

# Impacts of Urban Expansion on Land Use and Land Cover Change and Water Quality in the Dundori Forest Ecosystem in Bahati Sub-County, Nakuru County

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## ABSTRACT

Rapid, largely unplanned urbanisation of Dundori Market Centre has exerted increasing pressure on the Dundori Forest Ecosystem, a critical water catchment within the Mau Forest Complex, resulting in forest encroachment, deforestation, riparian degradation, and declining water quality in rivers draining into downstream Ramsar-listed wetlands such as Lake Elementaita. Localised empirical evidence linking urban growth to forest and freshwater ecosystem degradation had remained limited, constraining sustainable planning in Bahati Sub-county, Nakuru County. This research assessed land use and land cover (LULC) changes in the Dundori Forest Ecosystem between 1985 and 2025, evaluated the effects of urbanisation on the water quality of River Maimahiu, and identified existing mitigation strategies.

A mixed-methods design integrated remote sensing analysis across five epochs (1985–2025), physicochemical and microbiological water quality assessment at three sampling points (upstream, midstream, downstream) across dry and wet seasons, household and business surveys, and key informant interviews with institutional stakeholders. Using the Nasiuma (2000) sampling method, 106 households and businesses were surveyed alongside officials from the Water Resources Authority, Physical Planning Department, County Department of Environment, Kenya Forest Service, Agriculture Department, and Dundori Health Centre.

Findings revealed substantial land cover transformation: developed land increased by 2.5% and cultivated land expanded by 30.9%, while grassland declined by 67.7% and forest cover fell by 5.3%. Most respondents (81.0%) reported observable LULC changes, attributed mainly to farming expansion and population growth. Water quality deteriorated significantly from upstream to downstream ( $p < .001$ ), with downstream turbidity (54.12 NTU, wet season) exceeding WHO and Kenya Water Act thresholds, and elevated coliform counts confirming pollution introduced through human-modified reaches rather than the forested headwaters. Nearly 90% of households perceived declining river quality, linked mainly to upstream farming and waste dumping.

Institutions implement complementary mitigation strategies riparian protection, land use planning, afforestation, waste management, and community-based conservation though constrained by inadequate funding, weak enforcement, and limited capacity. The study establishes a clear linkage between urbanisation-driven land use change and water quality decline, and recommends an integrated, multi-sectoral management approach to safeguard the long-term sustainability of the Dundori Forest Ecosystem and River Maimahiu.

## Conceptual And Operational Definition Of Terms

| Term         | Conceptual Definition                                                              | Operational Definition                                                                                       |
|--------------|------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| Urbanization | The process through which rural areas transform into urban areas due to population | Measured by the expansion of built-up areas, population density, and land use changes within the study area. |

|                                       |                                                                                                                                                         |                                                                                                                                          |
|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
|                                       | growth, infrastructure development, and economic activities.                                                                                            |                                                                                                                                          |
| Forest Ecosystem                      | A biological community of trees, plants, animals, and microorganisms interacting with each other and their physical environment.                        | Assessed by forest cover, species diversity, vegetation types, and ecosystem services within Dundori Forest.                             |
| Urban Stream Syndrome (USS)           | A set of ecological changes in stream ecosystems caused by urbanisation, including altered hydrology, water quality degradation, and biodiversity loss. | Measured by changes in water quality parameters (e.g., turbidity, nutrient levels), stream morphology, and aquatic biodiversity.         |
| Land Use and Land Cover Change (LULC) | The alteration of natural land cover and its utilisation by human activities such as agriculture, settlement, and infrastructure development.           | Assessed using satellite imagery, GIS analysis, and classification of forest, urban, agricultural, and bareland areas over time.         |
| Community Forest Association (CFA)    | A local institution formed by community members to manage and conserve forest resources sustainably.                                                    | Evaluated through the number of active CFA groups, forest management plans, and community participation in forest protection activities. |
| Deforestation                         | The permanent removal of forest cover for alternative land uses leads to habitat loss and ecological imbalance.                                         | Measured by satellite-derived forest cover loss, tree density reduction, and an increase in non-forest land within the study area.       |
| River Ecosystem                       | A dynamic system consisting of flowing water, aquatic organisms, riparian vegetation, and the surrounding land interacting as a unit.                   | Measured by river water quality indicators, riparian vegetation cover, and species richness of aquatic life.                             |
| Land Degradation                      | The decline in land quality and productivity due to human activities or natural processes.                                                              | Assessed through soil erosion rates, loss of vegetation cover, and decrease in soil fertility in deforested areas.                       |
| Illegal Settlements                   | Human settlements established without legal permission on public or protected land.                                                                     | Measured by spatial mapping of encroached areas within forest boundaries and LULC analysis over time.                                    |
| Biodiversity                          | The variety of living organisms, including plants, animals, and microorganisms in an ecosystem.                                                         | Measured by species richness, abundance, and diversity indices in forest and river ecosystems.                                           |

## INTRODUCTION

### Background to the study

Rapid urbanisation is one of the most pressing environmental challenges of the 21<sup>st</sup> century, placing immense pressure on natural ecosystems, particularly forests and freshwater systems. Globally, over 55% of the world's population resided in urban areas in 2018, and this figure is projected to reach 68% by 2050, often growing in an unplanned manner that encroaches upon natural habitats and accelerates deforestation (UN-Habitat, 2020). Urban expansion leads to significant land use and land cover change (LULCC), habitat fragmentation, and biodiversity loss, altering ecosystem structure and functions (Zhang et al., 2025). Globally, urbanisation reduces key ecosystem services, including water regulation, soil stabilisation, and habitat provisioning and increases vulnerability to hydrological extremes (Liu et al., 2025). Urbanisation also significantly affects freshwater ecosystems: impervious surfaces, wastewater discharge, and altered hydrology increase nutrient loads, reduce water quality, and change aquatic community composition (Yuan et al., 2019).

Africa is experiencing some of the fastest rates of urban growth globally, with expanding towns and cities increasingly encroaching on forested and ecologically sensitive landscapes. Rapid urban expansion is a major driver of land-use and land-cover change (LULCC), evidenced by the conversion of wetlands, agricultural land, and green spaces into built-up areas. For example, urban growth patterns in the Densu Delta Ramsar wetland in Accra demonstrate that weak land-use control and high demand for housing have driven wetland encroachment and degradation, undermining important ecosystem functions (Oduro et al., 2024a). In Uganda's Kampala and Mbarara, substantial urban expansion has reduced agricultural land and fragile ecosystems, with a significant portion of wetlands and forests lost to built-up land between 2001 and 2015 (Muchelo et al., 2024). In Addis Ababa, the growth of informal settlements on previously natural land covers has resulted in marked declines in food production, climate regulation, and habitat services, reflecting broader LULCC impacts of urbanisation (Hailu et al., 2024). These studies consistently show that rapid urban growth fueled by population increases and insufficient land-use planning drives the loss of natural vegetation and ecosystem services essential for sustainable development in African urban regions.

Urbanisation in Africa has not only altered terrestrial ecosystems, but also affects freshwater ecosystems. Urban expansion increases impervious surfaces, alters runoff patterns, and degrades riverine and wetland systems, reducing water quality and ecological resilience (Chen et al., 2022a). Research indicates that wetlands and urban streams in Sub-Saharan Africa face threats from direct land conversion, pollution, and altered hydrology, undermining natural flood control, water filtration, and habitat provisioning (Chen et al., 2022b). Recent large-scale analyses also highlight combined impacts of LULCC and climate change on future water resources across Africa, with changing land cover affecting river flows, evapotranspiration, and water availability (Chawanda et al., 2024). Despite the critical role of smaller urban centres in shaping these dynamics, most empirical research has so far focused on major cities, leaving intermediate and emerging towns understudied (Sumari & Cobbinah, 2026).

In response to these challenges, African scholars and policymakers are increasingly advocating for integrated and sustainable urban management strategies. These include enforcement of land-use and wetland protection regulations, strengthening of institutional capacities for urban planning, and mainstreaming ecosystem conservation into broader development planning (OECD et al., 2022). For instance, research from Accra's Ramsar site emphasizes the need for better enforcement of wetland protection and coordinated planning between urban and environmental agencies to reduce habitat loss (Oduro et al., 2024b). In Kampala, predictive modelling and community engagement are recommended to guide urban development while restoring degraded wetland zones and maintaining ecological functions (Waswa et al., 2025). Across the continent, such interventions are intended to balance urban growth with ecosystem protection, although effective implementation remains uneven due to constraints in governance, resources, and coordination. These efforts underscore a pressing need to close knowledge gaps and strengthen localized strategies that address both urbanisation and ecosystem degradation in Africa.

Kenya has experienced rapid urbanisation in recent decades, driven by population growth, rural–urban migration, economic transformation, and infrastructure development. Urban populations are expanding not only in major cities but also in small and intermediate towns, many of which are located near ecologically sensitive areas. This growth has intensified pressure on forests, wetlands, and freshwater ecosystems that function as critical water towers. Urban expansion has emerged as a major driver of land-use and land-cover change (LULCC), converting forests, riparian zones, wetlands, and agricultural land into built-up areas. Remote sensing studies in Nairobi, Nakuru, Kisumu, and Eldoret show a rapid increase in impervious surfaces at the expense of natural vegetation, especially in peri-urban zones with weak development control (Munyoki, 2024a). The effects are particularly pronounced in settlements excised from gazetted forest reserves and water towers, such as the Mau Forest Complex, Aberdare Range, Mt. Kenya, and Cherangany Hills. These areas, initially established as rural settlement schemes, are now rapidly urbanising and densifying, leading to deforestation, landscape fragmentation, and loss of ecological buffers (Edmond, 2018).

The implications of urban-driven LULCC are especially severe for freshwater ecosystems. Replacement of forest cover and permeable soils with built-up surfaces alters hydrological processes, increasing surface runoff,

reducing groundwater recharge, and accelerating soil erosion. Rivers originating from Kenya's water towers, including those in the Mau, Aberdares, and Mt. Kenya catchments, are increasingly affected by sedimentation, nutrient loading, and pollution from domestic wastewater, solid waste, agriculture, and emerging industrial activities (Hellens et al., 2024; Onyango et al., 2021). Wetlands and riparian corridors are similarly encroached upon, reducing their capacity to provide water purification, flood regulation, and habitat services. Urbanisation within excised forest settlements further heightens vulnerability due to inadequate infrastructure, poor waste management, and weak enforcement of riparian regulations (Mwiti, 2014). While Kenya has implemented measures such as the Forest Conservation and Management Act (2016), EMCA, Community Forest Associations, and integration of safeguards into county and urban plans, interventions are often reactive rather than proactive, leaving critical knowledge gaps on managing urbanisation pressures in forest-adjacent settlements. Addressing these gaps is essential to sustainably manage land-use change, protect freshwater ecosystems, and guide urban growth in Kenya's water tower ecosystems (World Bank, 2016).

Dundori Market Centre in Nakuru County exemplifies the challenges of urbanisation at a local scale. The market centre has expanded into the adjacent Dundori Forest, which is part of the Mau Forest Complex and was historically excised for human settlement schemes. These excised areas, initially intended for rural habitation, are now undergoing rapid urbanisation and densification, intensifying pressures on the forest and surrounding ecosystems. Dundori Forest functions as a critical watershed supporting the Mai Mahiu River and provides essential ecosystem services, including water regulation, soil stabilization, and biodiversity conservation. However, unregulated urban expansion through land clearing for settlements, agriculture, and commercial activities has contributed to habitat fragmentation, deforestation, and soil erosion. Poor solid and liquid waste management practices have further degraded river water quality, impacting domestic water use, irrigation, and ecosystem health. Although mitigation measures such as community forest associations and local policies exist, their effectiveness in addressing localized pressures from settlement densification and urban growth within excised forest areas remains unclear (County Government of Nakuru, 2021; Local Environmental Surveys, 2022).

While global, regional, and national literature highlights the negative effects of urbanisation on forests and rivers, significant gaps remain. There is limited evidence on how small, rapidly urbanising towns like Dundori Market Centre experience interactions between urban growth, land use and land cover change (LULCC), and ecosystem degradation. Similarly, the cumulative impacts of urbanisation on river water quality and forest ecosystem services at a localized scale are underexplored. In addition, the effectiveness of mitigation measures, including community engagement and enforcement of environmental regulations, has not been adequately assessed in smaller forest-adjacent urban centres. Addressing these gaps is essential to provide evidence-based guidance for sustainable urban planning, effective conservation strategies, and the management of critical natural resources in peri-urban landscapes.

## Statement of the Problem

The rapid and largely unplanned urbanisation of Dundori Market Centre is increasingly exerting pressure on the Dundori Forest ecosystem, an important part of the Mau Forest Complex and a critical water catchment area. Expansion of settlements, commercial activities, infrastructure development, and population growth around the market centre are occurring with limited integration of environmental safeguards, leading to forest encroachment, deforestation for fuelwood and construction materials, improper solid waste disposal, and discharge of untreated wastewater. These activities are degrading forest cover, riparian zones, and biodiversity, while also affecting the quality and quantity of water in rivers emanating from Dundori Forest. Such rivers are of high ecological significance as they drain into downstream lakes, including Lake Elementaita, a Ramsar-designated wetland of international importance, thereby extending the impacts of local urbanisation beyond the immediate forest environment.

Despite the ecological importance of Dundori Forest and its hydrological connection to internationally recognized wetlands, there is limited localized and empirical research examining how the growth of Dundori Market Centre specifically influences forest ecosystem health and downstream water systems. Existing studies

largely focus on the broader Mau Forest Complex or general deforestation trends, while urban planning and environmental management frameworks often operate in isolation, resulting in weak integration of urban development controls within ecologically sensitive areas. As Dundori Market Centre continues to expand, the absence of site-specific evidence to guide sustainable planning poses a risk of irreversible ecosystem degradation and compromised downstream ecosystems. This research is critical to assess current urbanisation impacts, fill critical knowledge and planning gaps, and provide evidence-based recommendations to support sustainable urban development, forest conservation, and protection of Ramsar-listed wetlands within Nakuru County.

## **Objectives of the study**

### **General Objectives of the study**

The broad objective of this study is to assess the impacts of urban expansion associated with growth of Dundori forest ecosystem in Bahati subcounty, Nakuru County.

### **Specific Objectives of the study**

The study was guided by the following specific objectives:

1. To investigate the extent and patterns on Land Use and Land Cover Change associated with the expansion of Dundori market centre
2. To evaluate the impacts of the urbanisation activities on the quality of water in River Maimahiu within Dundori forest
3. To investigate the effectiveness of the strategies used to mitigate the impacts of urban development on the Dundori forest ecosystem

### **Research Questions**

1. What are the extent and patterns of land use and land cover changes associated with urban growth in the Dundori Forest ecosystem?
2. How does the urban development affected the quality of water in River Maimahiu within the Dundori Forest?
3. What sustainable strategies are currently being adopted to promote urbanization while conserving Dundori Forest ecosystem?

### **Justification of the study**

The rapid urbanisation of Dundori Market Centre has caused significant changes in land use and land cover, threatening the Dundori forest ecosystem and affecting water quality in River Maimahiu. This study provides critical evidence to guide sustainable urban planning, forest conservation, and water resource management, directly supporting SDG 6 (Clean Water and Sanitation), SDG 11 (Sustainable Cities and Communities), and SDG 15 (Life on Land). It aligns with Africa Agenda 2063, promoting inclusive growth and sustainable resource management, and supports Kenya Vision 2030 by informing resilient urban development strategies. By emphasizing wetland and watershed protection, the study also contributes to Kenya's obligations under the Ramsar Convention, enhancing conservation of water ecosystems. The findings will help county authorities, local communities, and NGOs make evidence-based decisions, strengthen forest and wetland conservation initiatives, and implement mitigation strategies to improve forest protection, water quality, and stakeholder engagement.

## Significance of the study

The significance of this study lies in its contribution to knowledge, policy, and practice. Academically, the study will contribute to the existing body of literature on urbanization ecosystem interactions, particularly within peri-urban and rural contexts in Kenya, by enhancing understanding of how localized urban centres such as Dundori Market Centre influence forest ecosystems and water quality. From a policy and planning perspective, the findings will provide county governments, the National Environment Management Authority (NEMA), the Kenya Forest Service (KFS), and other relevant institutions with evidence-based information to support spatial planning, forest conservation, environmental management, and regulation of urban development. At the community level, residents of Dundori and neighbouring settlements will benefit from recommendations and strategies aimed at promoting sustainable use of forest resources and safeguarding clean water for domestic and agricultural purposes. Furthermore, environmental conservation organisations and non-governmental organisations (NGOs) will benefit from the findings by gaining a practical evidence base for designing and implementing interventions aimed at conserving Dundori Forest, protecting the riparian environment, and reducing pollution and degradation of River Mai Mahiu.

## Scope of the study

### Geographic Scope

The study will be conducted in Dundori Market Centre and its surrounding areas that directly interact with the Dundori Forest ecosystem and River Mai Mahiu, a location chosen due to its rapid urban expansion and its vital role as a forest–river catchment area. The research will focus on three key areas: identifying urbanisation activities that impact the forest ecosystem, assessing their effects on the water quality of River Mai Mahiu, and proposing mitigation measures to promote sustainable coexistence between urban development and ecosystem conservation. Covering the period from 1990 to 2025, the study will incorporate historical data on land use and land cover changes to establish long-term trends and their implications for the forest and river systems. The target group will include residents of Dundori Market Centre, local traders, farmers, community forest associations, and government agencies responsible for land use planning and environmental conservation, as these stakeholders are directly linked to urbanisation processes and play a central role in the management and use of forest and river resources.

## Limitations of the study

This study faced several limitations:

1. **Data Limitations-** Accessing reliable historical data on land use and water quality may be constrained, limiting temporal comparisons. To overcome this, the researcher triangulated secondary data with remote sensing analysis and primary field surveys.
2. **Self-reporting Bias-** Data collected through questionnaires and interviews may have been subject to bias or exaggeration by respondents. To mitigate this, the researcher combined multiple data collection methods, including direct observation and GIS mapping.
3. **Financial and Time Constraints:** Conducting water quality tests and spatial analysis required resources and time. The researcher prioritized key parameters (e.g., turbidity, electrical conductivity, DO) and adopted cost-effective sampling strategies.
4. **Accessibility Challenges-** Some parts of Dundori Forest was difficult to access due to dense vegetation or restrictions by forest authorities. The researcher collaborated with the Kenya Forest Service (KFS) to gain access.

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## LITERATURE REVIEW

### Introduction

This chapter provides a general overview of the existing relevant literature to the effects of urbanisation on river ecosystems, mainly human activities, their effects on the river's water quality and the strategies used to mitigate the human activities on the river ecosystems. It delves into key concepts related to urbanisation and river ecosystems, theoretical and conceptual frameworks, and findings conducted by other authors relevant to this study.

### Theoretical review

This study is anchored on two interrelated theoretical perspectives that provide a holistic understanding of the relationship between urbanisation and environmental degradation. The Tragedy of the Commons explains the social drivers behind the overexploitation of forest and river resources, particularly under conditions of weak regulation and uncoordinated community action. On the other hand, the Urban Stream Syndrome illustrates the ecological consequences of urbanisation, specifically how land-use changes and inadequate waste management alter the health of rivers within forest ecosystems. By integrating these theories, the study establishes a comprehensive framework to examine how urbanisation pressures from Dundori Market Centre contribute to the degradation of both the Dundori Forest and its river resources, while also guiding the identification of context-specific mitigation strategies.

### The first theory

#### Tragedy of the Commons Theory

The Tragedy of the Commons theory was first introduced by (Hardin, 1968). The theory argues that when natural resources such as forests, rivers, and grazing lands are open for communal use, individuals tend to overexploit them for personal gain without considering the long-term collective consequences. This leads to resource depletion, environmental degradation, and ecosystem collapse. In the context of forest ecosystems, urban expansion often results in deforestation, encroachment, and unsustainable extraction of forest products as individuals act in their self-interest.

### Critiques

While Hardin's theory provides a strong foundation for understanding collective misuse of resources, critics argue that it oversimplifies community resource management. Scholars such as (Ostrom, 1990) demonstrated that local communities can successfully manage common resources through cooperative institutions, customary rules, and collective governance mechanisms. Hence, the "inevitability" of degradation in commons, as suggested by Hardin, may not always hold in settings where community-based management is strong. Recent studies continue to validate Ostrom's findings. For example, research in Kenya and other African countries shows that community forest associations and water user groups can outperform state-led or privatized management in sustaining resources, especially when supported by enabling policies(Rose, 2020)

### Relevance to the Study

This theory is highly relevant to the study of Dundori Market Centre urbanisation and its effects on the forest ecosystem. The forest and river systems surrounding Dundori are common-pool resources, which face the risk of overexploitation due to unregulated urban activities such as deforestation for settlement, agriculture, and infrastructure development. By framing the study under the Tragedy of the Commons, it becomes possible to analyze how urbanisation intensifies pressures on these shared resources and to explore governance strategies that could mitigate the degradation of Dundori Forest and its river ecosystem.

## **The second theory**

### **The Urban Stream Syndrome Theory**

The Urban Stream Syndrome (USS) theory was proposed by (Meyer, 2005) and further developed by (Walsh, 2005) to explain the ecological impacts of urbanisation on river systems. The theory suggests that urbanisation alters natural hydrological and ecological processes through impervious surfaces, poor stormwater management, and unregulated liquid and solid waste disposal. The syndrome is characterised by increased pollutant loads, frequent flash floods, reduced biodiversity, channel modification, and deteriorating water quality in rivers and streams within urbanised catchments.

### **Critique**

While Urban Stream Syndrome provides a robust framework for understanding how urbanisation degrades water resources, some scholars argue that the theory is too generalized, as it assumes uniform impacts across all urbanised rivers. In reality, the extent of urban stream syndrome can vary depending on local policies, the level of urban planning, and the existence of green infrastructure. Recent studies suggest that nature-based solutions and improved stormwater management can mitigate some of the predicted negative impacts, showing that urbanisation does not always lead to inevitable ecological collapse (Su et al., 2023).

### **Relevance to the Study**

The Urban Stream Syndrome theory directly informs this study by providing a lens to examine how Dundori Market Centre's urbanisation is affecting the rivers within the Dundori Forest ecosystem. Key urbanisation activities such as unregulated waste disposal, agricultural runoff, and land cover changes contribute to declining water quality and loss of aquatic biodiversity. Applying USS enables the study to assess how specific urban pressures manifest within Dundori's river systems and to recommend appropriate mitigation strategies to restore ecological balance.

### **Empirical review**

This section involves a critical assessment of past studies relevant to the current study, highlighting what has been done, the methodological approaches used, and the knowledge gaps that remain to be addressed.

Urbanisation, defined as the expansion of human settlements, infrastructure, and economic activities, is widely recognised as a driver of economic growth and improved access to services. However, this process often occurs at the expense of natural ecosystems, particularly forests and river systems, which are highly sensitive to land-use change (van Vliet, 2019). In rapidly urbanising regions of the Global South, including sub-Saharan Africa, weak land-use controls and inadequate environmental safeguards have intensified ecological degradation, creating a critical sustainability challenge (Ogunbode et al., 2025).

Urban expansion has been strongly linked to forest ecosystem degradation through land-use change, deforestation, and habitat fragmentation. As urban areas expand into surrounding natural landscapes, forest cover is increasingly converted into residential, commercial, and infrastructural developments (Enomah et al., 2024). Urban growth in tropical regions, including parts of Africa, has resulted in a 20–30% reduction in forest cover over the past two decades, significantly threatening biodiversity and carbon sequestration capacity. Beyond forest loss, urban-induced pressures also undermine ecosystem services such as climate regulation, soil stabilisation, and water purification. In East Africa, studies show that rapid urbanisation in East Africa has undermined forest resilience and intensified soil erosion, especially in peri-urban zones characterized by weak planning frameworks and limited environmental regulation.

Peri-urban areas at the interface of urban and forested landscapes are critical transition zones where urbanisation profoundly affects forest ecosystems, fragmenting habitat and disrupting ecological connectivity. In Kenya, peri-urban zones around major towns such as Nakuru have experienced significant land-use and land-cover changes

driven by housing and infrastructure expansion, at the expense of natural vegetation and forest fragments (Cherotich et al., 2025). Likewise, studies in the Nairobi metropolitan area show that urban forests have lost substantial tree cover, approximately 720 ha, or about 11 %, between 2000 and 2019, largely due to settlement and land conversion pressures on forested land near expanding urban and peri-urban zones. However, little is discussed about the urbanisation of these settlements(Oloo et al., 2020)

River systems within the forest ecosystems are equally affected by urbanisation through altered hydrological processes and increased pollution loads. The phenomenon commonly referred to as *urban stream syndrome* describes the cumulative impacts of impervious surfaces, stormwater runoff, and wastewater discharge on river health (Li et al., 2023). Rivers in urban areas of Africa exhibit widespread sediment contamination, elevated nutrient loading, and degraded ecological status, driven by unplanned urban expansion and human activities (Chen et al., 2022c). Studies in the Niger Delta demonstrated that heavy metals, pesticides, fertilizers, and plastics accumulate in urban river systems, negatively affecting sediment quality and aquatic organisms(Edegbene & Akamagwuna, 2022). Microplastic pollution is also pervasive in South African freshwater systems, with plastics detected in rivers and sediments, contributing to polluted freshwater habitats. Overall, these pollutants degrade water quality and pose risks to both ecosystems and human health(Mokgalaka-Fleischmann et al., 2024). Sediments of urban streams in Kenyan cities show high levels of organic carbon, nitrogen, phosphorus, and toxic heavy metals linked to urban runoff and pollutant inputs(Achieng', 2022).

Empirical studies from Kenya further illustrate these challenges, which identified elevated concentrations of heavy metals and microplastics in rivers flowing through Nairobi, linking these pollutants to urban runoff and poor waste management practices. Such contamination not only undermines aquatic ecosystems but also threatens downstream users who rely on river water for domestic, agricultural, and recreational purposes. These impacts are particularly concerning in watershed areas where rivers originate near urban or peri-urban settlements (Jelimo et al., 2025)

Despite these challenges, evidence suggests that well-designed mitigation strategies can reduce the negative impacts of urbanisation on river systems. Nature-based solutions (NBS), including green infrastructure such as constructed wetlands, riparian buffers, and permeable pavements, have proven effective in managing stormwater and improving water quality.(add citation). (Lemes De Oliveira et al., 2025) demonstrate that the application of NBS in urban environments can reduce surface runoff by up to 40% while simultaneously enhancing ecological resilience. At the policy level, (Mwanzu et al., 2023) highlight Kenya's *Green Urban Areas Initiative* as a promising framework for integrating environmental sustainability into urban planning.

However, while global and regional studies clearly document the ecological impacts of urbanisation, there remains a significant gap in localized, context-specific research. Many small and rapidly growing market centres, such as Dundori Market Centre in Nakuru County, lack empirical data on how urbanisation affects adjacent forest and river ecosystems. Without localized evidence, planning interventions risks being generic and ineffective. This gap underscores the need for site-specific studies to inform sustainable urban planning and ecosystem management in emerging urban centres.

### **Effects of Urbanisation Activities on the Land Use and Land Cover Changes**

Urbanisation is a primary driver of global environmental change, significantly reshaping land use and increasing pressure on forest ecosystems. The expansion of urban settlements coupled with infrastructure demands often occurs at the expense of forests, leading to habitat fragmentation, loss of biodiversity and altered ecosystem functions (Nayak, Shukla, & Devi, 2024). This direct land conversion is further intensified by energy demands from sources such as firewood collection and charcoal production, and agricultural expansion, which contribute to widespread forest degradation and deforestation (Santos, 2017). The cumulative effects of these changes are multifaceted, as urbanisation influences land cover and ecosystem integrity by fragmenting habitats and causing the loss of critical ecosystem functions. These processes, in turn, disrupt biodiversity and alter hydrological regimes. (Arfasa, Owusu-Sekyere, & Doke, 2023).

Land Use and Land Cover Change (LULCC) is a core mechanism through which urbanisation affects forest ecosystems. Globally, urban expansion and infrastructure development have replaced vast areas of natural vegetation, as observed in Europe, where built-up and agricultural lands have increasingly encroached on forested areas (The European Environment Agency, 2024). In the France-Monaco borderlands, (Behradfar, Castanho, & Ferreira, 2025) demonstrated that between the year 2000 and 2018, built-up areas increased by 18km<sup>2</sup> at the expense of 11km<sup>2</sup> of Mediterranean forest ecosystem. This transformation not only reduced the forest cover but also caused significant habitat fragmentation and diminished ecological connectivity. This demonstrates the need for integrated cross-border land management strategies.(add citation)

Similar studies were observed in China by (Zhou, Zhang, Yu, Wang, & Wan, 2017) ,who examined urban expansion across major Chinese megaregions, including the Pearl River Delta, Chengdu-Chongqing, and Changsha and Changsha–Zhuzhou–Xiangtan. This study emphasizes the importance of planning urban growth at appropriate spatial scales to mitigate ecological impacts. This shows that unregulated urbanisation can have profound long-term effects on the forest ecosystems.

Urbanisation also drives land use change indirectly through dietary shifts and energy demands. As the urban population grows, diet shifts towards more processed and animal-based foods, increasing the land required for staple crops and livestock feed (FAO, 2024). This trend is exemplified in the Brazilian Amazon, where beef and soy production linked to urban dietary demands accounts for over 60% of newly deforested areas (Harvey, 2025) Globally, agriculture accounts for more that 90% of deforestation, this shows strong link between urban consumption patterns and forest loss (Food and Agriculture Organization of the United Nations (FAO), 2021).

In African contexts, the impacts of urbanisation on LULCC are evident across multiple countries. Nigerian cities such as Lagos, Abuja and Ibadan have experienced rapid urban expansion, leading to widespread conversion of forests into built-up areas, farmlands, particularly in protected ecosystems like the Omo Forest Reserve and Cross River National Park (Akinola, 2023).In Ethiopia, small and medium-sized towns such as Burayu have witnessed extensive horizontal urban expansion, with peri-urban forests cleared for housing, industrial development, and infrastructure, illustrating how urbanisation can drive inefficient land use patterns and forest degradation (Talema & Nigusie, 2024).

Kenya provides further evidence of these dynamics. Studies on the Ngong Forest ecosystem indicate significant declines in forest and grassland cover due to settlement expansion and agricultural intensification (Ibrahim, 2021; Oloo et al., 2020). Similarly, research on the Mau Forest ecosystem documents declines in forest cover from 1976 to 2014, driven by agricultural expansion and illegal settlements (Jebiwott et al., 2021; Were et al., 2013). However, these studies often focus on the immediate effects of human settlements rather than the broader consequences of urbanisation over time, such as densification, infrastructure development and increased resource demand.

The present study addresses a geographical and contextual research gap concerning the limited empirical understanding of how urbanisation in small but rapidly growing market centres influences land-use and land-cover change (LULCC) and surrounding forest ecosystems. While considerable research has focused on large cities and metropolitan regions, less attention has been given to emerging market centres such as Dundori in Kenya, where increasing human settlement, commercial activities, cultivation, and infrastructure development may drive changes in forest cover and other land-cover categories. The study therefore seeks to generate localized evidence on the nature, extent, and temporal dynamics of urbanisation-induced LULCC within the Dundori Forest ecosystem. Addressing this gap is important for improving understanding of how small-scale urban growth contributes to landscape transformation and for providing evidence to support integrated land-use planning and sustainable management of forest resources in emerging urban centres.

### **Effects of the Urbanization activities on the water quality**

Urbanisation is widely recognized as a major driver of changes in forest ecosystems, with water quality in rivers and streams among the most vulnerable aspects. The expansion of settlements, infrastructure, and economic

activities reduces the natural filtering capacity of landscapes and introduces multiple physical, chemical, and biological contaminants into river systems, compromising ecosystem integrity and posing health risks (Mânica et al., 2025). The cumulative impact of these pressures is especially pronounced where urban growth is rapid and unplanned (Wiederkehr et al., 2020)

A range of human activities contribute to river pollution. Improper waste management and inadequate sanitation systems result in the indiscriminate disposal of both solid and liquid waste directly into rivers. Untreated domestic and commercial wastewater introduces organic matter, nutrients, and pathogens, reducing dissolved oxygen and disrupting the river's natural self-purification processes (Lema, 2025). Similarly, the intensification of urban agriculture increases the use of fertilizers and pesticides, which, through surface runoff during rainfall events, elevate concentrations of nitrates, phosphates, and agrochemicals in rivers, promoting eutrophication and chemical contamination (Karani, 2024)

Deforestation associated with urban expansion further exacerbates river pollution. The clearing of vegetation for settlements, roads, and farmland exposes soils to erosion, increasing sediment loads in rivers. Elevated turbidity not only reduces light penetration but also disrupts aquatic habitats and diminishes the rivers' natural purification capacity (Chen et al., 2022c). Market activities, small-scale industries, and slaughterhouses contribute additional pollutants, including organic waste, oils, heavy metals, and chemicals, which raise biochemical oxygen demand (BOD) and degrade water quality (Tomno et al., 2020). These combined pressures create a complex mixture of physical, chemical, and microbial pollution, highlighting the multifaceted nature of urbanisation's impacts on rivers.

Globally, urbanization has consistently been associated with water quality deterioration. In Europe, less than one-third of surface waters meet good ecological status, with nutrient pollution, poor chemical quality, and urban runoff identified as primary contributors to river degradation (European Environment Agency., 2018). In rapidly urbanizing regions of China, such as the Pearl River Delta, water quality declines correlate with the intensity of urban growth, with nutrient loading, chemical oxygen demand, and microbial contamination linked to expanded urban areas and agricultural intensification (Liang et al., 2023). These studies illustrate that urbanization disrupts natural hydrological and nutrient cycles, with site-specific factors influencing the severity of impacts.

Similar challenges are observed in African countries. In Ghana, water quality assessments of the Densu River basin revealed that increased urbanisation, coupled with untreated waste discharge, led to elevated concentrations of aluminium, phosphorus, turbidity, and other pollutants, exceeding WHO guidelines and posing risks to communities relying on the river for domestic use (Duncan et al., 2019). In East Africa, studies in Tanzania using upper-urban-down gradient assessments showed that urban rivers experienced elevated levels of nitrogen, chemical oxygen demand, total phosphorus, and ammonium in lower urban reaches, highlighting the direct impact of municipal and domestic waste on river ecosystems (Chen et al., 2022c)

In Kenya, urbanisation has been linked to similar degradation patterns in rivers originating from forest ecosystems. Studies on rivers such as Mbagathi, Kiserian, Nyangores, and Amala demonstrate the effects of settlements, agricultural expansion, and industrial activities on both physicochemical and microbial water quality parameters (Howland, 2023; James et al., 2018; Munyoki, 2017). Increased levels of faecal contamination indicators (*E. coli*, *Salmonella* spp., intestinal enterococci), turbidity, BOD, COD, and nutrient concentrations have been reported in rivers passing through peri-urban areas, which demonstrate the health risks for humans, livestock, and wildlife. Notably, rivers such as Nyangores and Ewaso Nyiro have shown that urbanised catchments produce measurable declines in water quality, particularly downstream of settlements and market areas (Ngatia et al., 2023)

Despite extensive documentation of these effects, most studies focus on immediate or local-scale pollution events rather than the long-term impacts of urbanisation on rivers originating in forest ecosystems, such as those within the Dundori and Mau forest complexes (Boitt et al., 2024; M. Chrisphine & A. Maryanne, 2015). While deforestation and settlement expansion are known drivers, there is limited understanding of how the cumulative process of urbanization including densification, infrastructure development, and increased human and livestock

pressure, alters river water quality over time. This gap is critical, as ongoing urban growth may exacerbate sedimentation, nutrient enrichment, microbial contamination, and chemical pollution, threatening both ecosystem services and public health.

Overall, the literature demonstrates that urbanisation degrades river water quality through multiple interacting pathways: direct discharge of waste, agricultural runoff, deforestation-induced erosion, and industrial effluents. Globally, regionally, and locally, rivers in urbanising areas exhibit reduced ecological integrity, heightened disease risk, and diminished biodiversity. In Kenya, rivers flowing from forested landscapes into peri-urban centers face particularly severe challenges due to the combination of anthropogenic pressures and limited regulatory enforcement. Addressing these complex, multi-scalar impacts requires integrated management approaches that combine urban planning, wastewater treatment, community engagement, and enforcement of environmental regulations. This forms the rationale for investigating the influence of urban development on the water quality in River Mai Mahiu within the Dundori Forest ecosystem.

### **Mitigation measures used to balance urbanisation and the forest ecosystems.**

Mitigating the impacts of urbanisation on forest ecosystems and associated river systems has been a central concern in environmental management and urban planning literature. Scholars emphasize that effective mitigation requires an integrated approach combining legal and policy frameworks, improved waste management systems, and active community participation to regulate urban expansion, reduce ecological degradation (UN-Habitat, 2021) and promote sustainable coexistence between human settlements and natural ecosystems. These measures operate at multiple scales, from international agreements to local-level implementation, and collectively shape how urban growth interacts with forest and river environments (Stockholm Resilience Centre, 2014).

Legal and policy frameworks form the backbone of mitigation strategies by setting enforceable limits on activities that threaten forest ecosystems and water resources. At the international level, global environmental agreements such as the Convention on Biological Diversity and the Paris Agreement provide guiding principles that encourage countries to balance economic development with environmental conservation (CBD, 2025). These frameworks influence national policies by promoting land-use planning, environmental impact assessments, forest protection legislation, and integrated water resource management as key tools for managing urban growth in ecologically sensitive areas. At regional and local levels, urban planning regulations, protected area laws, and municipal bylaws further operationalize these commitments by controlling pollution, restricting unplanned urban expansion, and safeguarding rivers flowing through forested landscapes. Literature consistently highlights that such legal frameworks not only regulate harmful activities but also enable restoration initiatives, incentivize sustainable (United Nations Environment Programme, 2021) land use, and enhance accountability among governments, developers, and communities (United Nations Environment Programme, 2021).

Experiences from Europe demonstrate the effectiveness of strong regulatory frameworks in protecting forests and river ecosystems from urban pressures. The European Union Forest Strategy emphasizes sustainable forest management and biodiversity conservation while discouraging urban sprawl into forested areas (*European Commission, 2021*). This is complemented by the EU Water Framework Directive, which requires member states to achieve and maintain “good ecological status” for rivers, addressing urban wastewater discharge and stormwater runoff that affect forested river basins (European Environment Agency, 2024). National planning instruments, such as the United Kingdom’s Green Belt policy under the Town and Country Planning Act, have further limited uncontrolled urban expansion into surrounding forest and agricultural lands, illustrating how coordinated policy instruments can effectively moderate urban growth.

In Asia, rapid urbanisation has necessitated the adoption of stringent conservation-oriented legal frameworks. In China, the revised Forest Law prohibits the conversion of forest land for urban construction while promoting reforestation and land-use zoning to protect critical ecosystems (*Forest Law of the People’s Republic of China, 2019*). Governance innovations such as the River Chief System have strengthened accountability by assigning local officials direct responsibility for river health, thereby addressing pollution associated with urban

settlements. Additionally, the Ecological Redline Policy has established protected zones where urban and industrial development is strictly controlled, reinforcing the protection of forest and watershed ecosystems (Wang et al., 2023). Similarly, Japan integrates forest and river conservation into its urban planning framework through legislation such as the Forest and Forestry Basic Act and the River Law, which promote integrated basin management and restrict development in ecologically sensitive forested river catchments (Government of Japan, *Forest and Forestry Basic Act*, 1964). These examples highlight how legal coherence across sectors can effectively balance urbanisation and ecosystem preservation.

Asian countries have also made notable progress in waste management reforms. China has implemented mandatory waste segregation systems in major cities and expanded wastewater treatment coverage to over 95 percent of urban sewage, significantly reducing contamination of rivers and riparian forests (World Bank Group, 2019) and Japan's community-based waste separation systems and advanced incineration technologies have minimized landfill dependence, reducing land-use pressure on forests while safeguarding river ecosystems (Hao et al., 2024). These interventions demonstrate how effective waste management can mitigate urban impacts on the forest ecosystem.

In Africa, although waste management systems remain inconsistent, improvements are evident in cities adjacent to forest ecosystems. Initiatives such as waste-to-energy programs in Lagos, engineered landfills in Ghanaian cities, and recycling and wastewater infrastructure improvements in Tanzania have contributed to reducing pollution of rivers and forested catchments (Ajulor et al., 2024). However, the literature consistently notes that inadequate coverage and rapid urban expansion continue to undermine these efforts (Atofarati et al., 2025)

In Africa, regional and national policy frameworks play an increasingly important role in mitigating urbanisation impacts, though implementation remains uneven. The African Convention on the Conservation of Nature and Natural Resources provides continent-wide guidance on sustainable management of forests and river ecosystems (*African Union*, 2022). At the national level, countries such as Nigeria and Ghana have adopted regulatory instruments to control urban pollution and protect forest reserves and river catchments from unregulated expansion (Federal Republic of Nigeria, 2009; Government of Ghana, 2017). However, literature notes that weak enforcement and rapid urban growth often limit the effectiveness of these policies (Prameela, 2024). This highlights the need for complementary mitigation measures in African urbanising countries (OECD et al., 2025).

In Kenya, a comprehensive legal framework has been established to protect forest and river ecosystems from urbanisation pressures. The Forest Conservation and Management Act promotes sustainable forest management and community participation while preventing illegal encroachment into forest land (Forest Conservation and Management Act, 2016). The Water Act operationalizes Integrated Water Resources Management to safeguard rivers from pollution and overexploitation driven by urban settlements (*Water Act*, 2016), while the Physical and Land Use Planning Act provides mechanisms for zoning, development control, and mandatory Environmental Impact Assessments for projects near forests and river ecosystems (*Physical and Land Use Planning Act No 13*, 2019). Despite this strong policy foundation, studies indicate that enforcement gaps and informal urban growth continue to pose significant threats, particularly in peri-urban forest zones (Jackson et al., 2025)

Beyond legal frameworks, waste management has been identified as a critical mitigation measure for protecting forest ecosystems and rivers in urbanising areas. In Europe, integrated waste management policies and advanced infrastructure have significantly reduced waste-related pollution (European Environment Agency, 2025). The EU Waste Framework Directive promotes waste prevention, reuse, recycling, and recovery, thereby minimising the pressure of urban waste on natural ecosystems. Together with the Water Framework Directive, these policies have helped protect rivers and adjacent forests from urban effluents and solid waste dumping (Smith, 2015)

In Kenya, waste management is closely linked to forest and river protection, particularly in urban areas bordering critical ecosystems. Regulations under the Environmental Management and Coordination Act control waste disposal near forests and riparian reserves (*Environmental Management and Coordination Act*, 2015), while community-driven recycling and collection initiatives play a growing role in reducing pollution. Programs such

as the Nairobi River Basin Rehabilitation Program illustrate how wastewater treatment expansion can mitigate urban impacts on river systems connected to forested areas.

Community-based approaches have also emerged as a vital component of mitigation strategies. Globally, literature emphasizes that involving local communities enhances stewardship, compliance, and long-term sustainability (WWF, 2021). In Europe, community forest management initiatives empower local populations to co-manage peri-urban forests, while river restoration projects along major rivers such as the Danube and Rhine engage communities in monitoring pollution and protecting riparian forests (Lawrence et al., 2021)

In Asia, participatory approaches have been integrated into national conservation strategies. In China, urban residents participate in reforestation and river clean-up programs under the Ecological Redline framework, while citizen science initiatives monitor water quality in urban-adjacent rivers). Japan's Satoyama landscape approach exemplifies community-led management of forests, agricultural land, and rivers, maintaining biodiversity while accommodating urban development pressures (Takeuchi et al., 2016).

Across Africa, community-driven conservation initiatives increasingly serve as buffers against urban encroachment. Community forest committees in Ghana, Nigeria, and Tanzania combine local bylaws, awareness campaigns, and participatory monitoring to protect forests and river ecosystems from settlement expansion and waste dumping (Ambrosetti et al., 2016; Blomley et al., 2008)

In Kenya, Community Forest Associations established under the Forest Conservation and Management Act have played a significant role in co-managing forests threatened by urban expansion. In areas such as Karura and Ngong Forests, collaboration between communities, civil society, and government agencies has enhanced protection of forest ecosystems and associated rivers (Osewe et al., 2025). However, existing studies indicate that many community initiatives focus more on rehabilitation than on proactively managing urbanisation pressures, highlighting a gap in integrating urban planning with community-led conservation efforts. Within the Mau Forest Complex, community-based interventions such as reforestation, riverbank rehabilitation, and monitoring of illegal settlements have been critical in mitigating pressures on water catchments (Makindi, 2024). Nevertheless, localized evidence on how these interventions address urbanisation-driven impacts remains limited.

Overall, the literature demonstrates that balancing urbanisation with forest and river ecosystem conservation requires a combination of strong legal frameworks, effective waste management systems, and meaningful community participation. While global and regional experiences offer valuable lessons, gaps persist in understanding how these mitigation measures function at the local scale, particularly in rapidly urbanising forest-adjacent areas. This study, therefore, seeks to examine the specific mitigation measures employed within the study area and assess their effectiveness in addressing the localized impacts of urbanisation on forest ecosystems and river resources.

## CONCEPTUAL FRAMEWORK

The conceptual framework guiding this study is anchored on the relationship between urbanisation activities at Dundori Market Centre and their effects on the Dundori forest ecosystem. The framework illustrates how the expansion of urban settlements, land use and land cover changes, waste generation (solid and liquid), agriculture intensification, and infrastructure development constitute the independent variables driving ecological change.

These activities exert direct pressure on the dependent variables, namely the Dundori forest ecosystem and its river resources, leading to deforestation, biodiversity loss, river pollution, soil degradation, and declining ecosystem services.

However, the interaction between these forces is influenced by intervening variables, including government policies, land use regulations, community-based conservation initiatives, enforcement of environmental laws,

and adoption of waste management practices. These factors can either exacerbate the negative impacts of urbanisation if weakly applied, or mitigate them if effectively implemented.

The framework establishes that the extent of urbanisation effects on Dundori's forest ecosystem is not only a function of the urban activities themselves but also of the effectiveness of institutional, legal, and community responses.

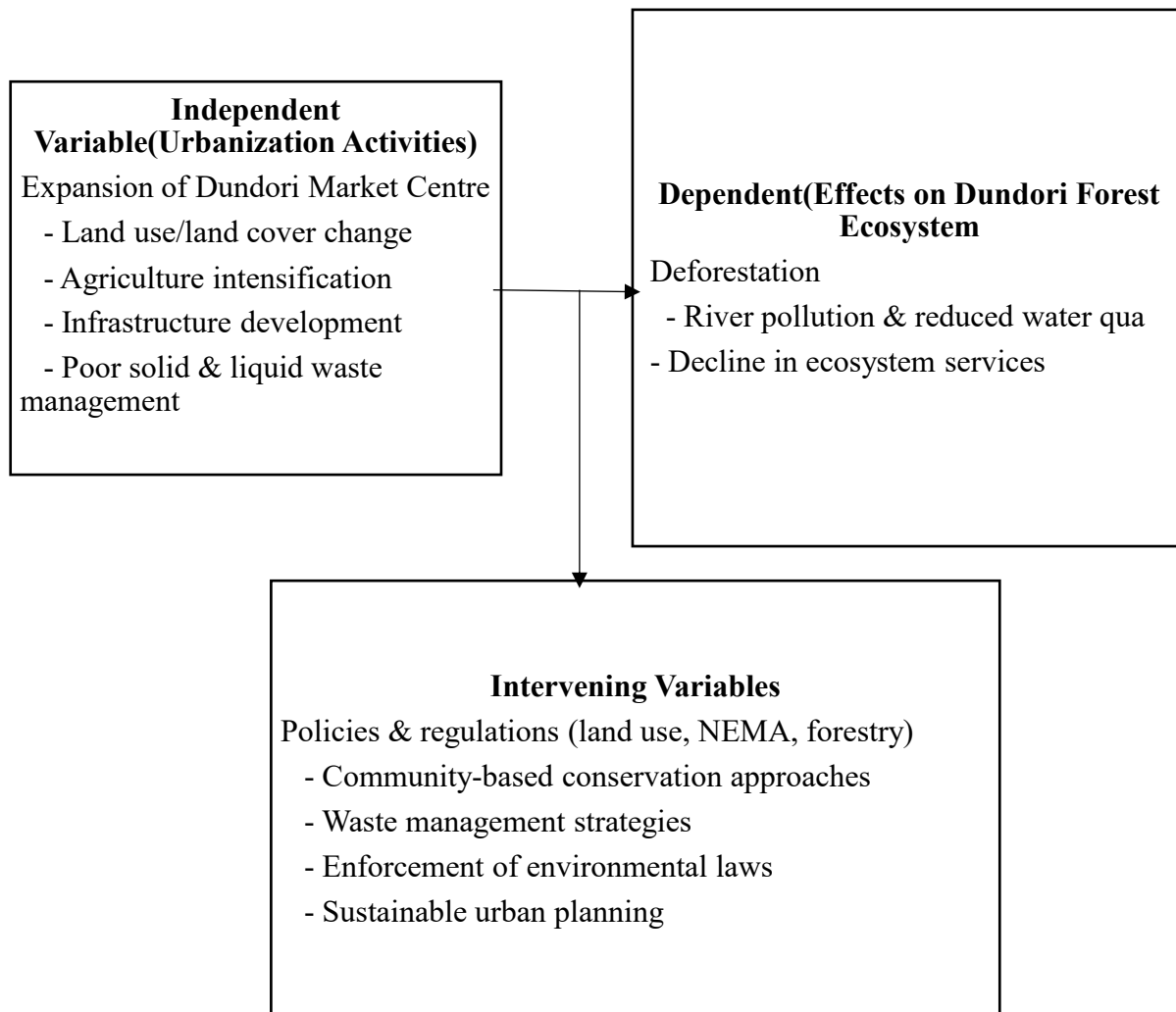


Figure 1:Conceptual framework

## Research Gaps

## Knowledge Void

Despite extensive research highlighting the interactions between urbanisation, forest ecosystems, and river resources, significant knowledge gaps remain, particularly at the local scale. Existing studies emphasize that urban expansion degrades river water quality through multiple pathways, including direct waste discharge, agricultural runoff, deforestation-induced erosion, and industrial effluents, while simultaneously reducing forest cover, fragmenting habitats, and altering ecosystem processes. However, much of this evidence originates from large cities or megaregions, leaving small but rapidly urbanising centres such as market towns in Kenya understudied. Furthermore, while legal frameworks, waste management systems, and community participation are recognized as critical mitigation measures, there is limited understanding of how these interventions function in practice within forest-adjacent peri-urban areas. Localized studies that examine the effectiveness of these mitigation strategies, as well as the cumulative impacts of urbanisation on rivers and forests, are therefore

essential to inform integrated land-use planning, ecosystem conservation, and sustainable urban growth. This knowledge void shows the need for context-specific investigations that capture the nuanced interactions between anthropogenic pressures, regulatory enforcement, and community engagement in small-scale urban landscapes.

### **Methodological Conflict**

Several studies rely on remote sensing and GIS techniques to measure LULC changes and forest loss, while others use ecological surveys, hydrological tests and socio-economic household surveys. The inconsistency in methodological approaches has led to fragmented evidence that either emphasizes physical forest cover change that ignore social dynamics and focuses on community perceptions without empirical validation of ecosystem changes. This methodological conflict shows the need for an integrated mixed-methods approach combining spatial data, ecological assessment, perceptions of the government officials and community perspectives to holistically capture the effects of urbanisation in the Dundori forest ecosystem.

### **Contradictory evidence**

Studies from different regions present contradictory evidence on the extent to which urbanisation affects forest ecosystems. For instance, some scholars argue that small-scale urban settlements have minimal effect compared to large towns and cities (Njenga, 2019), while others document that even small market centres can trigger significant forest edge degradation, river pollution, and biodiversity loss (Owuor, Mutiso, & Karanja, 2021). These contradictions create uncertainty in policy responses and point to the need for context-specific studies like Dundori to clarify whether localised urbanisation is a major ecological threat or it's a manageable process.

### **Gaps addressed by this study**

The study addresses the identified gaps through:

- i. Filling the knowledge void through carrying out an in-depth analysis of how Dundori Market Centre's urbanisation specifically affects the Dundori forest and its river ecosystems.
- ii. Resolving the methodological conflict by use of a mixed-methods approach that integrates GIS/remote sensing, water quality, and community-based surveys.
- iii. Contributing to debates surrounding contradictory evidence by generating empirical, site-specific data to clarify the actual magnitude of impacts from small-scale urbanisation on forest ecosystems.

## **RESEARCH DESIGN AND METHODOLOGY**

### **Introduction**

This chapter provides a comprehensive outline of the research approach and methods that will be used to assess the effects of urbanisation in the Dundori Market Centre on the surrounding forest ecosystem. It details the chosen research design, the geographic location of the study area, the study population, and the sampling procedures. Furthermore, it describes the instrumentation that were used for data collection, the measures to ensure the reliability and validity of these instruments, and the systematic data collection and analysis procedures. Finally, this chapter outlines the ethical considerations that guided the entire research process.

### **Research Design**

This study adopted a mixed-methods research design, combining both quantitative and qualitative approaches. This design is justified by its ability to provide a comprehensive understanding of the complex interactions between urbanization, forest ecosystems, and river water quality, allowing for a triangulation of data that strengthens the validity of findings (Creswell & Creswell, 2018). The mixed-methods approach is directly linked

to the study's objectives, enabling a holistic assessment that integrates spatial analysis, environmental measurements, and human perspectives.

## Location of the Study Area

The study focused on Dundori Market Centre and the adjoining Dundori Forest ecosystem, situated in the eastern part of the Mau Complex along the Olkalou Escarpment, at the boundary of Nyandarua and Nakuru Counties. Dundori Forest, gazetted as a state forest in 1932 and covering 3,767.3 hectares, forms part of the Eastern Mau water catchment and serves as the source of several perennial rivers, including Chania, Subukia/Momui, Kandutura, Kaburu, Ruiru, and Maimahiu. These rivers play a vital role in sustaining major lakes such as Lake Nakuru and Lake Elementaita, in addition to supporting downstream communities and ecosystems.

The study was undertaken within the Dundori Market Centre and its surrounding areas that have expanded beyond official administrative boundaries, encroaching on the Dundori Forest ecosystem. This encompassed both the formal administrative limits and the sprawled peri-urban areas where urban expansion was most evident. Dundori Market Centre is located in Dundori Sub-location, within Dundori Ward of Bahati Sub-County, Nakuru County, Kenya. Its geographic coordinates lie approximately between 0.10° N and 0.16° N latitude and 36.10° E and 36.16° E longitude, about 25 km from Nakuru City. This is illustrated in the map below:

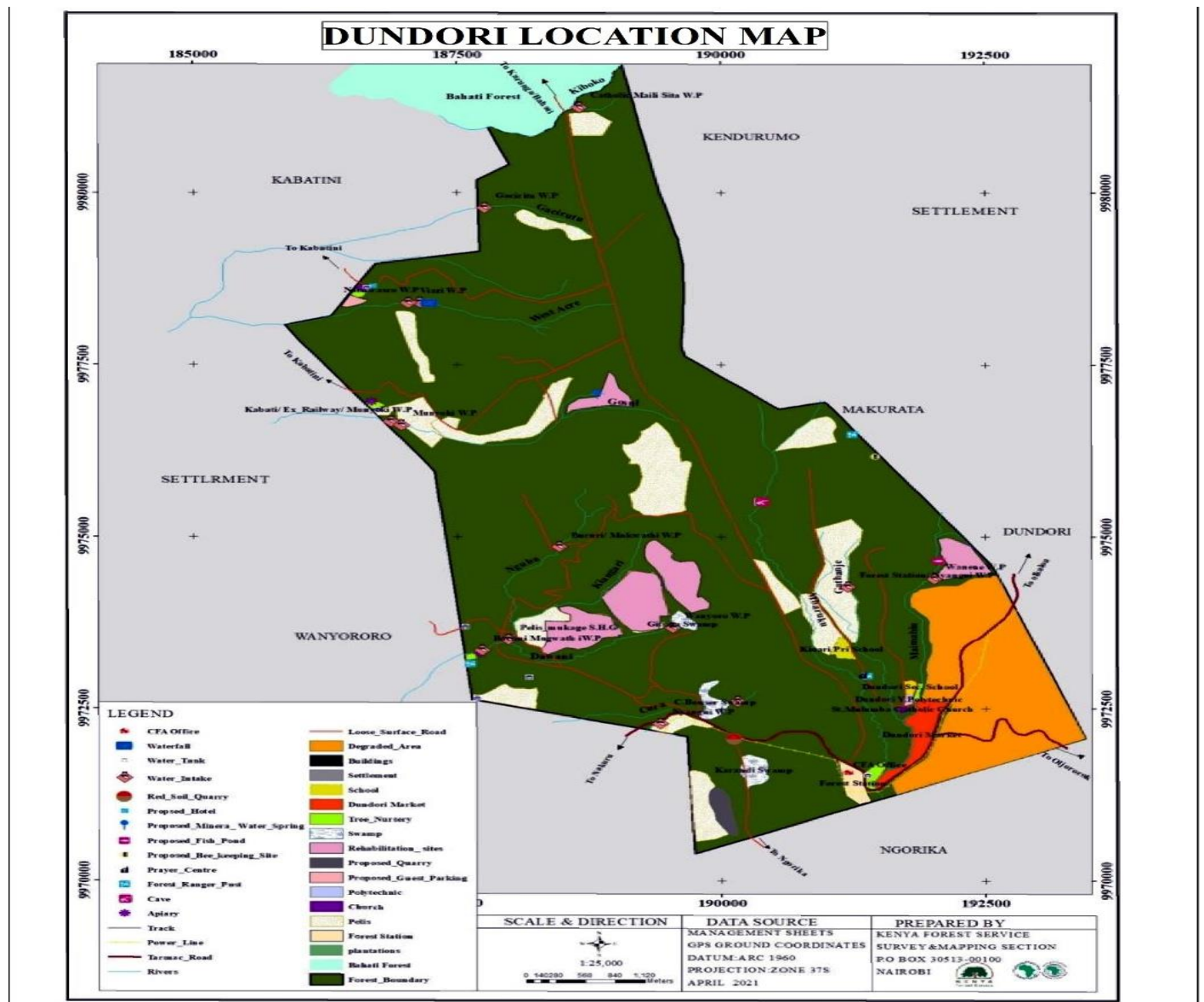


Figure 2:Dundori location Map

## Location of the Study Area

The choice of this site is justified by its unique location, where rapid urbanisation of Dundori Market Centre directly interfaces with a highly sensitive forest ecosystem. Increasing urbanisation activities such as settlement expansion, agricultural intensification, and rising demand for timber, fuelwood, and land have exerted considerable pressure on both the forest cover and the rivers it sustains. Unlike other extensively studied forests in Kenya, Dundori has received limited research attention despite its ecological and socio-economic importance. This made it ideal case study for examining how small but fast-growing urban centres influence fragile ecosystems, thereby filling an important knowledge gap.

## Target Population of the Study

The target population for this study comprised all individuals and entities residing or operating within the administrative boundary of the Dundori Market Centre and its peri-urban fringes that have sprawled into the Dundori Forest ecosystem. These included residents, businesses, community groups, and key informants who directly interact with or are influenced by the Dundori Forest ecosystem.

The accessible population consisted of households and businesses within the defined study area, as well as identified key informants from relevant institutions and community groups. The choice of this target population was justified because these groups are directly involved in, or affected by, the urbanisation activities and their impacts on the forest and river. Their perceptions, practices, and knowledge were crucial for a comprehensive understanding of the research problem.

According to the 2019 Kenya National Bureau of Statistics (KNBS) census, the total population of Dundori Location is 7,853, with an estimated 2,240 households, and this demographic data formed the basis for the sampling frame. A preliminary reconnaissance survey and consultation with official county records was undertaken to refine the exact number of businesses within the study area for accurate sampling. The study population was diverse, encompassing households residing within Dundori Market Centre and its peri-urban fringes, business premises operating within the market. In addition, key informants included county officials from urban planning, water, and environment departments; representatives from national agencies such as NEMA, WRA, and KFS; local administrators, including the chief.

## Sampling Procedure and Sample Size

### Sampling size

For the determination of the household and the business survey used the Nasiuma (Nassiuma, 2000) method to determine the sample size for the household and business survey. This method provided a reliable way to calculate a representative sample from a known population, taking into account variability and the desired margin of error.

The formula for the Nasiuma method is:

$$n = \frac{N.C^2}{C^2 + (N-1)e^2}$$

Where:

- n = sample size
- N= total population (households and businesses)
- C = coefficient of variation (set at 0.5)

- $e$  = margin of error (set at 0.05 for a 95% confidence level)

Based on the 2019 KNBS census, Dundori Market Centre has 2,240 households. Substituting into the formula:

$$n = \frac{2240 \cdot 0.5^2}{0.5^2 + (2240 - 1) \cdot 0.05^2}$$

$$n = \frac{560}{0.25 + 2239 \cdot 0.025}$$

$$n = \frac{560}{5.8475} = 95.8$$

The calculated sample size was 96 households. To account for possible non-response and data loss, an additional 10% was added

$$n_{\text{final}} = 96 + (96 \times 0.10) = 105.6 \approx 106$$

Thus, the final target sample size was 106 households and businesses. The sample was equally distributed across the zones identified within the study area to ensure adequate spatial representation.

### Sampling procedure

The sampling procedure for this study involved a multi-stage approach, factoring in the study objectives to ensure wide representation and capture diverse perspectives from the Dundori Market Centre.

### Household and Business Survey Sampling

This approach addressed Objective One, which focused on identification of urbanisation activities affecting the Dundori Forest ecosystem. A simple random sampling technique was adopted. The study area, comprising Dundori Market Centre and its surrounding peri-urban areas, was first spatially delineated to define the study population. A comprehensive sampling frame of all households and businesses within the delineated area was developed using the latest KNBS census data and a generated base map.

Each household and business unit within the sampling frame was assigned a unique identification number. Using a random number generator, the required sample size was then selected, ensuring that every unit in the population had an equal and known probability of being included in the study. This random selection process eliminated selection bias and enhance the representativeness of the sample.

The selected households and businesses was surveyed to collect data on urbanisation activities influencing the Dundori Forest ecosystem. The use of simple random sampling ensured unbiased coverage of the study area and provided reliable data for assessing the nature and extent of urbanisation pressures affecting the forest ecosystem.

### Key Informant Interview Sampling

This approach covered all three objectives of the study. Purposive sampling was used to identify and engage individuals with specialized knowledge and authority from both community and institutional backgrounds. The target groups included County department officials from urban planning, environment, health, and water sectors; national agency representatives (NEMA, KFS, and WRA); local administrators (chief) A total of eight (8) key informants were selected to ensure the collection of comprehensive and relevant information for the study.

Data from these key informants were collected primarily through key informant interviews (KIIs) using semi-structured interview guides tailored to each category of respondents. The interviews focused on urbanisation trends, forest and river management practices, institutional roles, policy implementation, and observed

environmental impacts within the study area. Field observations and review of relevant institutional documents and reports were used to supplement interview data and enhance the validity and triangulation of findings.

### Water Quality Sampling

This study addressed Objective Two by examining the effects of urbanisation activities on the water quality of the Maimahiu River within the Dundori Forest ecosystem. A purposive sampling approach guided by spatial and temporal stratification was adopted to adequately capture variations in water quality. Spatially, the river was stratified into three main sections—upstream, midstream, and downstream—based on land use intensity and proximity to urban activities. Within each section, two sampling points were established, resulting in a total of six spatially distributed sampling locations. The upstream points served as control sites representing minimal human disturbance, the midstream points located within the market centre near potential pollution sources such as livestock holding areas, solid waste disposal sites, and zones of concentrated human activity, while the downstream points captured the cumulative effects of urbanisation where the river exits the town.

Spatially, water sampling was conducted at the three strategically selected sites along the river system to capture variations in water quality associated with differing levels of human influence. The first site was located within the uninterfered watershed upstream of Dundori Forest, which represented baseline or reference conditions with minimal anthropogenic disturbance. The second site was situated within the urbanised section adjacent to Dundori Market Centre, where urban activities such as settlements, commercial developments, wastewater discharge, and solid waste disposal were most pronounced. The third site was established at the exit of the town downstream, capturing the cumulative impacts of urbanisation before the river continued beyond the market centre.

Temporally, water sampling was conducted during both the dry and wet seasons to account for seasonal variability in river flow and pollutant dynamics. Dry season sampling captured low-flow conditions when pollutant concentrations are typically higher, while wet season sampling assessed the influence of surface runoff, stormwater inflows, and sediment transport on water quality. At each sampling site and during each season, duplicate samples were collected to enhance analytical reliability and support internal quality control. This resulted in a total of 12 water samples ( $3 \text{ sites} \times 2 \text{ seasons} \times 2 \text{ replicates}$ ). All sampling locations were geo-referenced using GPS coordinates to ensure spatial accuracy and consistency across sampling periods. The spatial distribution of the sampling sites is illustrated in the map below.

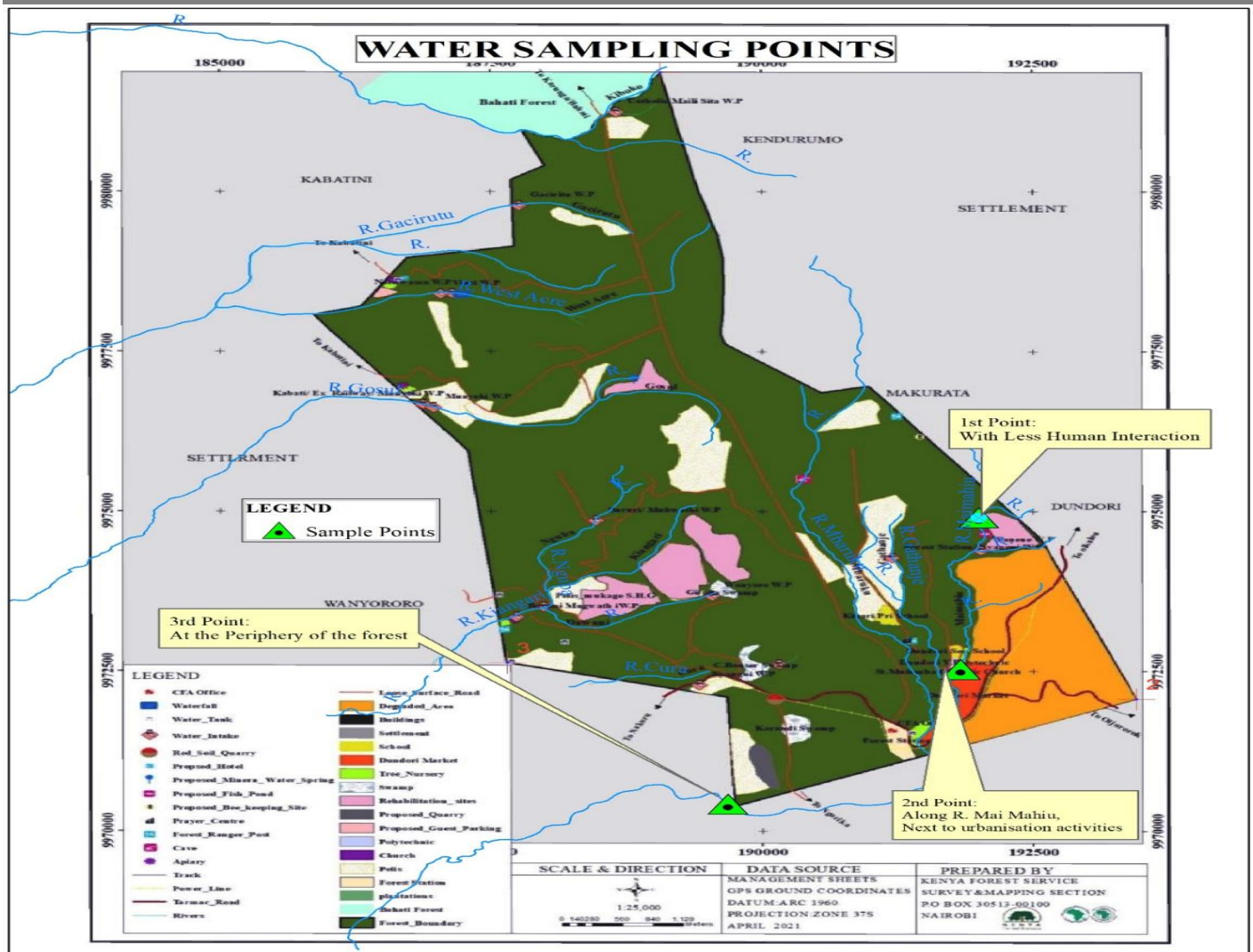


Figure 3: Water Quality Sampling

## Instrumentation and Data collection

This section describes the instruments that were used for data collection in line with the study objectives, as well as the procedures that were adopted to ensure data accuracy, reliability, integrity, and security.

## Geospatial Data Collection

The Avenza Maps mobile application was used to collect georeferenced data points within Dundori Market Centre. The application enabled real-time spatial data capture using smartphones, including offline functionality through the use of georeferenced PDF maps. This tool was cost-effective, user-friendly, and suitable for mapping water sampling points, forest use zones, and household and business survey locations. To ensure positional accuracy, GPS readings were cross-checked in the field, and coordinates recorded consistently using the same spatial reference system throughout the study.

## Household and Business Surveys

Structured questionnaires were used to collect quantitative data from households and businesses. The questionnaires were mainly consist of closed-ended questions to support statistical analysis, with a limited number of open-ended questions to capture qualitative insights on forest use, river interactions, and perceived environmental changes. The questionnaires were digitized and administered using the Kobo Collect mobile application, which enhanced efficiency, reduces data entry errors, and ensures secure data capture. Kobo

Collect's GPS tagging and offline data entry capabilities further improved data quality. Access to the Kobo server was password-protected, and collected data were encrypted and backed up regularly before export to SPSS for analysis.

### **Water Sampling for Laboratory Analysis**

Sterile sampling bottles were used to collect water samples from the Mai Mahiu River for physicochemical and microbiological analysis. Sampling was conducted following standard water-sampling procedures to minimise contamination and preserve the integrity of the samples. At each sampling location, the bottles were appropriately labelled with the sampling site, date, time and sample identification number. Samples intended for laboratory analysis were placed in a cool box and maintained at approximately 4°C during transportation. The samples were transported to the Kabarak University laboratory within two hours of collection for analysis.

A multiparameter water quality analyser was used to measure selected physicochemical parameters, including electrical conductivity (EC), total dissolved solids (TDS) and salinity. The instrument was calibrated according to the manufacturer's specifications before measurements were taken. Dissolved oxygen (DO) was determined using a calibrated DO meter, while turbidity was measured using a calibrated turbidimeter and expressed in Nephelometric Turbidity Units (NTU). Measurements were taken according to the manufacturer's operating procedures, and the results were recorded for each sampling site and sampling period.

For microbiological analysis, water samples were handled aseptically to minimise contamination. Nutrient Agar was used as a general-purpose culture medium for the enumeration of viable heterotrophic bacteria, while MacConkey Agar was used for the detection and enumeration of coliform and other Gram-negative enteric bacteria. Appropriate aliquots of the water samples were inoculated onto the respective culture media using aseptic techniques. The inoculated plates were incubated under appropriate laboratory conditions, after which visible colonies were counted and recorded as colony-forming units (CFU). The number and distribution of colonies obtained from the different sampling sites were used to assess spatial variations in bacterial contamination along the river.

A chain-of-custody procedure was maintained throughout the sampling and analytical process. Information on the sampling location, date and time of collection, sample identification, handling, transportation and receipt at the laboratory was documented. Laboratory analyses were conducted at the Kabarak University laboratory following established quality assurance and quality control (QA/QC) procedures. Instruments were calibrated before use, appropriate laboratory procedures were followed, and results were recorded systematically to enhance the reliability, accuracy and validity of the findings.

### **Key Informant Interviews**

An audio recorder was used during key informant interviews (KIIs) to accurately capture respondents' views and minimise information loss. Audio files were transferred to a password-protected computer immediately after interviews and stored securely. Transcriptions were anonymized to protect respondent confidentiality.

### **Photographic Documentation**

A digital camera was used to document observed urbanisation activities, river conditions, forest encroachment, and other relevant physical features. Photographs were stored in organised, password-protected folders to ensure secure handling and traceability of visual data.

### **Field Observations**

Field observation checklists guided systematic on-site assessments of river health, forest conditions, and human activities such as waste dumping, agriculture, and settlement expansion. The structured format of the checklists was used to ensure consistency across observation sites and facilitate comparative analysis.

## **Data Security and Management**

All digital data collected was stored on password-protected devices and backed up regularly on secure external storage with restricted access. Only authorized members of the research team had access to the data, ensuring confidentiality and compliance with ethical research standards.

## **Pilot Study**

A pilot study was conducted at Kiratina Market Centre, which is geographically adjacent to and abuts Dundori Market Centre but lies outside the main study area. Kiratina Market Centre was selected because it exhibits socio-economic, settlement, land use, and environmental characteristics similar to those of Dundori Market Centre. This similarity made it an appropriate location for testing the research instruments while ensuring that the main study area remains uncontaminated.

The pilot study was undertaken approximately two weeks before the main fieldwork and it involved a limited sample to test the feasibility and reliability of the data collection tools. The pilot included the administration of ten household and business questionnaires, the conduct of one key informant interview, and water sampling at two points along a nearby river section with characteristics comparable to the Maimahiu River. These activities helped identify potential logistical challenges, assess respondent understanding and acceptance of the study, and evaluate the clarity, relevance, and sequencing of the questionnaires and interview guides.

In addition, the pilot study was used to verify the proper functioning and calibration of water quality measurement equipment and to standardize data collection procedures among research assistants through practical field-based training. Data obtained from the pilot study was analyzed solely for the purpose of refining research instruments and field procedures. To prevent bias arising from prior exposure to the research tools, all participants involved in the pilot study were excluded from the main study sample. Any necessary adjustments to the instruments and methodology was completed before the commencement of the main data collection in Dundori Market Centre.

## **Validity and reliability of the Instrument**

The validity and reliability of the research instruments was ensured through a combination of expert review, pilot testing, and systematic data analysis procedures. Content and construct validity was established through review by three experts with relevant expertise in environmental planning, hydrology/water quality, and social science research methods, who assessed the clarity, relevance, and alignment of the instruments with the study objectives. Reliability and practical feasibility was tested through a pilot pre-test involving ten household and business questionnaires, one key informant interview, and two water sampling points conducted at Kiratina Market Centre. A test-retest procedure was applied to a subset of five pilot respondents after a two-week interval to assess consistency of responses, a timeframe considered feasible given the stable nature of the survey variables. For qualitative data, interview transcripts were independently coded by two researchers, and inter-coder reliability was assessed using percentage agreement and Cohen's Kappa coefficient of 0.614, with discrepancies resolved through consensus. Quantitative data was analyzed using SPSS, with descriptive statistics complemented by inferential tests aligned to specific objectives, including ANOVA for comparing water quality parameters across multiple sites, regression analysis to examine relationships between land use/land cover (LULC) changes and water quality indicators, and correlation analysis assessed associations between urban activities and environmental outcomes. LULC classification accuracy was evaluated using a confusion matrix and Kappa statistic to ensure the reliability of remote sensing outputs. Integration of quantitative and qualitative findings was achieved through a convergent mixed-methods approach, where spatial, statistical, and thematic results were triangulated during interpretation to strengthen the robustness and credibility of the study findings.

## Data Collection Procedure

The data collection process followed a structured and systematic approach to ensure valid and reliable data in alignment with the research objectives. The first step involved securing all necessary ethical and research permissions. Authority to conduct the research was obtained from the National Commission for Science, Technology and Innovation (NACOSTI). Ethical clearance was sought from the Kabarak University Ethical Review Board (KUREC). In addition, letters of introduction and support were obtained from the County Commissioner, relevant county departments such as Environment, Water, and Urban Planning, as well as national agencies including NEMA, WRA, and KFS, to facilitate smooth operations during fieldwork.

Preliminary agreements and consent was established with participants. Initial visits were conducted to introduce the study, explain its purpose and benefits, and assure community members of voluntary participation and confidentiality. Informed verbal consent was sought through local chief and elders, while written consent was obtained from all participants for their direct involvement and for photography.

Following the acquisition of permissions, research assistants were recruited and provided with intensive training. The training covered interview techniques, ethical data collection practices, administration of structured questionnaires using the Kobo Collect tool, and the use of Avenza Maps for georeferencing. To strengthen preparedness, a pilot study was carried out with the research assistants to assess their understanding and proficiency in the outlined procedures.

Data collection was undertaken through multiple concurrent activities. Satellite imagery for Land Use and Land Cover (LULC) change analysis was acquired from Landsat archives, to establish baseline data and track trends. Quantitative data was systematically collected from households and businesses in Dundori Market Centre using Kobo Collect, ensuring accuracy and efficiency. Qualitative data was obtained through Key Informant Interviews conducted at convenient venues, with audio recordings made subject to participant consent.

Water-quality sampling was conducted at three designated sampling sites along River Mai Mahiu to assess spatial and seasonal variations in the physicochemical and microbiological characteristics of the river. The three sampling sites represented distinct sections of the river, namely the upstream/source section, middle section, and downstream/exit section. The exact geographical coordinates of each sampling site were recorded in decimal degrees using a handheld Global Positioning System (GPS) device.

Sampling was undertaken during two seasons, namely the dry and wet seasons, to capture seasonal variations in water quality. At each sampling site, two replicate water samples were collected during each sampling season, resulting in a total of 12 water samples (three sampling sites  $\times$  two seasons  $\times$  two replicates). Water samples were collected for both physicochemical and bacteriological analyses.

During each sampling occasion, field conditions at the respective sites were recorded. These included prevailing weather conditions, river flow conditions, visible sources of pollution, surrounding land-use activities, and other relevant physical characteristics of the sampling locations. Each sample container was appropriately labelled with the sampling site, sampling date, season, replicate number, and type of analysis required.

Samples intended for physicochemical analysis were collected in clean and appropriately prepared sample containers, while samples for bacteriological analysis were collected using aseptic techniques. Immediately after collection, all samples were placed in a cool box and transported to the certified Kabarak University laboratory for analysis. Appropriate sample preservation and handling procedures were followed throughout transportation, with samples protected from direct sunlight, excessive heat, and external contamination. Microbiological samples were handled under aseptic conditions and analysed within the recommended holding times to minimize changes in microbial populations. The collection, preservation, transportation, and laboratory handling of all samples were therefore undertaken in accordance with the required procedures and holding-time requirements for physicochemical and bacteriological water-quality analyses.

Throughout the process, photographic documentation and field observations were undertaken to provide visual and contextual evidence. Observations was guided by a structured checklist to ensure consistency across sites and to facilitate comparative analysis. All recorded interviews was transcribed, while water quality data and quantitative data from surveys were digitized and organized using spreadsheet software the Microsoft Excel. This systematic preparation ensured the data was ready for detailed analysis.

To ensure completeness and integrity of the data, all questionnaires were reviewed daily for completeness and consistency before leaving the field. Any incomplete responses was clarified immediately with the respondent where possible. During data entry, responses were carefully cross-checked to minimize errors and ensure accuracy. Additionally, a clear coding framework was developed prior to analysis to promote consistency and reliability in data processing and interpretation.

Data collection for objective No 3 should be here

### **Data Analysis**

Data analysis commenced after the completion of data collection, guided by a mixed-methods research design that integrated both qualitative and quantitative approaches. This approach revealed the effects of urbanisation in the Dundori Market Centre on the forest ecosystem. To ensure the enhancement of the validity of the results, findings from the different methods were integrated through triangulation. Data from water quality tests, satellite imagery, and community perceptions were cross-referenced to strengthen the conclusions. The outcomes of the analysis were presented in text narratives, tables, and graphical representations for clarity and ease of interpretation of the results.

Qualitative data were analysed to address the study objectives, particularly the assessment of institutional responses, policy implementation challenges, and mitigation strategies for managing the effects of urbanisation on the Dundori Forest ecosystem and River Mai Mahiu. The qualitative data were obtained primarily through Key Informant Interviews (KIIs), field observations and field notes. Interview recordings and notes were transcribed, organised and analysed using a thematic analysis approach.

The analysis followed several sequential steps. First, the researcher familiarised herself with the data by reading and reviewing the transcripts and field notes to gain an overall understanding of the information provided by respondents. Second, initial codes were generated by identifying meaningful statements and grouping similar responses into smaller units of information. Third, related codes were categorised into broader and recurring themes reflecting the study objectives. The emerging themes were subsequently reviewed, refined and clearly defined to ensure that they accurately represented the views and experiences of the key informants. Finally, the themes were synthesised and presented in narrative form, with relevant evidence from the interviews and field observations used to support the findings. ATLAS.ti software was used to facilitate systematic coding, organisation, retrieval and management of the qualitative data.

For the third objective, which focused on identifying mitigation strategies, qualitative analysis was complemented by documentary and policy analysis. Relevant policy and planning documents, including water resource management strategies, local physical and land-use planning documents, forest management frameworks and environmental regulations, were reviewed. The analysis focused on the provisions of these instruments, the roles and responsibilities of relevant institutions, mechanisms for implementation and enforcement, and the extent to which the prescribed measures were reflected in practice. This enabled the study to identify policy implementation gaps, institutional weaknesses, coordination challenges and differences between formal environmental management provisions and conditions observed on the ground.

In addition to the qualitative assessment, the perceived effectiveness of existing mitigation strategies was assessed quantitatively using a five-point Likert scale. Key informants were asked to rate the effectiveness of identified strategies based on their implementation and observed outcomes. The responses were coded numerically and summarised using descriptive statistics, including mean scores, to provide a quantitative

indication of the perceived effectiveness of the different mitigation measures. The quantitative ratings were then interpreted alongside the thematic findings and documentary evidence to provide an integrated assessment of the effectiveness of existing mitigation strategies and the institutional factors influencing their implementation.

Quantitative data analysis for the first objective involved the assessment of Land Use and Land Cover (LULC) changes and the extent of urban expansion within the Dundori Forest ecosystem. Landsat satellite imagery for the years 1985, 1995, 2005, 2015 and 2025 was used to assess temporal changes in LULC. The imagery was processed and analysed using ArcGIS Pro, with post-classification change detection applied to quantify changes in the major LULC categories.

The Landsat imagery had a spatial resolution of 30 m and was selected from comparable acquisition periods to minimise seasonal and phenological differences between the different epochs. Image preprocessing involved selecting imagery with minimal cloud cover, masking unwanted pixels, clipping the imagery to the defined study-area boundary, and preparing the images for classification. These procedures improved image quality and ensured comparability among the different temporal datasets.

A supervised classification approach was used to classify the imagery into four LULC classes: Forest, Developed, Cultivated/Planted and Grassland. Training samples representing each LULC class were generated for each image and used to define their respective spectral characteristics. The resulting classified images were subsequently validated using independent reference samples.

Classification accuracy was assessed using confusion matrices, from which overall accuracy, producer's accuracy, user's accuracy and Kappa coefficients were calculated. The overall classification accuracy was **84.66% (Kappa = 0.73) in 1985, 85.90% (Kappa = 0.75) in 1995, 86.36% (Kappa = 0.78) in 2005, 90.00% (Kappa = 0.81) in 2015, and 91.54% (Kappa = 0.83) in 2025**. These results indicated an acceptable to strong level of classification accuracy across the five epochs.

The class-specific accuracy assessment showed that **Forest** had producer's accuracies of **81.40%, 83.33%, 86.54%, 87.50% and 90.91%** for 1985, 1995, 2005, 2015 and 2025, respectively. **Developed land** recorded producer's accuracies of **90.91%, 92.31%, 100.00%, 100.00% and 100.00%**, while **Cultivated/Planted land** recorded **89.69%, 90.00%, 89.74%, 93.33% and 94.81%**, respectively. Grassland recorded comparatively lower producer's accuracies of **68.00%, 71.43%, 57.14%, 66.67% and 66.67%**, indicating greater spectral confusion between grassland and other LULC categories.

Following classification and accuracy assessment, post-classification change detection was undertaken by comparing the classified maps for successive epochs. The area occupied by each LULC class was calculated in hectares, while changes were expressed as absolute area change, percentage-point change, relative percentage change and annual rate of change. This enabled assessment of the magnitude and direction of LULC transformation over the 40-year study period.

Transition matrices were also generated to identify the direction and magnitude of conversion between LULC classes. Particular attention was given to transitions such as Forest to Cultivated/Planted, Forest to Developed, Grassland to Cultivated/Planted, and Cultivated/Planted to Developed land. The transition analysis provided further evidence of the processes contributing to forest ecosystem transformation and urban expansion.

In addition, spatial analysis and spatial metrics were applied to assess the spatial pattern of LULC change, land fragmentation and the extent of urban expansion in relation to the forest ecosystem. The analysis examined changes in the spatial distribution and configuration of forest, developed, cultivated/planted and grassland areas across the study period. The results were used to establish the spatial and temporal relationship between urban expansion, agricultural expansion, forest-cover change and ecosystem degradation within the study area.

Overall, the quantitative LULC analysis provided measurements of the magnitude, direction, spatial distribution and temporal trends of land-cover change between 1985 and 2025. These results were subsequently integrated

with the water-quality findings to assess the environmental changes associated with urbanisation in the Dundori Forest ecosystem.

The physicochemical parameters analysed included electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), and turbidity. Microbiological analysis involved the determination of bacterial indicators, including coliform bacteria, using appropriate culture media. MacConkey Agar was used for the detection and enumeration of coliform bacteria, while Nutrient Agar was used to assess general bacterial growth. Microbiological results were recorded as colony counts per plate in accordance with the laboratory procedures.

Laboratory analyses were undertaken using standard procedures applicable to the respective physicochemical and microbiological parameters. The physicochemical measuring instruments were calibrated according to the manufacturers' specifications before measurements were taken. Quality-control procedures were applied throughout sample collection, transportation, preparation, and analysis to enhance the reliability and accuracy of the results. These procedures included instrument calibration, proper sample labelling, use of appropriate sample containers, duplicate sampling, aseptic handling of microbiological samples, and adherence to recommended sample preservation and holding times.

Replicate samples were analysed to assess the consistency and repeatability of measurements. Field and laboratory blanks were used where applicable to identify possible contamination arising during sample collection, transportation, and laboratory analysis. Laboratory observations and field records were reviewed where unusual or anomalous results were obtained before the results were included in the final dataset. The detection and reporting limits applicable to each analytical method were also considered during data interpretation. For microbiological analysis, plates with counts exceeding the reliable counting range were recorded as greater than 100 colonies ( $>100$ ) or as too numerous to count (TNTC), where applicable, rather than being treated as exact counts. This approach prevented overestimation of the precision of the microbiological results.

The laboratory results were entered and analysed using the Statistical Package for the Social Sciences (SPSS). Descriptive statistics, including means, medians, and standard deviations, were used to summarise the observed values of each water-quality parameter across the sampling sites and seasons. The results from the upstream/source, middle, and downstream/exit sites were compared to assess spatial variations in water quality, while comparisons between the dry and wet seasons were used to assess seasonal variations.

Inferential statistical analysis was undertaken using analysis of variance (ANOVA) to determine whether differences in water-quality parameters among the three sampling sites were statistically significant. The analysis was used to establish whether observed spatial variations in water quality were associated with differences in the level of urbanisation and surrounding land-use activities along the river. Statistical significance was assessed at the 5% significance level ( $p < 0.05$ ).

The measured water-quality parameters were further compared with applicable World Health Organization (WHO) guidelines and relevant national water-quality standards and guidelines to assess the suitability of the river water and determine the extent to which the observed values complied with recommended water-quality limits. Microbiological results were interpreted based on the applicable standards, taking into consideration results reported as  $>100$  colonies. The sampling coordinates, sampling dates, seasonal conditions, replicate numbers, field observations, sample preservation procedures, laboratory methods, quality-control measures, and applicable detection or reporting limits were documented to ensure traceability and reproducibility of the water-quality assessment.

Third, data from household and business surveys, which were linked to the second objective, were analyzed using descriptive statistics that is frequencies and percentages. It summarized community practices, perceptions, and activities related to forest and river use. Together, these analyses provided an integrated understanding of both the ecological and social dimensions of urbanisation's impacts on the Dundori Forest ecosystem.

Table 1: **Summary of data analysis methods as per the objectives**

| Objective                                                                                         | Research Approach                         | Data Sources                                                                                                                                                                                                                                                                                                                                                              | Methods of Data Collection & Analysis                                                                                                                                                                                                                                                                                                            |
|---------------------------------------------------------------------------------------------------|-------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. To examine urbanisation activities affecting the Dundori Forest ecosystem                      | Mixed (Quantitative & Qualitative)        | <ul style="list-style-type: none"> <li>- Satellite imagery (LULC data)</li> <li>- Forest officers &amp; county planners</li> <li>- Community members</li> </ul>                                                                                                                                                                                                           | <ul style="list-style-type: none"> <li>- GIS &amp; Remote Sensing analysis of land use/cover change</li> <li>- Field observations of urbanisation activities</li> <li>- Key Informant Interviews (KIIs)</li> </ul>                                                                                                                               |
| 2. To assess the effects of urbanisation activities on River Mai Mahiu water quality              | Quantitative & Qualitative (Experimental) | <ul style="list-style-type: none"> <li>- River water samples collected at three points: <ul style="list-style-type: none"> <li>(i) Source with no human interference,</li> <li>(ii) Section within an urbanised area,</li> <li>(iii) Downstream where the river exits the town</li> </ul> </li> <li>- Households near the river</li> <li>- FGDs with community</li> </ul> | <ul style="list-style-type: none"> <li>- Laboratory tests of physico-chemical parameters (Conductivity, Total Dissolved Solids (TDS), Dissolved Oxygen (DO), )</li> <li>- Microbiological analysis for bacterial load (Coliforms and other bacterial contamination)</li> <li>- Household surveys on water use &amp; pollution sources</li> </ul> |
| 3. To evaluate mitigation measures for containing urbanisation activities on the forest ecosystem | Qualitative & Comparative                 | <ul style="list-style-type: none"> <li>- Policy documents &amp; county strategies</li> <li>- Community &amp; NGOs</li> <li>- Government agencies</li> </ul>                                                                                                                                                                                                               | <ul style="list-style-type: none"> <li>- Policy and institutional review</li> <li>- Comparative case study analysis (Kenya &amp; global lessons)</li> </ul>                                                                                                                                                                                      |

## Ethical Considerations

The research strictly adhered to ethical principles to protect the dignity, rights, and welfare of all participants. Informed consent was obtained before data collection, ensuring participants fully understand the study's purpose, procedures, risks, and benefits, as well as their right to withdraw at any time without penalty. Separate consent was sought for photography to respect participants' control over their images. Confidentiality and anonymity was prioritized, with personal information treated confidentially and data anonymized where possible. No identifiable details or photographs was included in publications, reports, or presentations, and pseudonyms was used to protect identities. Data collection respected participants' privacy and convenience, avoiding disruption to their daily lives.

The study involved discussions on land use change, forest governance, and environmental management practices around Dundori Market Centre and the Dundori Forest Ecosystem. These topics were perceived as sensitive, particularly where issues of land ownership, forest resource use, or governance decisions were involved. Participants feared that expressing their views could lead to social tension, reputational harm, or strained relationships within the community. To minimize these risks, no personal identifiers such as names or specific household details were collected. Interviews were conducted privately, and responses were recorded using codes instead of identifiable information. Questions were framed in neutral and non-accusatory language to avoid implying blame or wrongdoing. All findings were reported in aggregated form to ensure that no individual participant can be identified.

The study was designed to uphold the principles of non-maleficence and beneficence, ensuring participants face no physical, psychological, social, or financial harm while contributing valuable knowledge to sustainable land-use planning and environmental conservation in Dundori. Transparency and accountability guided all research procedures, data collection, and analysis. Environmental responsibility was maintained to prevent harm to the Dundori Forest ecosystem, and the study complied with all legal and institutional requirements, including obtaining necessary permits and ethical clearance from NACOSTI, KUREC, and relevant authorities before fieldwork began.

## RESULTS AND DISCUSSION

This chapter presents and discusses findings organized around each of the study's three objectives. Each subsection reports descriptive statistics derived from field measurements, remote sensing data, and key informant interviews, interprets patterns relative to established thresholds and comparable literature, and draws inferences about the mechanisms linking urban expansion to ecological degradation and the adequacy of current mitigation responses.

### Land Use and Land Cover Change in the Dundori Forest Ecosystem (1985–2025)

#### Overview of LULC Change

Remote sensing analysis captured land cover trajectories across five epochs: 1985, 1995, 2005, 2015, and 2025. Four principal cover classes were delineated: Developed (built-up) land, Forest, Grassland, and Planted/Cultivated land. Table 2 summarizes the area in hectares for each class per epoch, and Table 3 presents the verified net changes between 1985 and 2025.

Table 2: Land Use and Land Cover Area (Hectares) in the Dundori Forest Ecosystem, 1985–2025

| Land Cover Class       | 1985 (ha)    | 1995 (ha)    | 2005 (ha)    | 2015 (ha)    | 2025 (ha)    |
|------------------------|--------------|--------------|--------------|--------------|--------------|
| Developed              | 25           | 62           | 119          | 98           | 119          |
| Forest                 | 2,463        | 2,601        | 2,333        | 1,764        | 2,333        |
| Grassland              | 1,187        | 711          | 383          | 766          | 383          |
| Planted/Cultivated     | 99           | 449          | 968          | 1,177        | 983          |
| <b>Total Landscape</b> | <b>3,774</b> | <b>3,823</b> | <b>3,803</b> | <b>3,805</b> | <b>3,818</b> |

Table 3: Net Land Use and Land Cover Change in the Dundori Forest Ecosystem, 1985 to 2025

| Land Cover Class   | Change (ha) | Direction |
|--------------------|-------------|-----------|
| Developed          | +94         | Gain      |
| Forest             | −130        | Loss      |
| Grassland          | −804        | Loss      |
| Planted/Cultivated | +884        | Gain      |

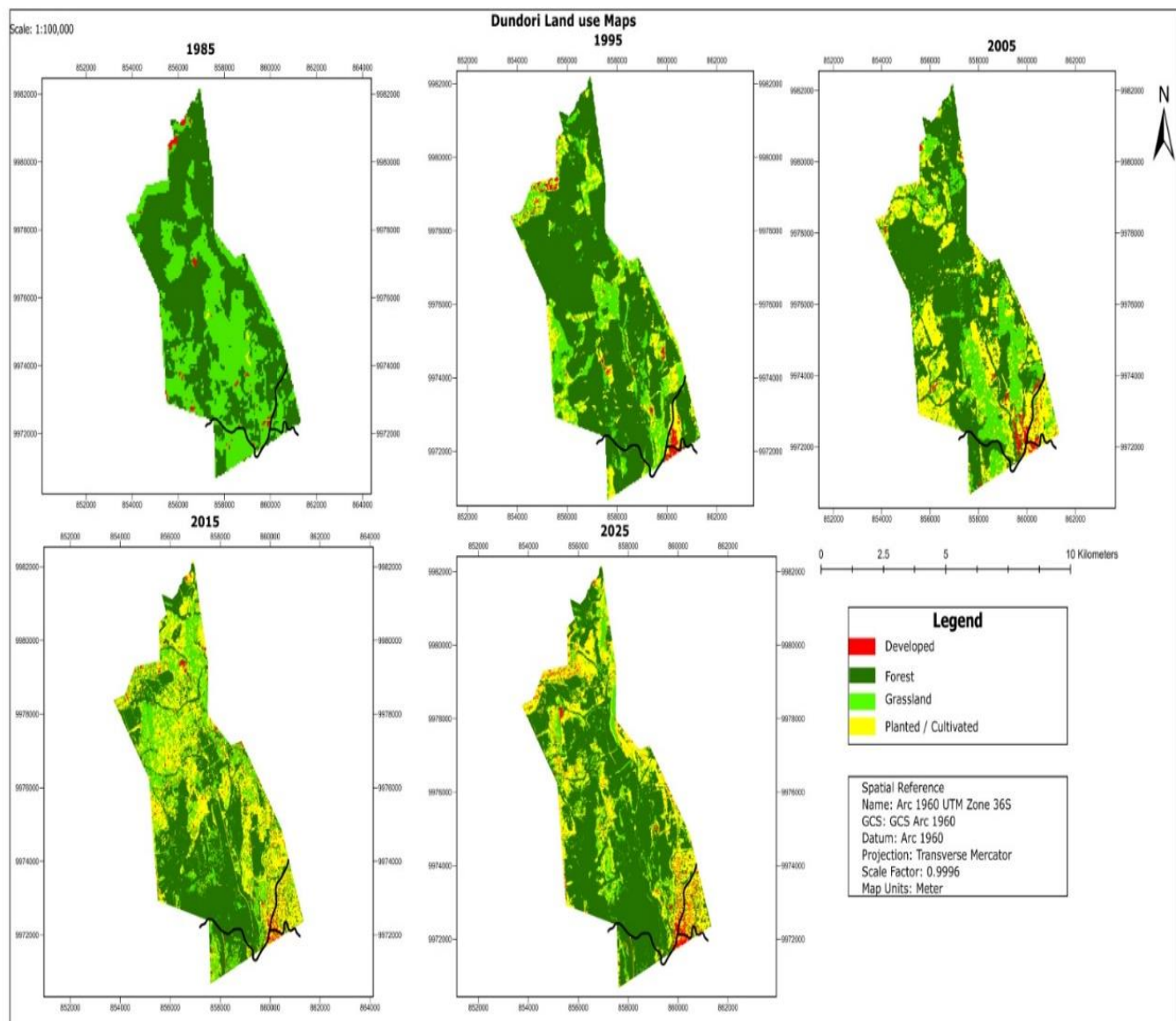


Figure 4: Net Land Use and Land Cover Change in the Dundori Forest Ecosystem, 1985 to 2025

### Temporal Trends in LULC Percentage Share

Table 4 presents the percentage share of each cover class and the mean decadal rate of change in percentage points (pp). Figure 5 visualizes these trends through a stacked area chart (panel a) and individual trend lines (panel b), both derived directly from the verified percentage data in Table 4.

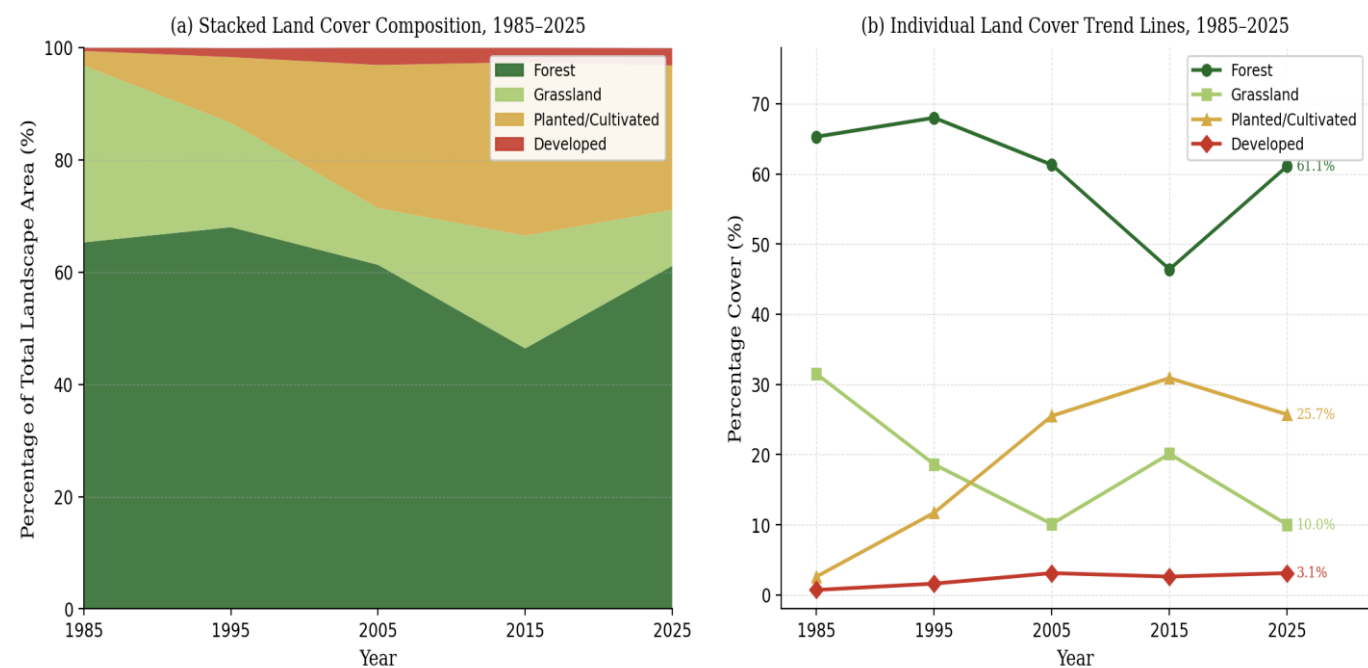
The most dramatic shift is the near-collapse of grassland, which fell from 31.5% in 1985 to 10.0% in 2025 a net reduction of 804 ha (67.7%). Planted/Cultivated land registered the sharpest proportional gain, rising from 2.6% to 25.7%, tracking directly against the grassland decline. This pattern is consistent with conversion of open land to smallholder agriculture, well-documented in peri-urban fringe zones across Sub-Saharan Africa (Talema & Nigusie, 2024).

Forest cover followed a non-monotonic path, peaking at 68.0% in 1995 before declining sharply to 46.4% in 2015 the lowest value across the study period and recovering partially to 61.1% by 2025. The 2015 trough coincided with the highest recorded Planted/Cultivated extent (30.9%), suggesting direct encroachment pressure at that juncture. The recovery by 2025 warrants interpretive caution: it may reflect plantation establishment or seasonal phenological differences in imagery rather than regeneration of indigenous canopy (Hansen et al.,

2013). Developed area grew 2.5% from its 1985 baseline, consistent with Dundori Market Centre's expanding role as a commercial node in Bahati Sub-county.

**Table 4: Percentage Share of Land Cover Classes and Mean Decadal Change (Percentage Points), 1985–2025**

| Land Class         | Cover | 1985 (%) | 1995 (%) | 2005 (%) | 2015 (%) | 2025 (%) | Mean $\Delta$ /Decade (pp) |
|--------------------|-------|----------|----------|----------|----------|----------|----------------------------|
| Developed          |       | 0.70     | 1.60     | 3.10     | 2.60     | 3.10     | +0.60                      |
| Forest             |       | 65.30    | 68.00    | 61.30    | 46.40    | 61.10    | −1.05                      |
| Grassland          |       | 31.50    | 18.60    | 10.10    | 20.10    | 10.00    | −5.38                      |
| Planted/Cultivated |       | 2.60     | 11.70    | 25.50    | 30.90    | 25.70    | +5.78                      |



**Figure 5: Temporal Trends in Land Use and Land Cover Percentage Share in the Dundori Forest Ecosystem, 1985–2025**

The average decadal shift in Planted/Cultivated area (+5.78 pp per decade) and in Grassland (−5.38 pp per decade) represent the two most dynamic transitions in the landscape. (Jebiwott et al., 2021) documented peri-urban land conversion rates averaging 4–7% per decade in Nakuru County, a range encompassing the grassland-to-farm rates observed here. Even the modest Developed-area gain (+0.60 pp per decade) carries disproportionate ecological significance: impervious surfaces alter runoff regimes, sediment delivery, and water quality even at low areal proportions (Mânica et al., 2025).

### Household Perceptions of Land Cover Change

Survey data from 106 respondents corroborate the remote sensing findings (Table 5). When asked to characterize the dominant land use at the time of their settlement, 92.2% identified forest ( $n = 97$ ), while only 5.2% reported farmland ( $n = 6$ ) and 2.6% built-up area ( $n = 3$ ). By the time of the survey, only 10.3% identified forest as the current dominant land use around their residence; mixed-use (54.3%,  $n = 63$ ) and farmland (33.6%,  $n = 39$ ) were the most common responses. An overwhelming majority of respondents (81.0%,  $n = 94$ ) reported observable LULC changes over the preceding 10–20 years.

Table 5: Household Perceptions of Land Use Change in the Dundori Forest Ecosystem (n = 106)

| Variable                             | Category      | Frequency (n) | Percent (%) |
|--------------------------------------|---------------|---------------|-------------|
| Dominant land use at settlement (Q6) | Forest        | 107           | 92.2        |
|                                      | Farmland      | 6             | 5.2         |
|                                      | Built-up area | 3             | 2.6         |
| Current dominant land use (Q7)       | Mixed use     | 63            | 54.3        |
|                                      | Farmland      | 39            | 33.6        |
|                                      | Forest        | 12            | 10.3        |
|                                      | Residential   | 2             | 1.7         |
| Observed LULC change, 10–20 yrs (Q8) | Yes           | 94            | 81.0        |
|                                      | No            | 22            | 19.0        |

Among the 94 respondents who observed change, conversion of forest to farmland was the most frequently cited change (75.5%, n = 71). Increase in residential buildings was reported by 26.6% (n = 25), while reduction in forest cover was noted by 40.4% (n = 38). The dominant perceived driver was farming expansion (55.3% of valid responses to Q10, n = 52), followed by population increase (36.2%, n = 34) and housing development (8.5%, n = 8). These perceptions align with (Akanga et al., 2022), who found that 78% of households adjacent to Mau Forest reported encroachment-driven land use shifts within a 15-year recall period. Critically, the primacy of farming expansion over direct urban growth as a perceived driver has direct management implications: interventions targeting smallholder land use practices will likely yield greater conservation returns than controls focused solely on built-up area expansion.

## Water Quality of River Maimahiu

### Overview of Analytical Approach

Water quality was assessed at three points along River Maimahiu upstream (the source, referred to as Part A in the bacteriological dataset), midstream (the middle section, Part B), and downstream (the exit point, Part C) during the dry and wet seasons. Two components of water quality were examined. Four physicochemical parameters—electrical conductivity ( $\mu\text{S}/\text{cm}$ ), total dissolved solids (TDS, ppm), dissolved oxygen (DO, mg/L), and turbidity (NTU)—were measured with three replicate readings per season-by-site combination. Microbiological quality was assessed separately through colony counts on two culture media: Nutrient Agar, which enumerates total heterotrophic bacteria, and MacConkey Agar, which enumerates presumptive coliform bacteria—also measured in triplicate per season-by-site combination.

A two-way factorial ANOVA (Season  $\times$  Water Source) had originally been fitted to each physicochemical parameter, and a three-way factorial ANOVA (Season  $\times$  Water Source  $\times$  Bacteria/Medium) had originally been fitted to the bacterial counts. Before either set of results could be reported, the normality assumption underlying each ANOVA was tested separately for every level of every independent variable, since a factorial ANOVA assumes the dependent variable is normally distributed within every group being compared, not merely in the pooled sample. As Sections 4.3.2 and 4.3.6 show, this assumption was violated for all or nearly all of the groups tested in both datasets. Once normality fails for a given group, further assumption tests such as homogeneity of variance no longer have any bearing on whether the ANOVA can be used, since the ANOVA is already ruled out on normality grounds alone; those follow-ups tests were therefore not run. Instead, the non-parametric Scheirer–Ray–Hare (SRH) tests a rank-based extension of the Kruskal–Wallis test to factorial designs, which carries no distributional assumption about the raw data—was used throughout in place of ANOVA, with Dunn's and Mann–Whitney post hoc tests used to interpret any significant omnibus effects.

## Test of Assumptions for Physicochemical Water Quality Parameters

The Shapiro-Wilk test was run on each of the four physicochemical parameters separately for each level of Season ( $n = 9$  per level) and each level of Water Source ( $n = 6$  per level) five groups per parameter, twenty tests in total. As Table 4.5 shows, every single group tested, for every parameter, departed significantly from normality ( $p < .05$ ). Figure 4.2 illustrates why: the boxplots for every parameter are visibly asymmetric by season and by source, which is expected given that pooling across the other factor's levels mixes together sub-groups with quite different centers for instance, pooling upstream, midstream, and downstream readings within one season combines three visibly different distributions into one, which a normality test is bound to flag.

Because normality failed for every group tested across all four parameters, no further assumption tests were necessary, and the originally planned ANOVA results were not used for inference for any of the four parameters. Instead, the SRH test was used throughout to test the effects of Season, Water Source, and their interaction on each parameter, with results reported in Table 6.

**Table 6: Shapiro-Wilk Normality Tests by Level of Each Independent Variable, for Each Physicochemical Water Quality Parameter**

| Parameter                         | Independent Variable | Level      | n | p    |
|-----------------------------------|----------------------|------------|---|------|
| Conductivity ( $\mu\text{S/cm}$ ) | Season               | Dry Season | 9 | .003 |
|                                   | Season               | Wet Season | 9 | .004 |
|                                   | Water Source         | Upstream   | 6 | .004 |
|                                   | Water Source         | Midstream  | 6 | .004 |
|                                   | Water Source         | Downstream | 6 | .005 |
| TDS (ppm)                         | Season               | Dry Season | 9 | .003 |
|                                   | Season               | Wet Season | 9 | .003 |
|                                   | Water Source         | Upstream   | 6 | .005 |
|                                   | Water Source         | Midstream  | 6 | .004 |
|                                   | Water Source         | Downstream | 6 | .005 |
| Dissolved Oxygen (mg/L)           | Season               | Dry Season | 9 | .007 |
|                                   | Season               | Wet Season | 9 | .045 |
|                                   | Water Source         | Upstream   | 6 | .005 |
|                                   | Water Source         | Midstream  | 6 | .006 |
|                                   | Water Source         | Downstream | 6 | .005 |
| Turbidity (NTU)                   | Season               | Dry Season | 9 | .044 |
|                                   | Season               | Wet Season | 9 | .037 |
|                                   | Water Source         | Upstream   | 6 | .009 |
|                                   | Water Source         | Midstream  | 6 | .006 |
|                                   | Water Source         | Downstream | 6 | .005 |

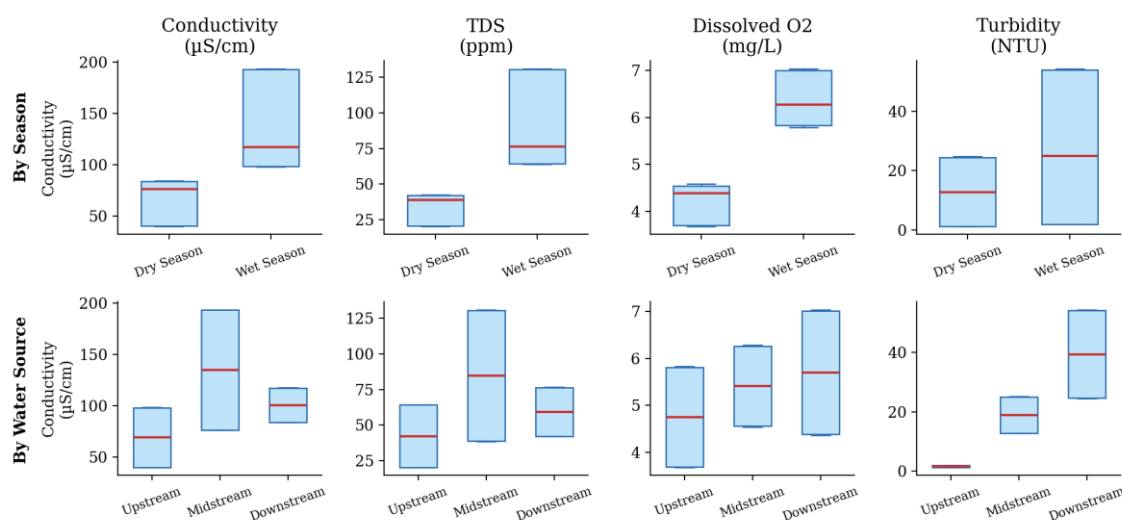


Figure 6: Distribution of Each Physicochemical Water Quality Parameter by Season and by Water Source

### Descriptive Physicochemical Water Quality Values

Because the parametric assumptions were not satisfied, the medians and interquartile ranges (IQR) of each parameter are reported below rather than means and standard deviations, consistent with the non-parametric approach adopted for inference.

Table 7: Median (IQR) of Each Physicochemical Water Quality Parameter by Season

| Parameter                         | Dry Season    | Wet Season     | n  |
|-----------------------------------|---------------|----------------|----|
| Conductivity ( $\mu\text{S/cm}$ ) | 76.60 (43.60) | 117.40 (94.80) | 18 |
| TDS (ppm)                         | 38.60 (21.50) | 76.40 (66.10)  | 18 |
| Dissolved Oxygen (mg/L)           | 4.38 (0.84)   | 6.27 (1.17)    | 18 |
| Turbidity (NTU)                   | 12.80 (23.09) | 25.04 (51.88)  | 18 |

Table 8: Median (IQR) of Each Physicochemical Water Quality Parameter by Water Source

| Parameter                         | Upstream      | Midstream       | Downstream     |
|-----------------------------------|---------------|-----------------|----------------|
| Conductivity ( $\mu\text{S/cm}$ ) | 69.15 (57.93) | 135.00 (116.78) | 100.75 (33.20) |
| TDS (ppm)                         | 42.25 (43.73) | 84.65 (92.08)   | 59.30 (34.10)  |
| Dissolved Oxygen (mg/L)           | 4.75 (2.11)   | 5.42 (1.70)     | 5.70 (2.63)    |
| Turbidity (NTU)                   | 1.65 (0.69)   | 18.90 (12.18)   | 39.35 (29.41)  |

Descriptively, conductivity, TDS, and dissolved oxygen were all higher in the wet season than in the dry season (for example, conductivity rose from a median of 76.60  $\mu\text{S/cm}$  in the dry season to 117.40  $\mu\text{S/cm}$  in the wet season), Table 7 consistent with increased surface runoff carrying dissolved ions, organic matter, and entrained oxygen into the river during rains. Turbidity showed the same direction of seasonal difference (median 12.80 NTU in the dry season versus 25.04 NTU in the wet season). Across water source, turbidity rose sharply from upstream (median = 1.65 NTU) to midstream and downstream (medians = 18.90 and 39.35 NTU, respectively), consistent with progressive sediment loading as the river passes through the urbanized Dundori Market Centre area. Conductivity, TDS, and dissolved oxygen also varied considerably across sites descriptively, with midstream generally showing the highest and most variable readings (for instance, conductivity IQR = 116.78  $\mu\text{S/cm}$  at midstream versus 57.93  $\mu\text{S/cm}$  upstream); however, as Table 8 shows, this raw site-to-site variation in

conductivity, TDS, and dissolved oxygen did not translate into a statistically significant Water Source effect under the rank-based SRH test, for reasons discussed there.

### Scheirer–Ray–Hare Test of Season and Water Source Effects on Physicochemical Parameters

The SRH test was used in place of the two-way ANOVA to test the main and interaction effects of Season and Water Source on each of the four physicochemical parameters. The SRH procedure ranks all observations, submits the ranks to the same two-way analysis-of-variance decomposition used for the parametric model, and converts each source's sum of squares to an H statistic (SS source divided by the total mean square of the ranks), referred to a chi-square distribution on the source's degrees of freedom. As a cross-check, every SRH H statistic for a main effect reported below was confirmed to equal the corresponding standard Kruskal-Wallis H statistic computed directly on that factor.

**Table 9: Scheirer–Ray–Hare Test of Season and Water Source Effects on Each Physicochemical Water Quality Parameter**

| Parameter                                   | Source                       | SS     | df | H      | p      |
|---------------------------------------------|------------------------------|--------|----|--------|--------|
| Conductivity<br>( $\mu\text{S}/\text{cm}$ ) | Season                       | 364.50 | 1  | 12.789 | < .001 |
|                                             | Water Source                 | 81.00  | 2  | 2.842  | .241   |
|                                             | Season $\times$ Water Source | 27.00  | 2  | 0.947  | .623   |
| TDS (ppm)                                   | Season                       | 364.50 | 1  | 12.789 | < .001 |
|                                             | Water Source                 | 81.00  | 2  | 2.842  | .241   |
|                                             | Season $\times$ Water Source | 27.00  | 2  | 0.947  | .623   |
| Dissolved Oxygen<br>(mg/L)                  | Season                       | 364.50 | 1  | 12.789 | < .001 |
|                                             | Water Source                 | 81.00  | 2  | 2.842  | .241   |
|                                             | Season $\times$ Water Source | 27.00  | 2  | 0.947  | .623   |
| Turbidity (NTU)                             | Season                       | 112.50 | 1  | 3.947  | .047   |
|                                             | Water Source                 | 351.00 | 2  | 12.316 | .002   |
|                                             | Season $\times$ Water Source | 9.00   | 2  | 0.316  | .854   |

Season had a statistically significant effect on conductivity, TDS, and dissolved oxygen ( $H(1) = 12.789$ ,  $p < .001$ , for all three parameters, since the identical rank structure of these three variables – discussed further below produced identical SRH statistics), and a borderline effect on turbidity ( $H(1) = 3.947$ ,  $p = .047$ ). Water Source had a statistically significant effect on turbidity ( $H(2) = 12.316$ ,  $p = .002$ ), but not on conductivity, TDS, or dissolved oxygen ( $H(2) = 2.842$ ,  $p = .241$ , for all three). The Season  $\times$  Water Source interaction was not significant for any of the four parameters.

The identical SRH statistics obtained for conductivity, TDS, and dissolved oxygen are a genuine numerical feature of these data rather than a computational error. All three parameters ranked the eighteen observations into exactly the same relative order between the midstream and downstream sites – that is, whichever of the two sites had the higher reading for conductivity also had the higher reading for TDS and for dissolved oxygen, observation for observation – so the rank-based sums of squares that the SRH test operates on came out identical across the three parameters even though the raw measurement scales and raw values differ substantially. This was verified directly against the standard Kruskal-Wallis statistic for each factor and confirmed to be exact, not an artifact of rounding.

The absence of a statistically significant Water Source effect for conductivity, TDS, and dissolved oxygen, despite visibly large differences in the descriptive medians across sites (Table 9), is attributable to the ranks for Water Source not being consistent across the two seasons: which site (midstream or downstream) recorded the higher reading changed between the dry and wet season for these three parameters, so pooling both seasons together to test the marginal Water Source effect worked against, rather than with, the seasonal pattern, diluting

the rank-based main effect even though neither the Water Source main effect nor the interaction term individually reached significance on its own. Turbidity did not show this reversal downstream and midstream turbidity remained consistently elevated relative to upstream in both seasons which is consistent with why only turbidity produced a statistically significant Water Source effect.

### Post Hoc Comparisons for Physicochemical Parameters

Because the Water Source omnibus effect was statistically significant only for turbidity, Dunn's pairwise post hoc test (with Bonferroni correction) is interpreted below only for that parameter; the corresponding non-significant omnibus tests for conductivity, TDS, and dissolved oxygen mean their pairwise comparisons are not meaningfully interpretable and are not tabulated.

Table 10: Dunn's Pairwise Post Hoc Comparisons for Water Source on Turbidity (Bonferroni-Adjusted)

| Site A    | Site B     | p    |
|-----------|------------|------|
| Upstream  | Midstream  | .045 |
| Upstream  | Downstream | .002 |
| Midstream | Downstream | .991 |

For turbidity, Dunn's test located the Water Source effect between upstream and the two downriver sites: turbidity at the midstream site was significantly higher than upstream ( $p = .045$ ), and turbidity at the downstream/exit site was also significantly higher than upstream ( $p = .002$ ), while midstream and downstream did not differ significantly from each other ( $p = .991$ ). This pattern indicates that turbidity increases sharply once the river passes the upstream point but does not continue increasing significantly further downstream.

Seasonal comparisons were additionally verified with the exact Mann-Whitney U test for each parameter. For conductivity, TDS, and dissolved oxygen, the Mann-Whitney U test confirmed the significant seasonal difference found by SRH ( $U = 0.00$ ,  $p = .00041$ , for all three parameters, reflecting the same identical rank structure noted above). For turbidity, however, the exact Mann-Whitney U test ( $U = 18.00$ ,  $p = .052$ ) did not quite reach statistical significance, in contrast to the SRH chi-square approximation, which returned a borderline significant result ( $p = .047$ ). This small discrepancy is an expected consequence of the SRH test's reliance on a large-sample chi-square approximation, which can diverge slightly from an exact test when sample sizes are small and tied ranks are present, as they are here; given the exact test is the more trustworthy of the two in this small-sample setting, the seasonal effect on turbidity is best regarded as suggestive rather than firmly established.

### Test of Assumptions for Bacteriological Water Quality

Microbiological quality was assessed at the same three points along River Maimahiu the source (Part A), a middle section (Part B), and a downstream/exit point (Part C) during both the dry and wet seasons, and was cultured on two media: Nutrient Agar, which enumerates total heterotrophic bacteria, and MacConkey Agar, which enumerates presumptive coliform bacteria. With three replicate samples per season-by-site-by-medium combination, this yielded a balanced  $2 \times 3 \times 2$  factorial design with 36 bacterial counts in total, recorded as colony-forming units per milliliter (CFU/mL).

The Shapiro-Wilk test was run on CFU/mL separately for each level of Season, Water Source, and Bacteria. As Table 4.10 shows, five of the seven groups tested departed significantly from normality ( $p < .05$ ): both levels of Season, two of the three Water Source levels (Part B and Part C), and Nutrient Agar under Bacteria. Only Part A (Source) and MacConkey Agar showed no significant departure from normality. Figure 7 illustrates the same pattern: the boxplots for most groups are visibly asymmetric, with the median line sitting off-center within the box and, for Nutrient Agar in particular, pulled sharply toward the upper edge.

Because the normality assumption failed for the majority of the groups being compared, it was not necessary to proceed to any further assumption tests once normality is violated, those follow-up tests no longer have a bearing on whether the ANOVA can be used, since the ANOVA is already ruled out on normality grounds alone. The originally planned ANOVA results were therefore not used for inference. Instead, the SRH test was used to test the effects of Season, Water Source, and Bacteria (and their interactions) on CFU/mL, with results reported in Section 4.3.8.

Table 11: Shapiro-Wilk Normality Tests of CFU/mL by Level of Each Independent Variable

| Independent Variable | Level                    | n  | W    | p                |
|----------------------|--------------------------|----|------|------------------|
| Season               | Dry Season               | 18 | 0.89 | <b>.038</b>      |
| Season               | Wet Season               | 18 | 0.84 | <b>.006</b>      |
| Water Source         | Part A (Source)          | 12 | 0.88 | .100             |
| Water Source         | Part B (Middle Section)  | 12 | 0.82 | <b>.017</b>      |
| Water Source         | Part C (Downstream/Exit) | 12 | 0.79 | <b>.007</b>      |
| Bacteria (Medium)    | Nutrient Agar            | 18 | 0.69 | <b>&lt; .001</b> |
| Bacteria (Medium)    | MacConkey Agar           | 18 | 0.92 | .143             |

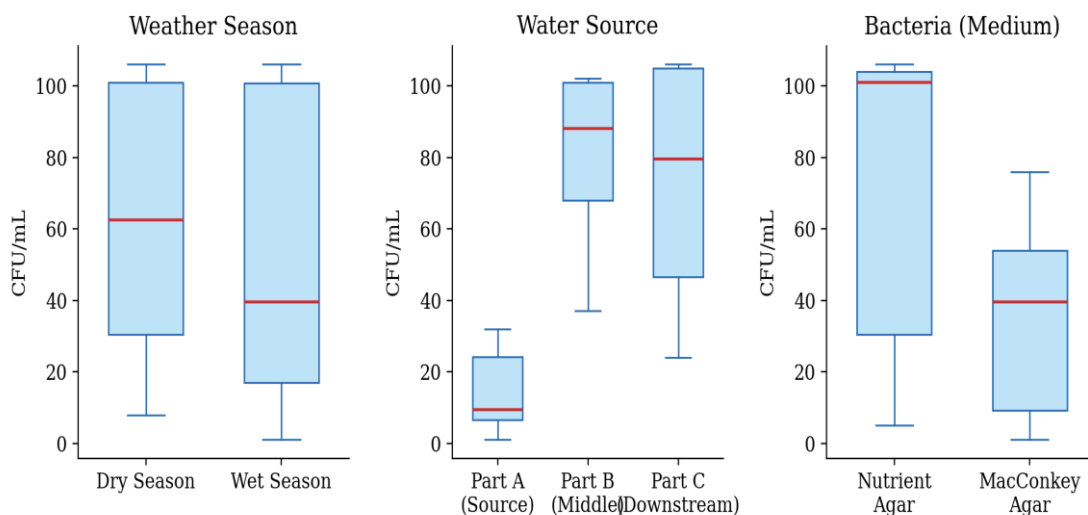


Figure 7: Distribution of CFU/mL by Level of Each Independent Variable

### Descriptive Bacterial Counts

Because the data did not satisfy the normality assumption, the median and interquartile range (IQR) rather than the mean and standard deviation are the appropriate summary statistics for describing bacterial counts across the study's factors, and are used throughout the remainder of this section. Table 12 presents these summary statistics for CFU/mL by season, water-sampling point, and culture medium.

Table 12: Median CFU/mL by Season, Water-Sampling Point, and Culture Medium (N = 36)

| Factor / Level              | n  | Median | IQR   | Range       |
|-----------------------------|----|--------|-------|-------------|
| <b>Weather Season</b>       |    |        |       |             |
| Dry Season                  | 18 | 62.50  | 70.50 | 8.00–106.00 |
| Wet Season                  | 18 | 39.50  | 83.75 | 1.00–106.00 |
| <b>Water Sampling Point</b> |    |        |       |             |

|                                  |    |        |       |              |
|----------------------------------|----|--------|-------|--------------|
| Part A (Source)                  | 12 | 9.50   | 17.75 | 1.00–32.00   |
| Part B (Middle Section)          | 12 | 88.00  | 33.00 | 37.00–102.00 |
| Part C (Downstream/Exit)         | 12 | 79.50  | 58.50 | 24.00–106.00 |
| <b>Culture Medium (Bacteria)</b> |    |        |       |              |
| Nutrient Agar                    | 18 | 101.00 | 73.50 | 5.00–106.00  |
| MacConkey Agar                   | 18 | 39.50  | 44.75 | 1.00–76.00   |

Descriptively, bacterial counts were highest at the middle (Part B; median = 88.00 CFU/mL) and downstream/exit (Part C; median = 79.50 CFU/mL) points, and lowest at the source (Part A; median = 9.50 CFU/mL). Nutrient Agar counts (total heterotrophic bacteria; median = 101.00 CFU/mL) were, as expected, substantially higher than MacConkey Agar counts (presumptive coliforms; median = 39.50 CFU/mL). Bacterial counts were somewhat lower in the wet season (median = 39.50 CFU/mL) than in the dry season (median = 62.50 CFU/mL), though, as Section 4.3.6

shows, this seasonal difference did not reach statistical significance.

### Scheirer–Ray–Hare Test of Season, Water Source, and Bacteria Effects

The SRH test was used in place of the three-way ANOVA to test the main and interaction effects of Season, Water Source, and Bacteria on CFU/mL. As a cross-check, the SRH H statistics for the two significant main effects reported below were confirmed to equal the corresponding standard Kruskal–Wallis H statistics computed directly on Water Source and on Bacteria.

Table 13: Scheirer–Ray–Hare Test of Season, Water Source, and Bacteria Effects on CFU/mL

| Source                           | SS (rank) | df | H     | p      |
|----------------------------------|-----------|----|-------|--------|
| Season                           | 128.44    | 1  | 1.16  | .282   |
| Water Source                     | 2383.88   | 2  | 21.50 | < .001 |
| Bacteria (Medium)                | 940.44    | 1  | 8.48  | .004   |
| Season × Water Source            | 6.76      | 2  | 0.06  | .970   |
| Season × Bacteria                | 18.78     | 1  | 0.17  | .681   |
| Water Source × Bacteria          | 258.76    | 2  | 2.33  | .311   |
| Season × Water Source × Bacteria | 35.76     | 2  | 0.32  | .851   |

Water Source had a highly significant effect on bacterial counts,  $H(2) = 21.50$ ,  $p < .001$ , as did Bacteria (culture medium),  $H(1) = 8.48$ ,  $p = .004$ . Season, by contrast, did not have a significant effect on CFU/mL,  $H(1) = 1.16$ ,  $p = .282$ , and none of the two-way or three-way interactions among Season, Water Source, and Bacteria were significant (all  $p > .30$ ). This pattern differs from the originally fitted ANOVA, which had additionally flagged Season and several interaction terms as significant; because those F-tests rested on the normality assumption that Section 4.3.6 showed to be violated, the rank-based SRH results—which point to two robust main effects (Water Source and Bacteria) and no reliable interaction effects—are taken as the more trustworthy basis for interpretation.

### Post Hoc Comparisons for Bacteriological Water Quality

Because Water Source has three levels and returned a significant omnibus effect, pairwise Dunn's tests with Bonferroni correction for three comparisons were carried out to identify which sampling points differed. Because Bacteria has only two levels, its significant omnibus effect already identifies the direction and location of the difference, and was corroborated with a Mann–Whitney U test.

Table 14: Dunn's Pairwise Post Hoc Comparisons for Water Source (Bonferroni-Adjusted)

| Water Source (I)        | Water Source (J)         | p (adjusted) |
|-------------------------|--------------------------|--------------|
| Part A (Source)         | Part B (Middle Section)  | < .001       |
| Part A (Source)         | Part C (Downstream/Exit) | < .001       |
| Part B (Middle Section) | Part C (Downstream/Exit) | 1.000        |

The source point (Part A; median = 9.50 CFU/mL) had significantly lower bacterial counts than both the middle section (Part B; median = 88.00 CFU/mL;  $p < .001$ ) and the downstream/exit point (Part C; median = 79.50 CFU/mL;  $p < .001$ ). The middle section and the downstream/exit point did not differ significantly from each other ( $p = 1.000$ ). In other words, bacterial contamination rose sharply between the river's source and the middle of its course through the study area, but did not continue to rise significantly between the middle section and the downstream/exit point.

For Bacteria, a Mann-Whitney U test confirmed the SRH result: Nutrient Agar counts (median = 101.00 CFU/mL) were significantly higher than MacConkey Agar counts (median = 39.50 CFU/mL),  $U = 254$ ,  $p = .004$ . This is an expected pattern rather than a novel finding. Nutrient Agar supports the growth of a much broader range of heterotrophic organisms than the more selective, lactose-fermenting-coliform-targeted MacConkey Agar and its significance here mainly confirms that the two media were behaving as intended. For completeness, a Mann-Whitney U test on Season (not significant under SRH) likewise found no significant difference between the dry season (median = 62.50 CFU/mL) and the wet season (median = 39.50 CFU/mL),  $U = 196$ ,  $p = .289$ .

### Community Perceptions of Water Quality

Household survey data reinforced the physical measurements (Table 4.14). Only 10.3% of respondents used River Maimahiu as their primary water source; the majority relied on wells (51.7%,  $n = 60$ ) and springs (30.2%,  $n = 35$ ). Nevertheless, 89.7% ( $n = 104$ ) reported having observed changes in river water quality over time. Among observers, increased turbidity was the most frequently cited change (60.6%,  $n = 63$ ), followed by color change (39.4%,  $n = 41$ ), reduced water volume (4.8%,  $n = 5$ ), and solid waste presence (2.9%,  $n = 3$ ). Farming activities upstream were identified as the primary cause of deterioration by 68.1% of all respondents ( $n = 79$ ), with solid waste dumping (16.4%,  $n = 19$ ) and soil erosion (15.5%,  $n = 18$ ) also cited. Water-related health impacts were reported by 29.3% of households ( $n = 34$ ), aligning with the documented enteric disease burden in communities relying on unprotected water sources in Kenya (Daly et al., 2024).

Table 15: Household Perceptions of Water Source Use and River Water Quality Changes ( $n = 106$ )

| Survey Item                            | Category            | n   | %    |
|----------------------------------------|---------------------|-----|------|
| Main water source (Q12)                | Well                | 60  | 51.7 |
|                                        | Spring              | 35  | 30.2 |
|                                        | River Maimahiu      | 12  | 10.3 |
|                                        | Piped water         | 8   | 6.9  |
|                                        | Rainwater           | 1   | 0.9  |
| Observed river quality change (Q14)    | Yes                 | 104 | 89.7 |
|                                        | No                  | 12  | 10.3 |
| Changes observed Q15 (base $n = 104$ ) | Increased turbidity | 63  | 60.6 |
|                                        | Color change        | 41  | 39.4 |
|                                        | Reduced volume      | 5   | 4.8  |
|                                        | Solid waste         | 3   | 2.9  |
| Perceived cause (Q16)                  | Farming upstream    | 79  | 68.1 |

|  |                     |    |      |
|--|---------------------|----|------|
|  | Solid waste dumping | 19 | 16.4 |
|  | Soil erosion        | 18 | 15.5 |

## Summary of Water Quality Findings

Across both components of water quality examined, diagnostic testing showed that the great majority of groups compared departed significantly from normality (all 20 groups tested for the physicochemical parameters, and 5 of 7 groups tested for bacterial counts), so the non-parametric Scheirer–Ray–Hare test was used in place of the originally planned ANOVA models throughout. For the physicochemical parameters, Season had a statistically significant effect on conductivity, TDS, and dissolved oxygen, all three markedly higher in the wet season, and a borderline effect on turbidity that did not hold up under an exact test; Water Source had a statistically significant effect only on turbidity, which rose sharply from upstream to the midstream and downstream sites, while conductivity, TDS, and dissolved oxygen showed no statistically significant Water Source effect despite large raw differences across sites, attributable to the ranking of midstream versus downstream reversing between the two seasons for these three parameters. For the bacteriological data, Water Source and Bacteria (culture medium) both had statistically significant effects on bacterial counts, with counts significantly lower at the source (Part A) than at the middle section (Part B) and downstream/exit point (Part C), which did not differ significantly from each other; Season and all interaction terms were not significant. No Season  $\times$  Water Source interaction reached significance for any parameter, physicochemical or bacteriological. Taken together, these results indicate that urbanization activities around Dundori Market Centre are most clearly reflected in elevated turbidity and elevated bacterial contamination downstream of the source, while the seasonal pattern of rising conductivity, TDS, and dissolved oxygen during the wet season most likely reflects broader hydrological effects of rainfall and runoff common to the whole river reach. These physical and microbiological findings converge closely with community perceptions: increased turbidity was the most commonly observed change in river water quality, and farming activities upstream were the most commonly cited cause, consistent with the statistically confirmed spatial gradients in both turbidity and bacterial contamination.

## Strategies for Mitigating the Effects of Urbanization on the Dundori Forest Ecosystem

This section presents the findings on the third objective of the study, which sought to find out the strategies used to mitigate the effects of urbanization activities on the Dundori Forest ecosystem. Data for this objective were collected using a key informant questionnaire administered to representatives of institutions and agencies directly involved in environmental management within the study area. A total of eight (8) key informants took part in the study, drawn from the Kenya Forest Service, the Water Resources Authority, the Water Resource Users Association, the County Environment Department, the Physical Planning Department, the Agriculture Department, the Health Department, and the Community Forest Association. The findings are organized around the institutional profile of the respondents, the extent of implementation of mitigation measures, the effectiveness of those measures, their contribution to environmental outcomes, the constraints affecting their implementation, the state of inter-institutional collaboration, and the key informants' overall assessment of mitigation effectiveness.

Ratings on the five-point scales used in Sections B through E of the questionnaire were converted to mean scores computed from the exact response counts recorded for each item, and interpreted using equal score bands of 0.80(Koo & Yang, 2025): a mean of 1.00–1.80 corresponds to the lowest anchor of the scale in question, 1.81–2.60 to the second band, 2.61–3.40 to the midpoint band, 3.41–4.20 to the fourth band, and 4.21–5.00 to the highest anchor, with the exact wording of each band drawn from the anchor labels of the scale being reported.

## Institutional Profile of the Key Informants

Table 16 summarizes the institutional and respondent characteristics of the eight key informants. Each of the eight participating institutions was represented by exactly one respondent (12.5% each): the Agriculture Department, the Community Forest Association, the County Environment Department, the Health Department,

the Kenya Forest Service, the Physical Planning Department, the Water Resource Users Association, and the Water Resources Authority. By position, the sample comprised two chairmen (25.0%), two officers (25.0%), and one each of director, forest officer, nurse, and physical planner (12.5% each). On length of involvement in the study area, the majority of key informants, six of the eight (75.0%), had more than six years of involvement, while one (12.5%) had between one and three years and one (12.5%) had between four and six years. Asked about their institution's main role in environmental management, the eight key informants again described eight distinct roles at 12.5% each, spanning forest and water conservation, development control, solid waste management, and the promotion of good agricultural and WASH practices.

**Table 16:** Institutional and Respondent Characteristics of the Key Informants (N = 8)

| Characteristic                                             | f | %     |
|------------------------------------------------------------|---|-------|
| <b>Institution/Organization Represented</b>                |   |       |
| Agriculture Department                                     | 1 | 12.5% |
| Community Forest Association (CFA)                         | 1 | 12.5% |
| County Environment Department                              | 1 | 12.5% |
| Health Department                                          | 1 | 12.5% |
| Kenya Forest Service (KFS)                                 | 1 | 12.5% |
| Physical Planning Department                               | 1 | 12.5% |
| Water Resource Users Association (WRUA)                    | 1 | 12.5% |
| Water Resources Authority (WRA)                            | 1 | 12.5% |
| <b>Position/Designation</b>                                |   |       |
| Chairman                                                   | 2 | 25.0% |
| Director                                                   | 1 | 12.5% |
| Forest Officer                                             | 1 | 12.5% |
| Nurse                                                      | 1 | 12.5% |
| Officer                                                    | 2 | 25.0% |
| Physical Planner                                           | 1 | 12.5% |
| <b>Years Involved in Activities within the Study Area</b>  |   |       |
| 1–3 years                                                  | 1 | 12.5% |
| 4–6 years                                                  | 1 | 12.5% |
| More than 6 years                                          | 6 | 75.0% |
| <b>Institution's Main Role in Environmental Management</b> |   |       |
| Conservation of the forest                                 | 1 | 12.5% |
| Development control                                        | 1 | 12.5% |
| Forest conservation                                        | 1 | 12.5% |
| Promoting WASH activities                                  | 1 | 12.5% |
| Promotion of good agricultural practices                   | 1 | 12.5% |
| Protection of water resources                              | 1 | 12.5% |
| Solid waste management                                     | 1 | 12.5% |
| Water conservation activities                              | 1 | 12.5% |

## Implementation of Mitigation Measures

Key informants rated the extent to which twelve mitigation measures had been implemented in the study area, on a scale of 1 (not implemented) to 5 (very well implemented). As Table 17 shows, none of the twelve measures reached the moderately-implemented band; every mean fell within the two lowest bands of the scale, and the aggregate mean across all twelve measures was 1.54, indicating that mitigation measures had, on the whole, been implemented to only a small extent. Agroforestry recorded the highest mean ( $M = 2.50$ ,  $SD = 0.53$ ), split evenly between four key informants (50.0%) rating it implemented to a small extent and four (50.0%) rating it moderately implemented. Afforestation and reforestation, forest conservation and protection, waste collection

and management, and environmental sensitization followed ( $M = 2.12$ ,  $SD = 0.35$  for each), each rated by seven of the eight key informants (87.5%) as implemented to a small extent and by one (12.5%) as moderately implemented. At the other end of the scale, riparian protection, river monitoring and inspection, development control and enforcement, and community-based forest/riparian monitoring were unanimously rated by all eight key informants (100%) as not implemented at all ( $M = 1.00$ ,  $SD = 0.00$ ).

Table 17: Level of Implementation of Mitigation Measures as Rated by Key Informants ( $N = 8$ )

| Rank | Mitigation Measure                          | M    | SD   | Interpretation                |
|------|---------------------------------------------|------|------|-------------------------------|
| 1    | Agroforestry                                | 2.50 | 0.53 | Implemented to a small extent |
| 2    | Afforestation and reforestation             | 2.12 | 0.35 | Implemented to a small extent |
| 3    | Forest conservation and protection          | 2.12 | 0.35 | Implemented to a small extent |
| 4    | Waste collection and management             | 2.12 | 0.35 | Implemented to a small extent |
| 5    | Environmental sensitization                 | 2.12 | 0.35 | Implemented to a small extent |
| 6    | WASH and environmental-health sensitization | 1.25 | 0.46 | Not implemented               |
| 7    | Community conservation and restoration      | 1.12 | 0.35 | Not implemented               |
| 8    | Soil and water conservation                 | 1.12 | 0.35 | Not implemented               |
| 9    | Community-based forest/riparian monitoring  | 1.00 | 0.00 | Not implemented               |
| 10   | Riparian protection                         | 1.00 | 0.00 | Not implemented               |
| 11   | River monitoring and inspection             | 1.00 | 0.00 | Not implemented               |
| 12   | Development control and enforcement         | 1.00 | 0.00 | Not implemented               |

1 = Not implemented, 2 = Implemented to a small extent, 3 = Moderately implemented, 4 = Well implemented, 5 = Very well implemented. Aggregate mean across items = 1.54.

### Effectiveness of Mitigation Measures

Key informants also rated how effective each of the same twelve measures had been in addressing the effects of urbanization on the Dundori Forest ecosystem and River Maimahiu, on a scale of 1 (not effective at all) to 5 (very effective). As shown in Table 18, the aggregate mean across the twelve measures was 1.39, lower than the corresponding implementation ratings, and no measure was rated above the slightly-effective band. Three measures tied for the highest mean ( $M = 2.00$ ): forest conservation and protection and agroforestry were each rated "slightly effective" by all eight key informants (100%,  $SD = 0.00$ ), while afforestation and reforestation showed more variation ( $SD = 0.53$ ), rated "not effective at all" by one key informant (12.5%), "slightly effective" by six (75.0%), and "moderately effective" by one (12.5%). Riparian protection, river monitoring and inspection, development control and enforcement, and soil and water conservation were unanimously rated "not effective at all" by all eight key informants ( $M = 1.00$ ,  $SD = 0.00$ ).

Table 18: Effectiveness of Mitigation Measures in Addressing the Effects of Urbanization ( $N = 8$ )

| Rank | Mitigation Measure                          | M    | SD   | Interpretation       |
|------|---------------------------------------------|------|------|----------------------|
| 1    | Afforestation and reforestation             | 2.00 | 0.53 | Slightly effective   |
| 2    | Forest conservation and protection          | 2.00 | 0.00 | Slightly effective   |
| 3    | Agroforestry                                | 2.00 | 0.00 | Slightly effective   |
| 4    | Waste collection and management             | 1.62 | 0.52 | Not effective at all |
| 5    | Environmental sensitization                 | 1.62 | 0.52 | Not effective at all |
| 6    | WASH and environmental-health sensitization | 1.12 | 0.35 | Not effective at all |
| 7    | Community conservation and restoration      | 1.12 | 0.35 | Not effective at all |
| 8    | Community-based forest/riparian monitoring  | 1.12 | 0.35 | Not effective at all |
| 9    | Riparian protection                         | 1.00 | 0.00 | Not effective at all |
| 10   | River monitoring and inspection             | 1.00 | 0.00 | Not effective at all |

|    |                                     |      |      |                      |
|----|-------------------------------------|------|------|----------------------|
| 11 | Development control and enforcement | 1.00 | 0.00 | Not effective at all |
| 12 | Soil and water conservation         | 1.00 | 0.00 | Not effective at all |

1 = Not effective at all, 2 = Slightly effective, 3 = Moderately effective, 4 = Effective, 5 = Very effective.  
Aggregate mean across items = 1.39.

### Contribution of Mitigation Measures to Environmental Outcomes

Key informants rated the extent to which the mitigation measures had contributed to twelve specific environmental outcomes, on a scale of 1 (no improvement) to 5 (very significant improvement). As Table 19 shows, the aggregate mean across the twelve outcomes was 1.42, and no outcome was rated above the little-improvement band. Increased adoption of agroforestry recorded the highest mean ( $M = 2.25$ ,  $SD = 0.46$ ), rated "little improvement" by six key informants (75.0%) and "moderate improvement" by two (25.0%). Increased community participation in conservation and reduction in forest encroachment followed ( $M = 2.12$ ,  $SD = 0.35$  each), each rated "little improvement" by seven key informants (87.5%) and "moderate improvement" by one (12.5%). Improvement in forest cover was close behind ( $M = 1.88$ ,  $SD = 0.35$ ), rated "no improvement" by one key informant (12.5%) and "little improvement" by seven (87.5%). Overall reduction in environmental degradation was rated lower still ( $M = 1.50$ ,  $SD = 0.53$ ), split evenly between four key informants (50.0%) reporting no improvement and four (50.0%) reporting little improvement, and improved sanitation practices scored similarly low ( $M = 1.12$ ,  $SD = 0.35$ ). At the lower end, riparian vegetation, riparian degradation, River Maimahiu water quality, waste entering the river, soil and water conservation, and compliance with physical planning requirements were each unanimously rated "no improvement" by all eight key informants ( $M = 1.00$ ,  $SD = 0.00$ ).

Table 19: Contribution of Mitigation Measures to Environmental Outcomes (N = 8)

| Rank | Environmental Outcome                                   | M    | SD   | Interpretation     |
|------|---------------------------------------------------------|------|------|--------------------|
| 1    | Increased adoption of agroforestry                      | 2.25 | 0.46 | Little improvement |
| 2    | Increased community participation in conservation       | 2.12 | 0.35 | Little improvement |
| 3    | Reduction in forest encroachment                        | 2.12 | 0.35 | Little improvement |
| 4    | Improvement in forest cover                             | 1.88 | 0.35 | Little improvement |
| 5    | Overall reduction in environmental degradation          | 1.50 | 0.53 | No improvement     |
| 6    | Improved sanitation practices                           | 1.12 | 0.35 | No improvement     |
| 7    | Improvement in riparian vegetation                      | 1.00 | 0.00 | No improvement     |
| 8    | Reduction in riparian degradation                       | 1.00 | 0.00 | No improvement     |
| 9    | Improvement in River Maimahiu water quality             | 1.00 | 0.00 | No improvement     |
| 10   | Reduction in waste entering the river                   | 1.00 | 0.00 | No improvement     |
| 11   | Improvement in soil and water conservation              | 1.00 | 0.00 | No improvement     |
| 12   | Improved compliance with physical planning requirements | 1.00 | 0.00 | No improvement     |

1 = No improvement, 2 = Little improvement, 3 = Moderate improvement, 4 = Significant improvement, 5 = Very significant improvement. Aggregate mean across items = 1.42.

## Constraints Affecting the Implementation and Effectiveness of Mitigation Measures

Key informants rated the extent to which twelve factors constrained the implementation and effectiveness of mitigation measures, on a scale of 1 (not a constraint) to 5 (very major constraint). Unlike the implementation, effectiveness, and outcome ratings, the constraint ratings were consistently high: as Table 20 shows, the aggregate mean across the twelve factors was 4.78, and every factor fell within the major- or very-major-constraint band. Inadequate funding, inadequate personnel, inadequate equipment, weak enforcement of regulations, limited stakeholder coordination, poverty and livelihood pressures, and inadequate monitoring and follow-up were each unanimously rated "very major constraint" by all eight key informants ( $M = 5.00$ ,  $SD = 0.00$ ). Increasing development pressure and political interference followed closely ( $M = 4.88$ ,  $SD = 0.35$  each), each rated "major constraint" by one key informant (12.5%) and "very major constraint" by seven (87.5%). Limited community participation ( $M = 4.50$ ,  $SD = 0.76$ ) and inadequate public awareness ( $M = 4.38$ ,  $SD = 0.92$ ) were rated somewhat lower but still within the very-major-constraint band. Forest/riparian encroachment recorded the lowest mean of the twelve factors ( $M = 3.75$ ,  $SD = 1.04$ ), the only factor to fall in the major-constraint band, with ratings spread across minor constraint (12.5%), moderate constraint (25.0%), major constraint (37.5%), and very major constraint (25.0%).

Table 20: Constraints Affecting the Implementation and Effectiveness of Mitigation Measures ( $N = 8$ )

| Rank | Constraint                          | M    | SD   | Interpretation        |
|------|-------------------------------------|------|------|-----------------------|
| 1    | Inadequate funding                  | 5.00 | 0.00 | Very major constraint |
| 2    | Poverty and livelihood pressures    | 5.00 | 0.00 | Very major constraint |
| 3    | Inadequate monitoring and follow-up | 5.00 | 0.00 | Very major constraint |
| 4    | Inadequate personnel                | 5.00 | 0.00 | Very major constraint |
| 5    | Inadequate equipment                | 5.00 | 0.00 | Very major constraint |
| 6    | Weak enforcement of regulations     | 5.00 | 0.00 | Very major constraint |
| 7    | Limited stakeholder coordination    | 5.00 | 0.00 | Very major constraint |
| 8    | Political interference              | 4.88 | 0.35 | Very major constraint |
| 9    | Increasing development pressure     | 4.88 | 0.35 | Very major constraint |
| 10   | Limited community participation     | 4.50 | 0.76 | Very major constraint |
| 11   | Inadequate public awareness         | 4.38 | 0.92 | Very major constraint |
| 12   | Forest/riparian encroachment        | 3.75 | 1.04 | Major constraint      |

: 1 = Not a constraint, 2 = Minor constraint, 3 = Moderate constraint, 4 = Major constraint, 5 = Very major constraint.

## Inter-Institutional Collaboration

Key informants were asked whether their institution collaborated with other institutions in implementing environmental mitigation measures. As shown in Table 21, all eight key informants (100%) reported that their institution did not collaborate with other institutions. Consistent with this, when asked to rate the effectiveness of inter-institutional collaboration in addressing environmental challenges in the study area, seven key informants (87.5%) rated it "not effective" and one (12.5%) rated it "slightly effective" ( $M = 1.12$ ,  $SD = 0.35$ ), on a scale of 1 (not effective) to 5 (very effective), as shown in Table 22.

Table 21: Inter-Institutional Collaboration: Does Your Institution Collaborate with Other Institutions? ( $N = 8$ )

| Response | f | %      |
|----------|---|--------|
| Yes      | 0 | 0.0%   |
| No       | 8 | 100.0% |

|              |          |               |
|--------------|----------|---------------|
| <b>Total</b> | <b>8</b> | <b>100.0%</b> |
|--------------|----------|---------------|

Table 22: **Rated Effectiveness of Inter-Institutional Collaboration (N = 8)**

| <b>Response</b>    | <b>f</b> | <b>%</b>      |
|--------------------|----------|---------------|
| Not effective      | 7        | 87.5%         |
| Slightly effective | 1        | 12.5%         |
| <b>Total</b>       | <b>8</b> | <b>100.0%</b> |

Key informants who identified challenges affecting collaboration among institutions cited three main issues. As Table 23 shows, the lack of a coordinating framework was the most frequently cited challenge, mentioned by five key informants (62.5%), followed by a general lack of collaboration, mentioned by two (25.0%), and a lack of funds, mentioned by one (12.5%).

Table 23: **Main Challenges Affecting Collaboration among Institutions (N = 8)**

| <b>Challenge</b>                 | <b>f</b> | <b>%</b>      |
|----------------------------------|----------|---------------|
| Lack of a coordinating framework | 5        | 62.5%         |
| Lack of collaboration            | 2        | 25.0%         |
| Lack of funds                    | 1        | 12.5%         |
| <b>Total</b>                     | <b>8</b> | <b>100.0%</b> |

### Overall Effectiveness of the Mitigation Measures

Finally, key informants gave an overall rating of how effective the mitigation measures had been in addressing the effects of urbanization on the Dundori Forest ecosystem, on a scale of 1 (not effective at all) to 5 (very effective). As Table 24 shows, seven key informants (87.5%) rated the mitigation measures overall as "not effective at all" and one (12.5%) rated them "slightly effective" ( $M = 1.12$ ,  $SD = 0.35$ ). This overall assessment is consistent with the item-level findings reported in Sections 4.4.2 through 4.4.5: mitigation measures were implemented and perceived as effective to only a small extent, had contributed little to measurable environmental outcomes, and were constrained by factors that key informants rated as major to very major across the board.

Table 24: **Overall Effectiveness of Mitigation Measures in Addressing the Effects of Urbanization (N = 8)**

| <b>Overall effectiveness rating</b> | <b>f</b> | <b>%</b>      |
|-------------------------------------|----------|---------------|
| Not effective at all                | 7        | 87.5%         |
| Slightly effective                  | 1        | 12.5%         |
| <b>Total</b>                        | <b>8</b> | <b>100.0%</b> |

## SUMMARY OF FINDINGS

Overall, the key informant findings indicate a consistent pattern across the four rating sections of the questionnaire. Mitigation measures were, on average, implemented to only a small extent (aggregate  $M = 1.54$ ) and were perceived as no more than slightly effective (aggregate  $M = 1.39$ ), and their contribution to tangible environmental outcomes in the study area was similarly limited (aggregate  $M = 1.42$ ). At the same time, the factors constraining the implementation and effectiveness of these measures were rated as major to very major constraints (aggregate  $M = 4.78$ ), most notably inadequate funding, personnel, equipment, and enforcement, weak stakeholder coordination, poverty and livelihood pressures, and inadequate monitoring and follow-up. This pattern was reinforced by the near-total absence of inter-institutional collaboration and by key informants' overall

assessment that the mitigation measures had not been effective in addressing the effects of urbanization on the Dundori Forest ecosystem.

### **Synthesis: Linking Land Use Change, Water Quality Degradation, and Mitigation Gaps**

The LULC, physicochemical, bacteriological, and perception data together describe a coherent degradation pathway. The expansion of Planted/Cultivated land and the increase in Developed cover since 1985 have progressively reduced the hydrological buffering capacity of the Dundori watershed. Even the net forest loss of 5.3% over 40 years—modest in percentage terms—reduces interception, increases direct runoff, and accelerates sediment mobilization (Guzha et al., 2018). These processes manifest directly in the observed turbidity gradient along River Maimahiu, which rises sharply and significantly from upstream to the midstream and downstream reaches regardless of season, and in the general seasonal elevation of conductivity, TDS, and dissolved oxygen during the wet season, consistent with runoff-driven mobilization of dissolved and particulate material from the increasingly cultivated and developed watershed.

The spatial pattern of bacterial contamination—clean at the forested headwaters, severely polluted through mid- and downstream reaches—maps onto the transition from forest to mixed agricultural and peri-urban land use. This is consistent with (Howland, 2023), who demonstrated that fecal coliform concentrations in Kenyan rivers increase sharply downstream of areas with inadequate sanitation, and with (Ngatia et al., 2023), who documented equivalent gradients in Ewaso Nyiro catchments. The midstream TDS peak supports inference of localized point-source contributions from the market centre itself, where inadequate solid waste management is a clearly articulated community concern: 44.3% of business respondents (valid responses to Q23) recommended improved waste collection as the single most important protective measure. The weight of evidence presented here demonstrates that urbanization-induced land use change in Dundori is producing measurable, compounding degradation of River Maimahiu's water quality—with direct implications for the households that depend on this catchment through direct abstraction or shallow groundwater.

These environmental degradation patterns are compounded by a marked shortfall in mitigation response. Despite the scale of land cover conversion and water quality decline documented above, key informants representing the institutions responsible for environmental management in the study area reported that mitigation measures had been implemented to only a small extent (aggregate  $M = 1.54$  of 5.00) and judged largely ineffective (aggregate  $M = 1.39$ ), with negligible measurable improvement in the specific environmental outcomes they were intended to address (aggregate  $M = 1.42$ ). The near-total absence of inter-institutional collaboration (100% of key informants reported no collaboration with other institutions) and the near-unanimous rating of resource, enforcement, and coordination constraints as major or very major (aggregate  $M = 4.78$ ) point to a structural rather than incidental gap: institutional capacity to respond to the documented land use and water quality changes has not kept pace with the changes themselves. Taken together, the three objectives of this study describe not only a watershed undergoing measurable urbanization-driven degradation, but also an institutional response that has, to date, been largely unable to arrest it.

## **RECOMENDATION, FINDINGS AND CONCLUSION**

### **Introduction**

This chapter presents a synthesis of the findings of the study on the effects of urbanization in Dundori Market Centre on the Dundori Forest Ecosystem. The chapter is organized according to the study objectives and provides a summary of the key findings derived from land use and land cover analysis, water quality assessment, household surveys, laboratory analyses, and key informant interviews. It further presents the conclusions drawn from the findings, highlighting the relationship between urbanization, land use change, and environmental degradation within the Dundori Forest Ecosystem. Finally, the chapter provides recommendations for sustainable environmental management, policy formulation, and future research aimed at enhancing the conservation of the forest ecosystem and the protection of River Maimahiu in the face of increasing urban development.

## Summary of major findings

The study established that urbanization around Dundori Market Centre has significantly transformed the Dundori Forest Ecosystem and adversely affected the water quality of River Maimahiu. The major findings are summarized according to the study objectives.

### **Objective One: To assess land use and land cover (LULC) changes in the Dundori Forest Ecosystem (1985–2025)**

The remote sensing analysis revealed substantial land use changes over the 40-year period. Developed (built-up) land increased (from 25 ha to 119 ha), while planted/cultivated land expanded (from 99 ha to 983 ha). Conversely, forest cover declined by **5.3%** (130 ha), and grassland experienced the greatest loss, decreasing by **67.7%** (804 ha). These findings indicate a progressive conversion of natural vegetation into agricultural and built-up land, driven primarily by urban expansion and agricultural encroachment. Household survey results supported the satellite imagery, with **81.0%** of respondents reporting noticeable land use changes over the past 10–20 years. The majority identified the conversion of forests into farmland as the dominant change, while farming expansion (55.3%) and population growth (36.2%) were perceived as the principal drivers of landscape transformation.

### **Objective Two: To assess the effects of urbanization on the water quality of River Maimahiu**

The physicochemical analysis demonstrated clear spatial and seasonal variations in water quality. Electrical conductivity and total dissolved solids (TDS) were significantly higher during the wet season and increased from upstream to downstream, reflecting increased runoff and pollutant loading from agricultural and urban activities. Dissolved oxygen concentrations were generally lower during the dry season, with upstream values falling below the recommended threshold for healthy aquatic ecosystems, indicating oxygen stress during low-flow conditions. Turbidity showed the greatest deterioration downstream, particularly during the wet season, where values substantially exceeded both WHO drinking water guidelines and Kenyan standards for domestic surface water, suggesting increased sediment transport resulting from land disturbance and soil erosion.

Microbiological analysis further confirmed deterioration in water quality downstream. Total viable counts exceeded the countable range ( $>100$  CFU/mL) at both the midstream and downstream sampling points in both seasons, while total coliform counts were substantially higher downstream than at the forested source. The highest coliform count was recorded at the midstream site during the dry season (73 CFU/mL), whereas the upstream source consistently recorded the lowest bacterial contamination. These findings indicate that microbial pollution is introduced as the river passes through agricultural and peri-urban areas rather than originating from the forest headwaters. Community perceptions corroborated these results, with **89.7%** of respondents reporting declining river water quality, mainly characterized by increased turbidity, changes in water colour, and reduced water volume. Most respondents attributed the deterioration to farming activities upstream, followed by solid waste disposal and soil erosion.

### **Summary of the Major Findings (Objective Three)**

The study found that several mitigation strategies have been implemented by government agencies and local stakeholders to reduce the impacts of urbanization on the Dundori Forest Ecosystem, although their effectiveness is constrained by weak implementation, inadequate resources, and poor institutional coordination. The Water Resources Authority (WRA) identified active involvement of Water Resource Users Associations (WRUAs) in catchment surveillance and monitoring, enforcement of the Water Act (2016), public sensitization programmes, riparian pegging and marking, and gazettement of critical ecosystems as the primary measures used to safeguard River Maimahiu and its catchment. WRA further emphasized that strengthening stakeholder participation, increasing financial support for regular monitoring, and enhancing collaboration among institutions would significantly improve watershed protection.

The Physical Planning Department reported that the Physical and Land Use Planning Act (2019) and the existing Dundori Local Physical and Land Use Development Plan provide the legal framework for guiding urban development. However, implementation remains weak due to inadequate enforcement capacity, political interference, limited manpower, and low public awareness of planning regulations. The department recommended clearer demarcation of riparian reserves, fencing of the forest boundary, abolition of the shamba system, and increased public education on land use planning and environmental conservation to minimize encroachment into the forest ecosystem.

The County Department of Environment highlighted solid waste management as a critical strategy for mitigating urbanization impacts. Existing interventions include zonation of waste collection services through licensed waste service providers, continuous community sensitization on waste management, and collaboration with other agencies during planning and infrastructure development. The department considered waste service zonation to be effective because households contribute to regular waste collection. However, limited funding, inadequate waste segregation infrastructure, and low public awareness continue to undermine effective waste management. The department recommended strengthening the Nakuru County Waste Management Act (2021), expanding community awareness programmes, and promoting stronger partnerships between the county government, private sector, and local communities.

The Kenya Forest Service (KFS) identified community-based forest management as the cornerstone of conservation efforts in Dundori Forest. Key interventions include collaboration with Community Forest Associations (CFAs), enforcement of the Forest Conservation and Management Act, civic education on forest conservation and agroforestry, implementation of the Plantation Establishment and Livelihood Improvement Scheme (PELIS), afforestation and reforestation programmes, and partnerships with Community-Based Organizations (CBOs) and other stakeholders. Despite these initiatives, KFS reported that conservation efforts are constrained by inadequate patrol equipment, limited financial resources, continued dependence of surrounding communities on forest resources for livelihoods, and institutional coordination challenges. The department recommended adopting a multi-agency approach to conservation and intensifying environmental education to strengthen community participation in forest protection.

## Overall Study Findings

The study established a strong relationship between land use and land cover change, urbanization, and environmental degradation within the Dundori Forest Ecosystem. The substantial expansion of cultivated land and built-up areas has reduced vegetation cover, increased surface runoff, accelerated soil erosion, and enhanced the transport of sediments, nutrients, and microbial contaminants into River Maimahu. Consequently, downstream sections of the river exhibited poorer physicochemical and microbiological water quality than the upstream forested section, demonstrating the cumulative impacts of agricultural expansion, settlement growth, and inadequate waste management on the catchment.

The convergence of remote sensing analysis, laboratory findings, household survey responses, and key informant interviews provides compelling evidence that unplanned urbanization and agricultural encroachment are the primary drivers of ecosystem degradation in the Dundori catchment. Although several mitigation strategies are currently being implemented—including enforcement of environmental legislation, land use planning, riparian protection, solid waste management, afforestation and reforestation programmes, community participation through Community Forest Associations (CFAs) and Water Resource Users Associations (WRUAs), public awareness campaigns, and inter-agency collaboration—their effectiveness remains constrained by weak enforcement, inadequate funding, insufficient technical and human capacity, political interference, limited public awareness, and poor institutional coordination.

Overall, the study concludes that the sustainable management of the Dundori Forest Ecosystem requires an integrated and multi-sectoral approach that strengthens policy implementation, enhances coordination among government institutions and local stakeholders, promotes sustainable land use planning and watershed conservation, improves agricultural and solid waste management practices, and empowers local communities to

actively participate in environmental stewardship. Such an approach is essential for safeguarding forest resources, improving the ecological integrity of River Maimahiu, and ensuring the long-term sustainability of ecosystem services that support livelihoods and socio-economic development in the Dundori catchment.

## CONCLUSIONS

The study concludes that urbanization has significantly transformed the Dundori Forest Ecosystem over the past four decades, resulting in substantial changes in land use and land cover. Remote sensing analysis revealed a marked increase in cultivated land and built-up areas at the expense of forest and grassland, demonstrating that agricultural expansion and settlement growth are the dominant drivers of landscape transformation. Household perceptions corroborated these findings, confirming that local communities have observed increasing conversion of forest land into agricultural and mixed-use developments. These changes indicate that urban expansion around Dundori Market Centre has progressively reduced the ecological integrity of the forest ecosystem.

The study further concludes that land use and land cover changes have negatively affected the water quality of River Maimahiu. Physicochemical parameters, including electrical conductivity, total dissolved solids, dissolved oxygen, and turbidity, exhibited significant spatial and seasonal variations associated with increasing human activities. Water quality deteriorated from upstream to downstream, with downstream sections recording higher turbidity, conductivity, dissolved solids, and microbial contamination. The presence of elevated total coliform counts and high total viable bacterial counts in the midstream and downstream sections confirms that urbanization, agricultural activities, poor sanitation, and inadequate waste management have contributed to the degradation of the river's water quality. Consequently, River Maimahiu is increasingly vulnerable to pollution, posing risks to both ecosystem health and communities that depend on its water resources.

The study also concludes that although various mitigation strategies are currently being implemented, they have not been sufficient to effectively address the impacts of urbanization on the Dundori Forest Ecosystem. Existing interventions—including environmental legislation, physical land use planning, riparian protection, afforestation and reforestation programmes, community participation through Community Forest Associations (CFAs) and Water Resource Users Associations (WRUAs), solid waste management initiatives, and institutional collaboration—provide an important foundation for environmental conservation. However, their effectiveness is constrained by weak enforcement of environmental regulations, inadequate funding, limited technical and human capacity, political interference, poor public awareness, and weak coordination among responsible institutions.

Overall, the study concludes that unplanned urbanization and agricultural expansion are the principal drivers of environmental degradation within the Dundori Forest Ecosystem. The findings demonstrate a clear linkage between land use change and declining water quality, confirming that continued encroachment into forest and riparian areas undermines ecosystem functions and threatens the sustainability of River Maimahiu. Addressing these challenges requires an integrated and participatory management approach that strengthens policy implementation, promotes sustainable land use planning, enhances watershed conservation, improves solid waste management, and fosters effective collaboration among government agencies, local communities, and other stakeholders. Such an approach is essential for conserving the Dundori Forest Ecosystem while supporting sustainable socio-economic development in the area.

## RECOMMENDATIONS

### Strengthen Land Use Planning and Control

The County Government of Nakuru should strengthen the implementation and enforcement of the Physical and Land Use Planning Act, 2019, and the Dundori Local Physical and Land Use Development Plan to regulate settlement expansion around the Dundori Forest Ecosystem. All developments should be subjected to planning approvals and Environmental Impact Assessments (EIAs), while encroachment into forest and riparian areas should be prevented through regular inspections and enforcement. Clear demarcation and protection of forest

boundaries and riparian reserves should be undertaken to minimize illegal settlements and agricultural encroachment.

### **Promote Sustainable Agricultural Practices**

The County Department of Agriculture, in collaboration with Kenya Forest Service (KFS) and the Water Resources Authority (WRA), should promote climate-smart and sustainable farming practices that minimize environmental degradation. Farmers should be trained on soil and water conservation techniques, controlled use of fertilizers and pesticides, contour farming, agroforestry, and the establishment of vegetative buffer strips along River Maimahiu to reduce sediment and nutrient runoff into the river.

### **Strengthen Water Resource Protection**

The Water Resources Authority should enhance routine water quality monitoring of River Maimahiu by establishing permanent monitoring stations and conducting regular physicochemical and microbiological assessments. Riparian areas should be clearly pegged and protected in accordance with the Water Act, 2016, while illegal abstractions, cultivation, and grazing along riverbanks should be strictly controlled. Water Resource Users Associations (WRUAs) should be adequately funded and empowered to support catchment surveillance and community-based monitoring.

### **Improve Solid Waste Management**

The County Government should strengthen solid waste management systems within Dundori Market Centre by providing adequate waste collection infrastructure, establishing waste segregation facilities, and increasing the frequency of waste collection services. The ongoing review of the Nakuru County Waste Management Act should incorporate emerging waste management approaches such as segregation at source, recycling, and Extended Producer Responsibility (EPR). Continuous public awareness campaigns should also be undertaken to promote proper waste disposal and discourage dumping into forests and watercourses.

### **Enhance Forest Conservation and Restoration**

The Kenya Forest Service should intensify afforestation and reforestation programmes using indigenous tree species to restore degraded forest areas and improve watershed functions. Community Forest Associations (CFAs), Community-Based Organizations (CBOs), schools, and local residents should be actively involved in tree planting, forest monitoring, and conservation initiatives. The Plantation Establishment and Livelihood Improvement Scheme (PELIS) should be continuously monitored to ensure that it supports forest restoration without encouraging encroachment.

### **Strengthen Institutional Coordination**

There is a need to establish an integrated multi-agency environmental management framework involving the County Government, KFS, WRA, NEMA, the Physical Planning Department, the Department of Agriculture, WRUAs, CFAs, and local communities. Regular joint planning meetings, coordinated enforcement operations, and shared environmental monitoring programmes should be institutionalized to improve coordination and reduce duplication of roles in managing the Dundori Forest Ecosystem.

### **Increase Community Participation and Environmental Awareness**

Environmental education and public awareness programmes should be strengthened to improve community understanding of sustainable land use planning, forest conservation, water resource protection, and waste management. Local communities should be empowered to participate actively in conservation activities through Community Forest Associations, Water Resource Users Associations, youth groups, women's groups, and Community-Based Organizations. Community participation should also be supported through alternative livelihood programmes that reduce dependence on forest resources.

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## **Strengthen Institutional Capacity and Financing**

Both national and county governments should allocate adequate financial, technical, and human resources to institutions responsible for environmental management. Increased funding is required for routine monitoring, enforcement, environmental education, patrols, equipment acquisition, and implementation of conservation programmes. Capacity-building programmes should also be conducted for planning officers, environmental inspectors, and enforcement officers to improve compliance with environmental and planning regulations.

## **Policy Recommendations**

Based on the study findings, the following policy recommendations are proposed to strengthen sustainable management of the Dundori Forest Ecosystem and minimize the impacts of urbanization.

### **Review and Strengthen Physical Land Use Planning Policies**

The County Government of Nakuru should review and fully implement the Dundori Local Physical and Land Use Development Plan in accordance with the Physical and Land Use Planning Act, 2019. The plan should incorporate forest conservation, riparian protection, ecological buffer zones, and watershed management as integral planning components. Development approvals should strictly comply with approved zoning regulations to prevent further encroachment into environmentally sensitive areas.

### **Strengthen Enforcement of Environmental Legislation**

National and county governments should strengthen enforcement of existing environmental laws, including the Environmental Management and Coordination Act (EMCA), 1999 (Revised 2015), the Forest Conservation and Management Act, 2016, and the Water Act, 2016. Regular compliance monitoring, environmental inspections, and stricter penalties for illegal logging, riparian encroachment, waste dumping, and unauthorized developments should be institutionalized.

### **Establish an Integrated Catchment Management Policy Framework**

The Government should establish a coordinated catchment management framework that integrates land use planning, forest conservation, water resource management, and agricultural development. This framework should clearly define the roles of the Kenya Forest Service (KFS), Water Resources Authority (WRA), National Environment Management Authority (NEMA), County Government of Nakuru, Community Forest Associations (CFAs), Water Resource Users Associations (WRUAs), and other stakeholders to improve coordination and eliminate overlapping mandates.

### **Institutionalize Riparian Protection and Watershed Conservation**

A county policy should be developed to ensure the mandatory demarcation, gazettement, restoration, and protection of all riparian reserves within the Dundori catchment. Activities such as cultivation, settlement, grazing, and infrastructure development within protected riparian zones should be prohibited and consistently enforced to safeguard River Maimahiu and its tributaries.

### **Strengthen Sustainable Solid Waste Management Policy**

The ongoing review of the **Nakuru County Waste Management Act, 2021** should incorporate mandatory waste segregation at source, recycling programmes, Extended Producer Responsibility (EPR), and improved waste collection systems in rapidly urbanizing market centres such as Dundori. The County Government should also require the inclusion of waste management infrastructure in all new urban development projects.

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## **Mainstream Environmental Conservation into Urban Development**

Environmental sustainability should be mainstreamed into all urban development policies and infrastructure projects. Environmental Impact Assessments (EIAs) and Strategic Environmental Assessments (SEAs) should be rigorously undertaken before approval of major public and private developments. Planning approvals should integrate green infrastructure, urban green spaces, stormwater management systems, and ecological buffers to reduce environmental degradation.

### **Promote Community-Based Natural Resource Governance**

Government policies should strengthen and institutionalize community participation in environmental management by supporting Community Forest Associations (CFAs), Water Resource Users Associations (WRUAs), Community-Based Organizations (CBOs), and local environmental committees. These groups should be provided with adequate legal recognition, technical support, and financial resources to actively participate in forest conservation, watershed protection, and environmental monitoring.

### **Enhance Financing for Ecosystem Conservation**

National and county governments should establish sustainable financing mechanisms for conservation programmes through increased budgetary allocations, payment for ecosystem services (PES), climate finance, public-private partnerships, and donor-supported conservation initiatives. Dedicated funding should support afforestation, catchment restoration, environmental monitoring, enforcement, and community livelihood programmes that reduce pressure on forest resources.

### **Strengthen Environmental Monitoring and Data Management**

A comprehensive environmental monitoring policy should be developed to support continuous monitoring of land use changes, forest cover, biodiversity, and water quality within the Dundori Forest Ecosystem. Government agencies should establish a centralized environmental database using Geographic Information Systems (GIS), remote sensing, and routine field monitoring to facilitate evidence-based decision-making and early detection of environmental degradation.

### **Promote Climate-Resilient Landscape Management**

The County Government should integrate climate change adaptation and ecosystem-based approaches into county spatial planning and environmental policies. This should include restoration of degraded forests and wetlands, promotion of agroforestry, conservation agriculture, sustainable watershed management, and protection of ecosystem services to enhance resilience to climate change while supporting sustainable urban development.

### **Recommendations for further Research**

1. Evaluate seasonal variations in additional water quality parameters such as heavy metals, nutrient loading, pesticides, and emerging pollutants.
2. Examine the socio-economic impacts of urbanization on household livelihoods and ecosystem service provision within the Dundori catchment.
3. Conduct predictive land use change modelling to forecast future urban expansion scenarios and support evidence-based planning and conservation interventions

### **Declaration**

I do by declare that:

1. I do This thesis is my original work and to the best of my knowledge it has not been presented for the award of a degree in any university or college.
2. That the work has not in-cooperated material from other works or a paraphrase of such material without due and appropriate acknowledgement
3. That the work has been subjected to processes of anti-plagiarism and has met Kabarak University 15% similarity index threshold

understand that issues of academic integrity are paramount and therefore I may be suspended or expelled from the University or my degree may be recalled for academic dishonesty or any other related academic malpractices

Signature: ..... Date: .....



**Kigen Dorcas Jephchirchir**

## RECOMMENDATION

This thesis has been submitted for examination with our recommendation as University supervisors.



Signature: ..... Date: .....

For : Dr. Eliud Garry Michura(PhD)



Signature: .....

Date: .....

Dr. Mary Wahu Kuria(PhD)

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## Dedication

I dedicate this work to all individuals and communities committed to the protection, restoration, and sustainable management of forest ecosystems. May it serve as a contribution toward providing knowledge and guidance to those who strive to safeguard our forests and rivers for present and future generations.

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