pollution and infrastructure developments, which complicate water management (Karanja, 2019). Limited research on the drivers of water abstraction in Kenya hinders effective management of these resources. The need for comprehensive studies on water supply and urban demand is critical to understanding the root causes of water diversion and abstraction in tropical river basins.

6.9 Branching River

Distributaries are streams that branch off from a main river, a process known as bifurcation. The Nairobi River flows through Nairobi and eventually merges with the Athi River, which empties into the Indian Ocean. Exploiting freshwater resources through river water abstraction and diversion is common globally, with societal demands driving these practices. Current trends indicate that about 60% of rivers worldwide have been diverted, influenced by climate change and shifting rainfall patterns (Karanja, 2019). The management of these diversions must align with the Environmental Management and Coordination Act (EMCA) and water resource regulations, ensuring sustainable practices are upheld.

CHAPTER SEVEN: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter presents a summary of the findings obtained in the study seeking to assess the contribution of the Nairobi River riparian zone in the management of flash floods in Nairobi City County, Kenya. It focuses on three objectives of the area, findings and recommendations based on the conclusions and suggestions for further research. Specifically, determining the relationship between vegetation cover distribution and flood occurrence along the Nairobi River riparian zone, examining the correlation between vegetation cover and the effects of flooding on households along the Nairobi River riparian zone and examining sustainable mitigation approaches of flooding along the Nairobi River riparian zone.

7.2 Summary of the Findings

7.2.1 Summary of Findings: Level of Degradation of the Nairobi River Riparian Zone

This study assessed the level of riparian degradation along the Nairobi River riparian zone over time and linked the findings to various indicators of riparian degradation, such as land use changes, vegetation cover, economic activities, and flood frequency across the upper, middle, and lower catchment zones of the Nairobi River Basin. Data were collected through field surveys, socio-economic assessments of riparian communities, and satellite imagery analysis.

The findings revealed considerable land use and cover changes between 1991 and 2021, where forest and bare land declined significantly, while built-up areas expanded significantly from 80.2 km² to 275.5 km². Similarly, vegetation cover initially declined, indicating potential riparian degradation due to the conversion of natural and agricultural land to urban developments that significantly reduced the infiltration capacity of the river basin and increased surface runoff, leading to high flood risk. Encroachment into riparian buffer zones also contributed to the loss of vegetation cover, which accelerated soil erosion, sedimentation, and degradation of the river channel, which were primarily driven by urbanisation, agricultural growth, and environmental policies. Notably, forest cover declined by around 50% between 1991 and 2001, owing to deforestation caused by agriculture and urbanisation, while a minor rebound was noted in subsequent years, indicating afforestation initiatives. Built-up areas have significantly increased from 80.2 km² in 1991 to 275.5 km² in 2021, indicating fast urban growth that threatens habitat integrity and biodiversity. Vegetation cover trends show a fall until 2011, then a rebound, indicating dynamic ecological reactions to land management methods.

The environmental consequences of human activity are most visible in upper catchments, where intensive agriculture and urban encroachment exacerbate soil erosion and water pollution. The Ondiri/Kikuyu wetland is under severe strain from deforestation, agricultural encroachment, and water exploitation, which jeopardises its ecological integrity. However, pollution from industrial and residential areas contributes to habitat degradation and declining water quality. These findings highlight the critical need for integrated land use planning and sustainable management approaches to reduce environmental degradation and strengthen the Nairobi River riparian zone's resilience to climate change and urbanisation.

7.2.2 Summary of Findings: Relationship Between the Level of Degradation and Occurrence of Flooding Along the Nairobi River Riparian Zone

The study established a strong and significant relationship between the level of ecological degradation and the occurrence of flooding along the Nairobi River Basin riparian zone.

Results from land use and land cover analysis, household surveys, and field observations indicated that riparian degradation has progressively intensified over the past three decades, mainly due to inappropriate human activities, such as deforestation and riparian encroachment, including cultivation and livestock grazing, development of informal settlements and poor solid waste management practices.

Households in the lower catchment experienced highly degraded riparian stretches and reported the highest flood frequency. In contrast, upper catchment areas dominated by less invasive agricultural practices or controlled development reported lower flood occurrences.

Cultivation and livestock grazing in the upper catchment area led to vegetation loss and the reduction of natural wetlands such as Ondiri Swamp. It facilitates riverbank erosion and sedimentation, especially in the middle and lower sections. Unplanned urbanisation contributes to increased industrial activities and the development of informal settlements in the middle and lower catchments, leading to illegal dumping of domestic effluents and solid waste into the river channel.

The analysis of the Nairobi River buffer zone indicated severe anthropogenic encroachment, suggesting the effective buffer zone area of 0.000117 km^2 is inadequate for effecting flood protection and management. Hence, sustainable land management methods are required to balance development with environmental conservation and strengthen the resilience of communities along the Nairobi River riparian zone.

7.2.3 Summary of the Findings: Sustainable Mitigation Approaches

This study provided sustainable interventions for mitigating flooding along the Nairobi River riparian zone that included the coping strategies, community perception of flooding, action for flood rehabilitation, and coping mechanisms.

Coping strategies represent the immediate and short-term actions, such as constructing temporary barriers using sandbags or elevating homes, to minimise flood impacts.

Community perception of flooding strongly influences how residents respond to flood risks. Flooding awareness campaigns and environmental education can help residents understand that the increasing frequency and severity of flooding are due to poor land use and environmental degradation. Increasing awareness can stimulate high enforcement of riparian regulations and adoption of preventive measures such as afforestation and proper waste management.

Actions for flood rehabilitation involve restoring the livelihoods of individuals and communities after flood events by reconstructing resilient facilities and repairing damaged systems to enhance future resilience.

Programs like the Kounkuey Design Initiative (KDI) and Nairobi River Regeneration Project provide community-led solutions that facilitate effective flood recovery by improving public spaces and rehabilitating the entire river system through infrastructure improvements.

Finally, adapting long-term behavioural and structural adjustments such as the incorporation of rainwater harvesting systems, reforestation of riparian land, and the establishment of green spaces can effectively enhance community resilience to flooding. However, the implementation of adaptive coping mechanisms is hindered by continued encroachment on riparian land, inadequate funding, and fragmented institutional coordination.

These findings highlight the riparian community's resilience, which is fuelled by local knowledge, resourcefulness, and social networks, and emphasise the importance of integrated, long-term flood mitigation strategies.

7.3 Conclusions

i. The Nairobi River riparian zone has experienced significant degradation from 1991 to 2021 due to urban growth and farming. Forest cover dropped by 50%, while built-up areas increased from 80.2 km^2 to 275.5 km^2. Although vegetation cover showed some recovery after 2011, the upper catchments face serious problems like soil erosion and water pollution from human activities. The Ondiri/Kikuyu wetland is also at risk because of deforestation and farming. These findings show a critical need for better land-use planning and sustainable management to reduce damage to the environment and help the ecosystem adapt to climate change.

ii. The association between degradation and floods along the Nairobi River riparian zone found that changes in population and land use influenced flood risks. Most respondents, particularly middle-aged adults, were aware of flooding, with 52% reporting annual flooding. Wooded land has declined by 45.7% during the last 30 years because of urbanisation and agriculture, whereas bare land has expanded by 89.2%. The loss of greenery and urban development exacerbated flood hazards. The findings emphasised the importance of appropriate flood mitigation methods and long-term land management in balancing development and environmental conservation, hence increasing community resilience along the river.

iii. Finally, the findings highlighted the devastating impact of flooding on communities along the Nairobi River, indicating severe disruptions such as livestock loss, home damage, and transportation failures. In response, these communities displayed extraordinary resilience by implementing a variety of coping methods, such as transferring cattle, changing farming operations, and devising improvised transportation options. The move to alternative energy sources demonstrated their resourcefulness and agility. Overall, our findings emphasise the necessity of using local knowledge and social networks to improve community resilience. They also emphasise the critical need for integrated and long-term flood mitigation policies that prioritise sustainable practices and community engagement to effectively manage flood-related concerns.

iv. Therefore, the study showed that the riparian zone of the Nairobi River has experienced the worst trend of degradation between 1991 and 2021, attributed to urbanisation and agriculture expansion, whereby the forest region reduced to 50%, whereas built-up areas tripled. These changes have led to increased flooding occurrences; respondents who stated they experience flooding annually were 52%; frequent flooding was most evident among the middle-aged. The results show the necessity of sound approaches to managing the land and to exclude floods as a dangerous threat to people. Nevertheless, the local communities demonstrated several forms of coping mechanisms, which should lend support to the need for mainstreaming local information and community involvement in flood mitigation programs to improve community resilience overall in Nairobi City County.

7.4 Recommendations

The significant degradation of the Nairobi River riparian zone from 1991 to 2021, driven by urban growth and farming, highlights the urgent need for improved land-use planning and sustainable management. Forest cover has halved, and built-up areas have expanded dramatically, leading to severe environmental issues such as soil erosion and water pollution. To address these challenges, it is crucial to enforce strict zoning regulations, promote reforestation, and encourage sustainable agricultural practices. These measures will help restore the ecosystem, protect critical areas like the Ondiri/Kikuyu wetland, and enhance the riparian zone's resilience to climate change.

The association between land degradation and increased flood risks along the Nairobi River riparian zone underscores the importance of integrated flood mitigation strategies.

Urbanisation and agriculture have significantly reduced wooded land and increased bare land, exacerbating flood hazards. Developing comprehensive flood management plans, enhancing drainage infrastructure, and promoting green infrastructure solutions are essential steps to mitigate these risks. By balancing development with environmental conservation, these strategies can improve community resilience and reduce the impact of flooding.

The devastating impact of flooding on communities along the Nairobi River, including livestock loss, home damage, and transportation failures, demonstrates the need for community engagement and resilience building. Local communities have shown remarkable adaptability through various coping mechanisms, such as relocating livestock, altering farming practices, and using alternative energy sources. Strengthening community-based organisations, using local knowledge, and providing education and training can further enhance community resilience. These efforts should be integrated into flood mitigation programs to ensure sustainable and effective management of flood-related challenges.

Finally, the study's findings on the worst trends of degradation between 1991 and 2021, primarily due to urbanisation and agricultural expansion, emphasise the necessity of sound land management approaches. The significant increase in built-up areas and the annual flooding experienced by 52% of respondents highlight the urgent need for policies that prioritise sustainable practices and community involvement. Establishing multi-stakeholder platforms, securing funding for environmental projects, and regularly monitoring progress are critical steps to address these issues. By mainstreaming local information and involving communities in flood mitigation efforts, Nairobi City County can enhance overall resilience and reduce the threat of floods.

7.5 Suggestions for further research

The following suggestions for further study were made:

i. Assessment of the Impact of Sustainable Agricultural Practices on Soil Health and Water Quality in the Nairobi River Riparian Zone in Nairobi City County, Kenya.
ii. Evaluation of Integrated Waste Management Systems and Their Role in Mitigating Pollution in Urban Riparian Zones in Nairobi City County, Kenya.
iii. Investigation of Community-Based Conservation Strategies and Their Impact on Flood Resilience and Riparian Ecosystem Health in Nairobi City County, Kenya

REFERENCES

Aberle, J., and Järvelä, J. (2013). Flow resistance of emergent rigid and flexible floodplain vegetation, Journal of Hydraulic Research 51(1), 33-45.

Abuje, Sunday & Moirongo, Bernard & Njuguna, Mugwima. (2020). Influence of Nairobi's Biophysical Characteristics on its Vulnerability to a Changing Climate. East African Journal of Environment and Natural Resources. 2. 64-85. 10.37284/eajenr. 2.2.201.

Alfred Opere (2013). *Floods in Kenya*. Developments in Earth Surface Processes, Vol. 16. http://dx.doi.org/10.1016/B978-0-444-59559-1.00021-9 Copyright© 2013 Elsevier B.V. All rights reserved.

Avery, S. (2024). Kenya's devastating floods expose decades of poor urban planning and bad land management. *The Conversation*. Retrieved from https://theconversation.com/kenyas-devastating-floods-expose-decades-of-poor-urban-planning-and-bad-land-management-229015

Baptist, M. J. (2005). Modelling floodplain biogeomorphology, PhD thesis, Delft University of Technology, ISBN 90-407-2582-9.

Baptist, M. J.; Babovic, V.; Rodríguez Uthurburu, J.; Keijzer, M.; Uittenbogaard, R.; Mynett, A. and Verwey, A. (2007). On inducing equations for vegetation resistance, Journal of Hydraulic Research 45(4), 435-450.

Beven, K. J. (2018). *Rainfall-runoff modelling: The primer*. Wiley.

Blumberg, B., Cooper, D., Schindler, P. (2005). *Business research methods*. Berkshire: McGraw-Hill Education.

Bolin Fu, Ying Li, Yeqiao Wang, Bai Zhang, Shubai Yin, Honglei Zhu, Zefeng Xing (2016). *Evaluation of ecosystem service value of the riparian zone using land-use data from 1986 to 2012.* Ecological Indicators 69:873-881

Borrelli P., Robinson D.A., Fleischer L.R., Lugato E., Ballabio C., Alewell C., Meusburger K., Modugno, S., Schutt, B., Ferro, V., Bagarello, V., Van Oost, K., Montanarella, L., Panagos P. 2017. An assessment of the global impact of 21st-century land use change on soil erosion. Nature Communications, 8 (1): art. no. 2013

Brierley, G. J., and Fryirs, K. A. (2005). Geomorphology and river management: applications of the River Styles framework. Oxford, UK, Blackwell Publishing.

Brinkmann, S. (2016). Methodological breaching experiments: Steps toward theorising the qualitative interview. *Culture & Psychology*, *22*(4), 520-533.

Bryman, A. (2016). *Social research methods*. Oxford University Press.

Carollo, F. G.; Ferro, V., and Termini, D. (2002). Flow Velocity Measurements in Vegetated Channels, Journal of Hydraulic Engineering 128(7), 664-673.

CBS (2001). "Counting our People for Development" Population and Housing Census. Vol. 1. Central Bureau of Statistics, Nairobi

Chambers, J.C. & Miller, J.R. (Eds). (2004). *Great basin riparian ecosystem, ecology, management, and restoration*. Washington, D.C: Society for Ecological Restoration International.

Charles, K. (2010). *A negotiated framework for rehabilitation of riparian zones in Nairobi city: the case of Mathare river valley*. Retrieved from http://isocarp.net/Data/case_studies/1780.pdf (Accessed 15th August 2017)

Chebet, R. C. (2019). Land degradation and riparian ecosystem dynamics in the Lake Victoria Basin, Kenya (Master's thesis, Maseno University).

Chovanec, A., Jäger, P., Jungwirth, M., Koller-Kreimel, V., Moog, O., Muhar, S., & others. (2000). The Austrian way of assessing the ecological integrity of running waters: a contribution to the EU Water Framework Directive. In Assessing the Ecological Integrity of Running Waters (pp. 445–452). Springer.

Chun, H., Sulaiman, A., and Samah, M. (2012). A case study on public participation in the conservation of a tropical urban river. *Polish Journal of Environmental Studies* 21 (4):821-829.

CIDP. (2018). Nairobi County Integrated Development Plan (CIDP) 2018-2022. Retrieved fromhttps://www.kpda.or.ke/documents/CIDP/Nairobi%20County%20Intergrated%20Development%20Plan%20(CIDP)%202018-2022.pdf. Accessed on February 10, 2022.

Cohen G. (1989) *On the Currency of Egalitarian Justice. Source*: Ethics, Vol. 99, No. 4, pp. 906-944. Published by the University of Chicago Press, Chicago

Costache, R., 2015. The identification of suitable areas for afforestation to reduce the potential for surface runoff in the upper and middle sectors of the Buzău catchment. *Cinq Continents* 5(11): 93-103

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage.

Darby, S. (1999). "Effect of Riparian Vegetation on Flow Resistance and Flood Potential." Journal of Hydraulic Engineering 125(5): 443-454.

Davis, S., et al. (2025). Restoring riparian habitats for benefits to biodiversity and ecosystem services: a systematic review. Environmental Evidence.

Department of resource surveys and remote sensing (2010), Nairobi, Kenya.

Dewan AM (2013) Modelling flood hazards. In: Dewan AM (ed) Floods in a megacity: geospatial techniques in assessing hazards, risk, and vulnerability. Springer, Berlin, pp 129–137

Dewan AM, Yamaguchi Y (2009) Land use and land cover change In Greater Dhaka, Bangladesh, using remote sensing to promote sustainable urbanisation. Appl Geogr 29:390–401

Diegues, A. (1991). The role of cultural diversity and communal participation in wetland management in Brazil. *Landscape and Urban Planning* 20(1-3):61-66.

Doreen Fualing (2009) Riparian ecosystem management – A case study of the Ellidaá and Ytri-Rangá Rivers in Iceland. *Land Restoration Training Programme Final project Keldnaholt, 112 Reykjavík, Iceland*

Downs, P.W., Skinner, K.S. & Kondolf, M.G. (2008). In Martin, R.P. & Anthony, J.D. (Eds), *Rivers and streams: Handbook of ecological restoration 2: Restoration in practice* (pp.267–291). New York: Cambridge University Press.

Erika T. Machtinger (2007). Riparian Systems. Unpublished report.

Erskine, W., Keene, A., Bush, R., Cheetham, M., and Chalmers, A. (2012). "Influence of riparian vegetation on channel widening and subsequent contraction on a sand-bed stream since European settlement: Widden Brook, Australia." Geomorphology 147–148(0): 102-114

FEMA. (2021). Historical Flood Risk and Costs. Retrieved from FEMA.gov

Foley-Congdon, E., et al. (2024). Revegetated riparian areas are dominated by weeds, and important structural elements may be missing. Restoration Ecology.

Food and Agriculture Organisation (FAO). 2000. Africover Multipurpose Land Cover Databases for Kenya. www.africover.org. Rome, Italy: FAO.

Fungomeli, M & Cianciaruso, M & Zannini, P & Githitho, A & Frascaroli, F & Fulanda, B & Kibet, S & Wiemers, M & Mbuvi, M & Matiku, P. & Chiarucci, A. (2020). Woody plant species diversity of the coastal forests of Kenya: filling in knowledge gaps in a biodiversity hotspot. Plant Biosystems. 154. 973-982. 10.1080/11263504.2020.1834461.

Gadain, H., M., Bidault, N., Stephen, L., Watkins, B., Dilley, M., and Mutunga, N. (2006*), in 'Natural Disaster Hotspots: Case Studies, Reducing the Impacts of Floods through Early Warning and Preparedness: A Pilot Study for Kenya*', Disaster Risk Management Series No. 6, Washington DC: World Bank.

Gathenya, J. M., Mwangi, J. K., & Langat, P. K. (2018). Application of the SWAT model to assess the impact of land-use changes on streamflow in the Upper Mara River Basin, Kenya. Hydrology Research Letters, 12(2), 54-63.

Gonza´lez, M., Garcı´a, D. and Roma´n, M. (2012). *River Restoration in Spain*: Theoretical and Practical Approach in the Context of the European Water Framework Directive. Accessed 15th August 2016

Hardy, R.J. (2005). Modelling granular sediment transport over water-worked gravels. *Earth Surface Processes and Landforms* 30(8): 1069-1076.

Heather Forbes, Kathryn Ball, and Fiona McLa, 2015. *Natural flood management handbook*. Scottish Environment Protection Agency, Strathallan House, Castle Business Park, Stirling. FK9 4TZNumber: 978-0-85759-024-4

ICPAC (2007), 'Climate Change and Human Development in Africa: *Assessing the Risks and Vulnerability of Climate Change in Kenya, Malawi and Ethiopia*', Nairobi: UNDP.

Ilhardt, B. Verry, S, and. Palik, B. (2000). Defining riparian areas. Pg. 29 In *Riparian management in forests of the continental eastern United States*. Verry, E. S., J. W. Hornbeck, and C. A. Dolloff (eds.). New York: Lewis Publishers.

Islam, K. (2011). Community-based water resource management - some regional experiences. Pages 3-12 *in* C. K. Jain, K. M. B. Islam, and S. K. Sharma, editors. *Community-based water resources management in Northeast India: lessons from a global context.* Allied, New Delhi, India.

Issaias, I. (2000). Environmental Impact of Urbanization on Water Resources a Case Study on Nairobi Dam. Imperial College of Science, Technology, and Medicine (University of London). 100pp.

Jean-Francois Pekel, Andrew Cottam, Noel Gorelick, Alan S. Belward (2016). High-resolution mapping of global surface water and its long-term changes. Nature 540, 418-422 (doi:10.1038/nature20584)

Jia K *et al* (2019). Land Use and Land Cover Classification Using Chinese GF-2 multispectral data in a region of the North China Plain. Front Earth Sci 13:327–335

Jiang, W., Yu, J., Wang, Q., & Yue, Q. (2022). Understanding the effects of digital elevation model resolution and building treatment for urban flood modelling. *Journal of Hydrology: Regional Studies*, *42*, 101122. https://doi.org/10.1016/j.ejrh.2022.101122

K. Saalmann, I. Mänttäri, C. Nyakecho, E. Isabirye. (2016). Age, tectonic evolution and origin of the Aswa Shear Zone in Uganda: Activation of an oblique ramp during convergence in the East African Orogen, Journal of African Earth Sciences, Volume 117, Pages 303-330, ISSN 1464-343X, https://doi.org/10.1016/j.jafrearsci.2016.02.002.

Karangi, M. (2017). Destruction of Riparian Zones in the Nairobi Metropolitan Region. Kenya Institute for Public Policy. Research and Analysis KIPPRA Discussion Paper No. 197.

Kenya Ministry of Environment and Forestry (2018). Nairobi River Basin Map – Nairobi County. Nairobi: Ministry of Environment and Forestry.

Kenya Wetlands Atlas (2012). Natural resource policy and practice. UNEP, Nairobi

Kenya's Vision 2030 (2007) Kenya's new long-term national planning strategies from 2008 to 2030.The government of Kenya. Kenyan Gazette, Nairobi

Kihato, C. W., Otieno, F. A. O., & Were, D. (2020). Application of resilience theory in urban flood risk management: Lessons from Nairobi River Basin. Journal of Environmental Sustainability, 8(2), 45–58.

King'oriah, G.K. (2004): Fundamentals of Applied Statistics. Jomo Kenyatta Foundation Publishers, 1st Edition.

Kinnoumè, S. M. D., et al. (2024). Tree diversity explains variations in biodiversity and ecosystem function in riparian corridors. Frontiers in Forests and Global Change.

Kipkorir, E. C., Mutua, B. M., & Lala, J. M. (2020). Hydrological modelling of the Lower Nzoia River Basin using SWAT for land-use and climate change scenarios. African Journal of Environmental Science and Technology, 14(9), 294-304.

Kiplagat, R. C. (2019). Geomorphological analysis of river channel dynamics and floodplain alterations along the Nzoia River, Kenya (Master's thesis, University of Eldoret). Gikonyo, L. W. (2022). Assessment of riparian land degradation and its implications on flood risk management in Nairobi City County, Kenya (Master's thesis, Kenyatta University).

Kithiia, Shadrack, & Wambua, Boniface. (2010). Temporal changes of sediment dynamics within the Nairobi River sub-basins between 1998–2006-time scale, Kenya. Annals of Warsaw University of Life Sciences - SGGW. Land Reclamation. 42. 10.2478/v10060-008-0060-z.

Koskey, J. C., M'Erimba, C. M., & Ogendi, G. M. (2021). Effects of land use on the riparian vegetation along the Njoro and Kamweti Rivers, Kenya. Open Journal of Ecology, 11, 807–827.

Kotler, P. (1994) *Marketing Planning Management: Analysis, Planning and Control,* 8th ed, Prentice-Hall, New York.

Krhoda, G. (2002). Nairobi River Basin Project Phase II: The Monitoring and Sampling Strategy for Ngong/Motoine River. Nairobi, Kenya. (In press).

Lamsal, P., Pant, K., Kumar, L., and Atreya, K. (2015). Sustainable livelihoods through conservation of wetland resources: a case of economic benefits from Ghodaghodi Lake, western Nepal. *Ecology and Society* 20(1): 10. http://dx.doi.org/10.5751/ES-07172-200110

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic Information Systems and Science*. Wiley.

Lwanga, A. I., Tsingalia, H. M., Agevi, H., & Shilenje, Z. W. (2022). Effects of Sand-Harvesting on River Water Quality and Riparian Soil Physico-Chemical Properties. Open Journal of Ecology, 12, 570-583. https://doi.org/10.4236/oje.2022.128032

Mahendra B. Baniya, Takashi Asaeda, Takeshi Fujino, Senavirathna M. D. H. Jayasanka, Guligena Muhetaer and Jinghao Li. (2019). **Mechanism of Riparian** Vegetation *Growth and Sediment Transport Interaction in Floodplain*: A Dynamic Riparian Vegetation Model (DRIPVEM) Approach

Makathimo, M., and Guthiga, P. (2010). *Land Use Policies and Natural Resource Management in Kenya*: *The Case of Nairobi River Basin*. Environment and Energy; Policy and Practice. FIG Congress 2010. Sydney, Australia,

Malanson, G. P. (1993). Riparian Landscapes. Cambridge University Press.

Ministry Of Environment and Natural Resources. (2016). Land degradation assessment in Kenya

Mitullah, W. (2003). "Understanding Slums: Case Studies for the Global Report on Human Settlements 2003: The Case of Nairobi, Kenya". UN-HABITAT, Nairobi.

Morgan, D. L. (2019). *Basic and advanced focus groups*. Sage.

Muchtar, A. & Bahar, A., 2010. Using Geographical Information Systems to Estimate Vulnerable Urban Settlements for Flood Hazard and Risk Assessment in a City. In Malaysia: The University of Malaysia Kelantan, pp. 1–12. Available at: http://umkeprints.umk.edu.my/26/1/Conference Paper_6.pdf

Mugambi, [Author(s)] et al. (2022). Examining the rate of built-up areas on the vegetation cover along the River Riara riparian within Kiambu Town, Kenya. (Journal/Conference paper).

Mugenda, O. And Mugenda, A. (2003). Research Methods: Quantitative and Qualitative Approaches. Act Press: Nairobi. Muketha, (accessed 28th August 2017),

Muhia, R. N., Ochola, W.O. and Mwarasomba, L.I. (2000). Culture, Traditions, and Society*: The Challenges to Natural Resource Management and Development. A report from a Socio-Cultural Study of the Lake Victoria Region: Kenya*. Edited by L. Nycander, Ministry of Agriculture and Rural Development, National Soil and Water Conservation Programme.

Muketha, S. (2019). Riparian Zones and Their Role in Enhancing Resilience to Flooding in Urban Areas. *AFRICA HABITAT REVIEW*, *13*(1), 1615-1625.

Muketha, S. M. (2020). Riparian land control, contestation and its implications to conservation in Nairobi City. Africa Habitat Review, 14(3), 1949–1962.

Muketha, S. M. (2020). Riparian zones and their role in enhancing resilience to flooding in urban areas. *Academia.edu*. Retrieved from https://www.academia.edu/76597091/Riparian_Zones_and_Their_Role_in_Enhancing_Resilience_to_Flooding_in_Urban_Areas_A_Case_Study_of_Nairobi_River_Basin

Muketha, S. M. (2020). *Stakeholder roles, perceptions and behaviour towards conservation of riparian zones in Nairobi River Basin*. Retrieved from the University of Nairobi Repository

Muketha, S. M. (2025). Land Use Policy Change and Its Contribution to Urban Flooding in Downstream Zones: A Case of Nairobi City County. *International Journal of Advanced Engineering and Management Research*, *10*(02), 151–194. https://doi.org/10.51505/ijaemr.2025.1108

Mulaku, G.C. and Kairui, L.W. (2001). "*Mapping and Analysis of Air Pollution in Nairobi, Kenya*". International Conference on Spatial Information for Sustainable Development. Nairobi

Muthee, J. K., Gathenya, J. M., & Mwangi, H. (2020). Impacts of land use and land cover changes on soil erosion and sediment yield in the Upper Tana River Basin, Kenya. Environmental Management Journal of Kenya, 4(2), 55–70.

Mutie, S. M., Gathenya, J. M., & Sang, J. K. (2020). Assessing the influence of land use and geomorphology on flooding within the Athi River Basin, Kenya. Hydrology and Earth System Sciences Discussions, 24(6), 3105–3120.

Mutua, F.M. (2000): Reducing the impacts of environmental emergencies on the Water resources sector through early warning and preparedness case of the 1997/1998 El Niño Southern Oscillation Floods in Kenya. A paper presented at the International Conference at Nairobi Safari Club, Nairobi-Kenya. (Accessed 17th November 2017).

Mwangi, J. K., Kinyamario, J. I., & Mungai, N. W. (2024). Ecosystem functions in degraded riparian forests of southeastern Kenya: Implications for ecological resilience. African Journal of Ecology, 62(1), 88–99.

Nally, M., Molyneux, G., Thomson, J., Lake, P., and Read, J. (2008). Variation in widths of riparian zone vegetation of higher-elevation streams and implications for conservation management. *Plant Ecology, 189*, 98–100.

Nassiuma, D. (2000). *Survey Sampling Theory and Methods.* Nairobi: University of Nairobi Press.

National Environmental Authority (NEMA) (2004): Strategy for Flood Management in Lake Victoria Basin, Kenya. NEMA, Nairobi. (Accessed on 02nd January 2018)

National Land Policy (2009). Sessional Paper No. 3 of 2009 on National Land Policy. (Accessed on 15th January 2018)

National Research Council, U.S. (2002). *Riparian areas, functions, and strategies for management.* Washington, D.C.: The National Academies Press.

Neuman, W. L. (2003). Social research methods: Qualitative and quantitative approaches. Fifth edition. Allyn and Bacon. Boston. Massachusetts.

Nilsson, C., Jansson, R., Malmqvist, B., and Naiman, R. (2007). Restoring riverine landscapes: the challenge of identifying priorities, reference states, and techniques. *Ecology and Society* 12(1): 16: http://www.ecologyandsociety.org/vol12/iss1/art16/

Nyamai, M. N., Mwangi, S. N., & Ngugi, J. K. (2022). Applying socio-ecological systems theory to urban riparian management: A case study of Nairobi City County, Kenya. Kenya Journal of Environmental Policy and Management, 5(1), 33–48.

Obiri J. A.F., Driver, M.F., Onyekwelu J. C., Akpoko J. G., Ramasawmy B. and Dramé-Yaye, A. 2017. Agricultural Risk Management in Africa - A contextualised manual for tertiary institutions and development practitioners. ANAFE, Nairobi.

Odadal, O.E., Olago, D.O., Bugenyi, F., Kulindwa, K., Karimumuryango, J., West, K., Ntiba, M., Wandiga, S., Aloo-Obudho, P. & Achola, P. (2003). Environmental assessment of the East African rift valley lakes, Overview article. *Aquatic Science*, 65, 254–271.

Odha, G. A. (2024). Environmental policy implementation effects on prevention of degradation of riparian zones: case studies from Ngong and Nairobi rivers (Master's thesis/report). Kenyatta University Repository.

Olajubu, V. & Trigg, M. & Berretta, C. & Sleigh, A. & Chini, M. & Matgen, P. & Mojere, S. & Mulligan, J. (2021). Urban correction of global DEMs using building density for Nairobi, Kenya. Earth Science Informatics. 14. 10.1007/s12145-021-00647-w.

Omukaga O. Panyako, Jacob W. Wakhungu, and Felix N. Kioli (2018). International Research Journal of Management, IT & Social Sciences, *Urban Flooding in Kenya from A Psychosocial Perspective,* Vol. 5 No. 5, pages: 17~27 ISSN: 2395-7492. https://ijcujournals.us/journals/index.php/irjmis/. Accessed on 23rd August 2018

Omusisi, A. (2022). Settlement development and its implications on the Nairobi River riparian zone, Nairobi City County, Kenya (Master's thesis). Kenyatta University Institutional Repository.

Onyango, S. A. (2024). *Land Use and Vegetation Changes Impact on Thermal Comfort in Urban Open Spaces of Nairobi City, Kenya* (Doctoral dissertation, JKUAT-CoANRE).

Otiende B. (2008). Risk Assessment for Extreme Riverine Floods in Kenya: A Tool for Flood Risk Management. (Accessed on 18th July 2017).

Otieno, C. A. (2020). Application of the socio-ecological systems framework in community-based wetland management: The case of Lake Naivasha Basin, Kenya (Master's thesis, Egerton University).

Owers K, Albanese B, and Litts T. (2011). *Using Aerial Photography to Estimate Riparian Zone Impacts in a Rapidly Developing River Corridor*. Environmental Management 49: 543– 552. DOI: 10.1007/s00267-011-9790-5

Patton, M. (1990). *Qualitative evaluation and research methods* (pp. 169-186). Beverly Hills, CA: Sage.

Paul, Shitangsu & Hassan, Md & Sultana, Mst. (2019). Indigenous Practices for Coping with Flood: An Assessment of the Riparian People Living in the Teesta Floodplain. 7. 18-29.

Penning Rowsell, E.C. (1996). Flood hazard response in Argentina: changing the concept and changing policies, *geographical review* 86, 1: 72-90

Perona, P.; Camporeale, C.; Perucca, E.; Savina, M.; Molnar, P.; Burlando, P.; Ridolfi, L. Modelling River and riparian vegetation interactions and related importance for sustainable ecosystem management. *Aquat. Sci.* **2009**, *71*, 266.

Peters, C.B. (1996). A guide to Academic writing. ACTS Publishers. Eldoret-Kenya.

Philip O., Okeyo J., and Foulata (2012), Community-Based Approach to the Management of Nyando Wetland, Lake Victoria Basin, Kenya PDF. 1st Edition, Mcpowl Media Ltd, Nairobi (accessed on 16th January 2018).

Rahman, M., and Begum, A. (2011). The implication of livelihood diversification on wetland resources conservation: a case from Bangladesh. *Journal of Wetlands Ecology* 5:59-65. http://dx.doi.org/10.3126/jowe.v5i0.4905

Reed, T., & Carpenter, S. R. (2002). Comparisons of P-Yield, Riparian Buffer Strips, and Land Cover in Six Agricultural Watersheds. Ecosystems, 5(6), 568–577.

Richard, L., Randall G., Shreeram P., David D., and Joseph M. (2001). Evaluation of Coastal Plain Conservation Buffers using the Riparian Ecosystem Management Model. PDF (Accessed 14 May 2016).

Roy, D., Jane, B., & Venema, D. (2011). Ecosystem Approaches in Integrated Water Resources Management (IWRM). *A Review of Transboundary River Basins Dimple Roy*. (pp. 12–14). International Institute for Sustainable Development & International Institute for Sustainable Development.

Ruto, D. K., et al. (2023). Effects of land use on riparian vegetation in the South-West Mau / Mau Forest complex (Kenya).

Saeed Mwaguni and Daniel Munga (2012). Pollution Prevention and Control Guidelines for the Coastal and Marine Environment of Kenya. The government of Kenya - National Environment Management Authority, Nairobi

Schanze, J., Olfert, A., Tourbier, J., Ines, G., & Schwager, T. (2004). Existing Urban River Rehabilitation Schemes. *Urban River Basin Enhancement Methods*. European Commission.

School Disaster Management Plan, Children's Participation in Disaster Risk Reduction (CPDRR)Project– Plan Bangladesh Oct 07 – Dec 08

School Flood Safety Program: Flood Risk Preparation and Reduction "Teachers Information Booklet 2nd Edition- October 2009

Shadrack Mulei Kithiia (2012). *Water Quality Degradation Trends in Kenya over the Last Decade*, Water Quality Monitoring, and Assessment, Dr Voudouris (Ed.), ISBN: 978-953-51-0486-5, Intech, Available from http://www.intechopen.com/books/water-quality-monitoring-and-assessment/water-quality-degradation-trends-in-kenya-over-the-last-decade.

Smith, K., and Ward, R.C. (1998), '*Floods: Physical Processes and Human Impacts*', Earth surface processes, and landforms. Vol 24 Issue 13, Pages 1171–1261.

10.1002/ (SICI) 1096-9837(199912)24:13<1171: AID-ESP71>3.0.CO; 2-W. John Wiley & Sons Ltd

Smith, L.A., 2002. What might we learn from climate forecasts? Proc. Natl. Acad. Sci. U.S.A. 99, 2487–2492

Soya, L.G. (1998): Flooding across Kenya has increased. Available Online: http://www.reliefweb.int/w/rwb. (Accessed on 12th February 2017).

Suárez, M.L., M.R. Vidal-Abarca, M. Sánchez-Montoya, J. Alba, M. Álvarez, J. Avilés, N. Bonada, J. Casas, P. Jaimez-Cuéllar, A. Munné, I. Pardo, N. Prat, M. Rieradevall, J. Salinas, M. Toro & S. Vivas. (2002). Las riberas de los ríos mediterráneos y su calidad: el uso del índice QBR. Limnetica, 21(3-4): 135-148.

Sustainable Development Goals (2015). Transforming our world: the 2030 Agenda for Sustainable Development pdf. UN. (Accessed on 20th January 2018)

Tadano T, Nagai H, Ishida H, Oda F, Naito S, Minakawa K, Iwamoto H (2016) Generation of the 30 m-mesh global digital surface model by Alos Prism. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLI-B4, 157-162

Takaku J, Tadono T, Tsutsui K, Ichikawa M (2016) Validation of "AW3D" global DSM generated from ALOS Prism. ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, III4, 25

The Constitution of Kenya (2010). Published by the National Council for Law Reporting with the Authority of the Attorney General

The government of Kenya (2007), 'Mission Report to Access the Impacts of Floods in Budalang'i and Rachuonyo Districts in Western Kenya', (Nairobi: Ministry of State for Special Programs).

The United States Environmental Protection Agency, Office of Water, Washington, DC. (1993). *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.* (Online) Available from: http://water.epa.gov/polwaste/nps/czara/index.cfm

Thiong'o, P. W., & Nyamweya, C. S. (2021). Geomorphological dynamics and riparian stability along urban rivers: A case of Nairobi River Basin, Kenya. African Journal of Environmental Science and Technology, 15(7), 289–301.

Tiecke, T., Liu, X., Zhang, A., Gros, A., Li, N., Yetman, G., Kilic, T., Murray, S., Blankespoor, B., Prydz, E., & Dang, H.-A. 2017. Mapping the world population one building at a time

Trochim William, (2006). The Research Methods Knowledge Base, 2nd Edition. Internet WWW page, at URL: http://www.socialresearchmethods.net/kb/

U.S. Geological Survey (USGS). (2021). Historical Flooding. Retrieved from USGS.gov

UNCSD (2012). The United Nations Conference on Sustainable Development, Congressional Research Service.

UNEP (2003). United Nations Environment Programme (UNEP), Government of Kenya (GoK), Regional Centre for Mapping of Resources for Development (RCMRD) and the United States Geological Survey (USGS) (2003), Kenya Atlas of Our Changing Environment

United Nations Environment Programme (2000). *Planning and Management of Lakes and Reservoirs: An Integrated Approach to Eutrophication.* United Nations Environment Programme (UNEP) [online]. Available from: http://www.unep.or.jp/i***etc***/publications/techpublications/techpub-11/6-9-1.asp

United Nations Office for the Coordination of Humanitarian Affairs (2006), 'Kenya Floods: OCHA Situation Report No. 3'. Ref: OCHA/GVA 2006/0234 Available at http://www.reliefweb.int (accessed on 27 March 2017).

United States Agency for International Development (USAID). (2008). *Sustainable livelihoods and water management in shared river basins: Lower Songkram Basin, Thailand*. Case Study. http://www.usaid.gov/locations/asia/countries/rdma/.

UoN, (2005). Aqua Systems Consortium. Unpublished report.

Vaka DS, Kumar V, Rao YS, DeSo R (2019) Comparison of Various DEMs for Height Accuracy Assessment Over Different Terrains of India. IGARSS 2019–2019 IEEE International Geoscience and Remote Sensing Symposium, 28 July-2 Aug. 2019. 1998-2001

Wambugu, G. M. (2018). Effects of industries and other land-use systems on the water quality within the Nairobi River sub-catchments, Kenya (MSc thesis). University of Nairobi.

Wanjiku, N. D. (2023). The effects of infrastructural development and settlement on drainage in the Nairobi National Park area (Thesis). Jomo Kenyatta University of Agriculture & Technology / KU repository.

Wanyonyi, C. K., Tsingalia, H. M., & Agevi, H. (2022). Modelling land-use change impacts on streamflow and sediment yield using SWAT: A case of Sondu River Catchment, Kenya. Journal of Water and Climate Change, 13(6), 2108-2121.

Watson, A., and Basher, L. (2006). Streambank erosion: A review of processes of bank failure measurement and assessment techniques and modelling approaches. *Motueka Integrated Catchment Management Programme. Land Care ICM Report No. 2006-2006/01*, 32.

Were, D. O., Gathenya, J. M., & Olago, D. O. (2021). Socio-ecological interactions and governance challenges in the Athi River Basin, Kenya. African Journal of Environmental Science and Technology, 15(9), 403–415.

William, M. (2006). *Research Methods Knowledge Base.* New York: Atomic Dog Publishing.

Williams, D. (2002). Community participation in conserving and managing inland waters. *Aquatic Conservation: Marine and Freshwater Ecosystems* 12(3):315-326. http://dx.doi.org/10.1002/

Wood, A., Hailu, P., Abbot, and Dixon, A. (2002). Sustainable management of wetlands in Ethiopia: local knowledge versus government policy. M. Gawler. *Strategies for wise use of wetlands: best practices in participatory management.* Wetlands International/IUCN/WWF Publication 56. Wetlands International, Wageningen, The Netherlands: http://www.wetlands.org/LinkClick.aspx.

Woomer, P. (2003). Monitoring Plan, Carbon sequestration projection, and verification protocols, Western Kenya Integrated Environmental Management Project, SACRED, and World Agroforestry Centre, Nairobi, Kenya.

World Agroforestry Centre (2000). Improved land management in the Lake Victoria basin: linking land and lake, research and extension, catchments and Lake Basin, final technical report-start-up Phase-July 1999 to June 2000, World Agroforestry Centre working paper 2000-2, Nairobi.

Xie, Z., Xu, X., and Yan, L. (2009). Analysing qualitative and quantitative changes in coastal wetlands associated with the effects of natural and anthropogenic factors in a part of Tianjin, China. *Estuarine, Coastal and Shelf Science* 86(3):379-386.http://dx.doi.org/10.1016/j.ecss.2009.03.040

Yamazaki D, Ikeshima D, Tawatari R, Yamaguchi T, O'Laughlin F, Neal JC, Sampson CC, Kanae S, Bates PD (2017) A high-accuracy map of global terrain elevations. Geophys Res Lett 44:5844–5853

Yin, R. K. (2018). *Case study research and applications: Design and methods*. Sage.

Zink M, Moreira A, Bachmann M, Bräutigam B, Fritz T, Hajnsek I, Krieger G, Wessel B (2016) TanDEM-X mission status: The completely new topography of the Earth.

2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 10–15 July 2016. 317–320

APPENDICES

Appendix I: Stakeholder Questionnaire

TOPIC: IMPACT OF RIPARIAN ZONE DEGRADATION ON FLOOD OCCURRENCE AND MANAGEMENT IN THE NAIROBI RIVER BASIN, NAIROBI CITY COUNTY, KENYA

Ivan Opanga Isialila, a student at Masinde Muliro University of Science and Technology, pursuing a master's degree in Disaster Management and Sustainable Development. You are invited to participate in this research by providing your views on the Nairobi River riparian zone and flash floods. Your contribution will help in the completion of this study. The information you provide will only be used strictly for academic purposes. No names or information about any individual will be published.

SECTION A: Demographic Information

1. Gender: Male ☐ Female ☐
2. Age Bracket
   - a) 15-25 years b) 26-35 years
   - c) 36-45 years d) 46 and above
3. Highest level of Education
   - a) Primary b) Secondary
   - c) Tertiary d) University
4. Occupation:
   - a) Student b) Employed d) Retired
   - c) Self-employed d) Homemaker

SECTION B:

5. What kind of vegetation cover is available in the area? (Tick appropriately)
   - a) Trees b) Shrub c) Grass
   - d) A mixture of trees shrubs and grass e) Plantations

6. According to you how would you describe the trend of tree and vegetation diversity along the Nairobi riparian reserve?
    a) More trees are being planted now than before
    b) Trees and vegetation are clustered around developed houses
    c) Trees are linearly distributed along the riparian reserve.
    d) There is no vegetation increase
    e) Others (specify)

7. How often do you experience flash floods?

a) Very frequent b) Frequently c) Occasionally

d) Rarely e) Never

8. What challenges do you face when flooding occurs?

a) Loss of livelihoods and livestock
b) Household displacement and destruction of property
c) Outbreak of diseases
d) Loss of biodiversity and aesthetic value
e) Other specify

9. The following statements to what extent do you agree about the Nairobi River as a service provider?

a) Very important b) Important c) Moderately important

d) Of little importance e) Unimportant

10. how do you agree with the following services that the river provides?

a) Provision of food due to aquatic life presence
b) Provision of water for domestic use
c) Provision of water for commercial use ***e.g.,*** car wash, irrigation scheme
d) Other specify

11. How have the activities below affected the river over the past 5 years? (Tick all four appropriately). 12. What changes have occurred to the river? 13. What has changed in the riparian reserve

Frequency of occurrence				
Attribute	**low**	**moderate**	**high**	**extreme**
Baseflow of water				
Downstream flooding				
Water quality				
Aquatic life				

14. Who is responsible for maintaining the river and the riparian zone?

a) Riparian owner b) Community c) County council

d) Environmental Agency e) Water companies

f) Other Specify

Appendix II: Key Informant Interview Guide

Questionnaire to officials and heads in their relevant jurisdictions

Ivan Opanga Isialila, a student at Masinde Muliro University of Science and Technology, is pursuing a master's degree in Disaster Management and Sustainable Development. I am currently carrying out **Impacts of riparian zone degradation on flood occurrence and management in the Nairobi River basin, Nairobi City County, Kenya.** You are invited to participate in this research by providing your views on the riparian ecosystem and flash floods. Your contribution will help in the completion of this study. The information you provide will only be used strictly for academic purposes. No names or information about any individual will be published. Please answer the questions to the best of your ability

1. What is the state of the riparian?
2. What is the state of the Nairobi River?
3. What are the effects of the flood when it occurs?
4. What are the challenges you experience during floods?
5. How does your organisation deal with the flooding challenges?
6. What would you do differently given a chance?

Appendix III: Focus Group Discussion Guide

1. What is the community's perception of flash floods in this area?
2. Are there any indigenous coping mechanisms for flash flood experiences in this area?
3. What actions have you taken regarding the flood towards rehabilitation and riparian ecosystem restoration?
4. Suggest future land use that is consistent with your expectations.

Appendix IV: Observation Checklist

Observable features about land-use change and the conservation of plant biodiversity

a) Pattern and location of buildings
b) The Trend of Existing Construction
c) Hill slope vegetation
d) Wetland vegetation
e) Vegetation cover along the Nairobi River
f) The pattern of tree and vegetation diversity
g) The river basin, wetland, and riparian reserve policies
h) Road reserve networks

Appendix V: Research Permit from NACOSTI

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **828542**

Date of Issue: **13/January/2022**

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