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School of Architecture and Built Environment

MSc in Geo-Information Science for Environment and Sustainable Development

Thesis Title:

Evaluating trends of urban growth and its impact on environmental sustainability in Kigali peri-urban areas: A probe from Masaka Sector.

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Declaration

I, hereby declare that this thesis entitled **" Evaluating trends of urban growth and its impact on environmental sustainability in Kigali peri-urban areas: A probe from Masaka Sector"** is entirely my original work. All the research findings, analysis, and conclusions presented in this document are the result of my independent scholarly investigation conducted under the guidance of my thesis supervisors, **Dr. Uwayezu Ernest and Ass. Prof. Theophile Niyonzima.**

I affirm that all sources used in this thesis have been duly acknowledged and cited in accordance with academic conventions and ethical standards. Any assistance received from individuals, organizations, or sources external to this research has been appropriately acknowledged.

Furthermore, I declare that this thesis has not been submitted for any academic qualification or degree to any other institution. Any material previously published or submitted by me or others is appropriately referenced in this thesis.

I take full responsibility for the accuracy, integrity, and originality of the content presented in this thesis. Any errors, omissions, or discrepancies are entirely my own.

Signed:

…… **Date: March/2025**

Approval

This thesis is entitled **"Evaluating trends of urban growth and its impact on environmental sustainability in Kigali peri-urban areas: A probe from Masaka Sector"** done by the student Salomon NSHIMIYIMANA has been done under my guidance and supervision.

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Abstract

Urban growth driven by rapid urbanization is a defining feature of our era. As global populations become increasingly urbanized, with more people moving from rural areas to cities, or moving from city center to per-urban areas, this dynamic continues to reshape our world. This growth can have both positive and negative effects on environmental sustainability, if not well managed and it can lead to environmental sustainability challenges. Despite the critical nature of these issues, there is a lack of focused research on how urban growth is impacting the environmental sustainability in per-urban areas of Kigali. This research aims to evaluate spatial temporal dynamics of land use land cover change, identify environmental sustainability challenges driven by the growth, and propose practical actions for enhancing environmental sustainability in Masaka sector, one of the per-urban area of Kigali city which is experiencing rapid growth. To achieve these objectives, various methods and techniques were used to assess the trends of that growth and their coupled impacts on the living conditions of urban dwellers, GIS Software were used to analyze land use and land cover change from 2008 to 2023. Additionally, sampling techniques, interviews with stakeholders, household survey of the sampled households and field observations on the spatial transformation were used. Significant findings reveal a marked expansion of built-up areas coupled accompanied by a reduction in vegetation and forest cover. Research statistics indicate that the forest cover declined from 13.38% in 2008 to 9.13% in 2023, while built-up areas expanded from 11.22% in 2008 to 32.08% in 2023 meaning that, the triplet over the 15years ago. Agriculture also decreased from 62.29% in 2008 to 43.5% in 2023. This land conversion and expansion present a significant environmental sustainability challenges, including insufficient share of green spaces, poor solid waste collection and its management, inadequate drainage systems that are causing wetland pollution, and the development of informal areas. The research findings highlight the urgent need for comprehensive urban planning strategies that prioritize environmental conservation and sustainable development in Masaka Sector. Addressing these challenges require concerted efforts from policymakers, urban planners, and local communities to enforce regulations and promote environmental sustainability practices.

Key words: *GIS, Urbanization, Environmental Sustainability*

List of Acronyms

CoK: City of Kigali

GIS: Geographical Information System

GPS: Global Positioning System

LULC: Land use land cover

MoE: Ministry of Environment

MININFRA: Ministry of Infrastructure

NISR: National Institute for Statistics of Rwanda

NLA: National Land Authority

NLUDMP: National Land Use and Development Master Plan

NST1: Nation Strategic for Transformation

OSM: Open Street Mapping

P3B: Forest zone

P3C: Steep Slopes (> 30%)

RCMRD: Regional Centre for Mapping of Resources for Development

RHA: Rwanda Housing Authority

REMA: Rwanda Environment Management Agency

SDG: Sustainable Development Goals

UAS: Unmanned Aircraft Systems

UN: United Nations

UN-Habitat: United Nations Human Settlements Programme

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Chapter 1. Introduction

Urban growth, derived from the concept of urbanization, refers to the expansion and increase in population within urban areas. Urbanization, a process shaping human societies for centuries, has accelerated dramatically in the 21st century. As more people move to cities seeking for better opportunities, amenities, and lifestyles, urban areas worldwide are expanding at an unprecedented rate (Zipperer et al., 2020).

The percentage of people living in cities globally has increased significantly and is anticipated to keep rising in the coming years (Nduwayezu et al., 2016). The global population growth trend indicates a consistent rise in urban populations from 1950 to 2025, followed by a projected slowdown from 2025 to 2050. The spatial pattern of urbanization has shifted from the Global North to the Global South.

Currently, cities in Asia and Africa are growing faster than those in other regions. Future estimates indicate that African cities will lead globally in growth rates from 2015 to 2050. Presently, over half of the world's population lives in urban areas, signifying a significant shift from rural to urban living. By 2050, it is projected that 70% of the global population will reside in cities (Kundu & Pandey, 2020).

Urban growth patterns are predominantly observed in developing countries, predicting that by 2030, cities in Asia, Africa, and Latin America will hold 80% of the global urban population. According to Hauer et al. (2018), urban expansion across the globe, spanning from north to South and East to West, reflects a culture prioritizing short-term economic gains and often unchecked consumption and production practices that jeopardize environmental sustainability (Habitat, 2016).

Urban growth often leads to significant changes in land use, such as deforestation and habitat loss, and can put a strain on natural resources like freshwater(Hassan & Elhassan, 2020). It also contributes to environmental challenges, including increased pollution of natural ecosystem and waste production, which impact both human health and biodiversity. This migration are caused by

different drivers such as socio-economic, political and environment but also these pose significant challenges to environmental sustainability (James, 2024).

The growth of these cities in Asia, Africa and Latin America are affecting nearby sensitive ecosystems, including wetlands, forests, and mountain regions, while also increasing the demand for resources, potentially leading to over-exploitation. However, the rapid pace of urban growth presents a unique opportunity to develop more sustainable, innovative, and equitable towns and cities (Bista, 2024).With the global acceleration of urbanization, it is crucial to assess the patterns of urban expansion and comprehend its effects on environmental sustainability.

Environmental sustainability is a crucial concept that focuses on maintaining the quality and longevity of natural resources and ecosystems. It involves the responsible management of resources to ensure that current development does not compromise the ability of future generations to meet their needs. This concept includes environmental sustainability challenges encompass a range of issues from rapid and often unplanned urban expansion. Urbanization typically leads to increased consumption of natural resources, heightened waste production, and significant alterations to land use, resulting in deforestation, habitat destruction, and biodiversity loss (Arfanuzzaman & Dahiya, 2019).

Measuring these impacts driven by the urbanization growth, it necessitates to have the indicators of environmental sustainability. Key indicators of environmental sustainability include resource efficiency, pollution levels, biodiversity health, land use the management of green spaces sharing and natural areas, and waste disposal and waste management which evaluates how urban areas handle waste generation and disposal. These indicators provide a comprehensive measure of the environmental impact of human activities and are essential for assessing the sustainability of urban growth (Yang & Khan, 2022).

Urban growth significantly impacts environmental sustainability through the transformation of natural landscapes into urban areas which affects land use patterns, reducing green spaces, open spaces, urban forest and altering local climates whereby it pollutes wetlands and other water bodies. Additionally, rapid urbanization can overwhelm waste management systems, leading to improper disposal and environmental hazards. Understanding these impacts is essential for

developing strategies to mitigate the negative effects of urban growth on environmental sustainability (Shao et al., 2021).

Recent years have seen the rapid urbanization and recognized as a catalyst for sustainable development, primarily due to its significant contributions to modernization, economic growth, and overall progress. The expansion and prosperity of urban areas are frequently regarded as indicators of human advancement. The transformation of natural landscapes into dense infrastructural clusters, the increased demand for services and resources, and the frequently unplanned nature of urban sprawl have prompted critical inquiries regarding the sustainability of this form of development (Chan & Chan, 2022).

Urbanization and environmental degradation are inherently interconnected, cities have the potential to significantly contribute to decoupling economic development from resource consumption and environmental impacts, while striving to achieve a more balanced approach to social, environmental, and economic objectives (de Roo & Miller, 2017). Resource-efficient cities integrate higher productivity and innovation with reduced costs and environmental footprints, simultaneously providing financial savings and enhanced sustainability.

This development has resulted in significant environmental challenges due to the high levels of pollutants generated by human activities. These environmental challenges are escalating globally, leading to natural resource depletion and numerous crises that deeply concern from environmentalists. It has been established that awareness of environmental issues is crucial for effective environmental management, urban development, and construction engineering (Kalhor & Mahdisoltani, 2015).

According to the United Nations, East Africa is expected to experience urban population growth rates significantly higher than the African average by 2030, with cities like Dar es Salaam, Kampala, Nairobi, and Antananarivo projected to expand rapidly. Additionally, Addis Ababa is already recognized among the 31 fastest-growing cities and urban areas (Li et al., 2022).

In Rwanda, rapid and uneven urbanization, combined with limited land availability, presents numerous challenges. These challenges include the rise of unplanned urban areas, a shortage of adequate housing, environmental degradation, and the creation of unsustainable cities (Duranton & Puga, 2023). A significant environmental protection issue is the imbalance between the growing population and the declining natural resources. This ongoing degradation is visible through extensive deforestation, loss of biodiversity, erosion and landslides, waterway pollution, and the deterioration of fragile ecosystems like swamps and wetlands (Bondinuba & Stephens, 2018).

Urbanization is primarily concentrated in Kigali, the capital city, where the urban population grows at a rapid annual rate of 4.5%, far surpassing the global average of 1.8%. Currently, nearly half of Rwanda's urban population resides in Kigali, which experiences an annual population growth rate of 9%(MoE, 2020). To mitigate the over-concentration of growth in Kigali and utilize urbanization as a catalyst for Rwanda’s economic development, the Government set a national target of achieving 35% urbanization by 2024 which is now is at 27.9% (NISR, 2024). Additionally, the Government has identified eight secondary cities namely Huye, Nyagatare, Rubavu, Musanze, Kirehe, Kayonza, Karongi and Rusizi and three satellite cities namely Rwamagana, Bugesera and Muhanga as growth pole focal for future growth and development (Rwanda & GGGI, 2015).

1.1. Problem statement

The Kigali city continued to experiencing swift population growth and expanding spatially, especially in the outskirts and surrounding regions. This rapid expansion presents considerable challenges to environmental sustainability. In Kigali, the ongoing urbanization and growth are driven by socioeconomic and demographic trends like population increase, industrialization, land consumption, and infrastructure development, all of which significantly influence the city's expansion. The periphery and fringe zones of Kigali have witnessed substantial expansion, especially in the core districts of Nyarugenge, Kicukiro, and Gasabo, marked by significant growth in built-up areas. Similarly, there has been urban expansion in the Southern, Eastern, Northern, and Western parts of the City of Kigali, where development is ongoing without adequate consideration for environmental sustainability (Cottyn, 2020).

The rapid development of the City of Kigali has led to several negative impacts on environmental sustainability. These include deforestation, habitat loss, air and water pollution, increased waste generation, water scarcity, high energy consumption, and greenhouse gas emissions. Other challenges include urban sprawl, informal settlements, land use changes, ecosystem degradation, the urban heat island effect, traffic congestion, and inadequate green spaces. Additionally, poor drainage systems, housing development in high-risk zones, and encroachment into wetlands and protected areas further threaten environmental sustainability (Huang & Cantada, 2019).

To address these challenges, the government of Rwanda has implemented measures aimed at promoting environmental sustainability in the city of Kigali. These include to waste management, promoting renewable energy sources, and development of green spaces within the city, urban built environment and urban physical infrastructure as detailed in the National urbanization policies (Mininfra, 2015). Documents such as the National Strategy for Transformation (NST1), the Kigali Master Plan, and the National Land Use Development Plan (NLUDP) 2020-2050 emphasize on the protection of environmental sensitive areas, including wetlands and forests, prohibition of construction on slopes exceeding 30%, waste management, drainage system development, forest conservation, tree plantation, green space promotion, and mitigation of urban heat islands (MoE, 2020).

Despite these efforts, studies indicate that Kigali continues to face environmental sustainability challenges. Although some researchers note that Kigali is one of the cleanest cities in Africa due to consistent urban policies (Festus et al., 2020). However, the city still faces environmental sustainability challenges, and no studies have explored whether the implementation of recent policies, regulations, and strategies has mitigated these problems in per-urban areas.

For instance, Baffoe et al. (2020) highlight the issues related to uncontrolled urbanization poses several challenges, such as poor housing conditions and informal settlement development, which undermine the achievement of the Sustainable Development Goals by 2030. In his studies, Anim et al. (2021) pointed out the problem of housing construction on high slope areas and the related risks on the lives of people, without leaving out the issues related to loss urban forest, loss green and open spaces, issues of drainage system, informality areas development and waste management

issues. These concerns raise questions about the effectiveness of urban sustainability initiatives in Kigali's peri-urban areas.

Although several studies have explored and examined different aspects of urbanization, there is a notable lack of comprehensive reports addressing environmental sustainability in Masaka Sector. While urban expansion continues in this region, its environmental consequences remain understudied. Therefore, this study aims to bridge that gap by evaluating the environmental sustainability impacts from the trends of urban over the past 15 years, meaning from 2008 to 2023, and providing insights and recommendations for sustainable urban development in the sector.

1.2. Research Motivation

The rapid urban growth in Kigali's peri-urban areas, particularly in the Masaka Sector, has raised significant concerns regarding its environmental sustainability. As urbanization accelerates, it is crucial to understand its impacts on environment to ensure sustainable development. Due to the absence of thorough reviews that comprehensively address the concern of environmental sustainability, this research is motivated by the need to evaluate these environmental impacts systematically, focusing on how the urban growth contribute to environmental sustainability challenges. By probing the Masaka Sector, this study aims to provide valuable insights and recommendations for policymakers and urban planners to foster more sustainable urban growth practices, ensuring that development meets current needs without compromising the ability of future generations to meet their own.

1.3. Research Objectives

1.3.1. Main Objective

The main objective of this study is to assess the spatial-temporal dynamics of urban growth in Maska and its impact on surrounding environment.

1.3.2. Specific Research objectives

- To evaluate spatial temporal dynamics of land use/land cover changes induced by urban growth in Masaka Sector the since 2008 up to 2023,

- To identify the environmental sustainability challenges driven by urban growth in Masaka Sector,
- To propose practical actions that policymakers and urban planners may apply to enhance environmental sustainability in Masaka sector.

1.4. Research Questions

- What are the key trends in land use and land cover changes in Masaka Sector from 2008 to 2023, and how have these changes been influenced by urban growth?
- What specific environmental sustainability challenges have arisen due to urban growth in Masaka Sector during the evaluated period?
- How can policymakers and urban planners effectively address the environmental sustainability challenges identified in Masaka Sector?
- What practical actions or strategies can be implemented to promote sustainable urban development in Masaka Sector, ensuring a balance between growth and environmental preservation?

1.5. Scope of the Research

The scope of this research encompasses a comprehensive evaluation of the environmental sustainability impacts resulting from urban growth trends in the Masaka Sector, a peri-urban area of Kigali. This study will analyze both the formal and informal developments within the sector, focusing on aspects such as land use changes, availability of drainage system in managing stormwater, solid waste management, loss of urban forest open space and green spaces, adherence to zoning regulations, and the implementation of the master plan. It will investigate the extent of environmental degradation specifically on wetland pollution from the drainage system, waste management issues and green space reduction. The research involved mapping and spatial analysis, field observations, and interviews with key stakeholders, including residents, local authorities, and urban planners. By providing a detailed assessment of the current situation, this study aims to offer actionable recommendations to mitigate adverse environmental impacts and promote sustainable urban development practices in Kigali's peri-urban areas

1.6. Research Matrix

The objectives of the research will be achieved, and the research questions will be addressed through the use of appropriate research methods. The presentation of the results of this research will be framed in tables, maps, and graphs, as well as in written form.

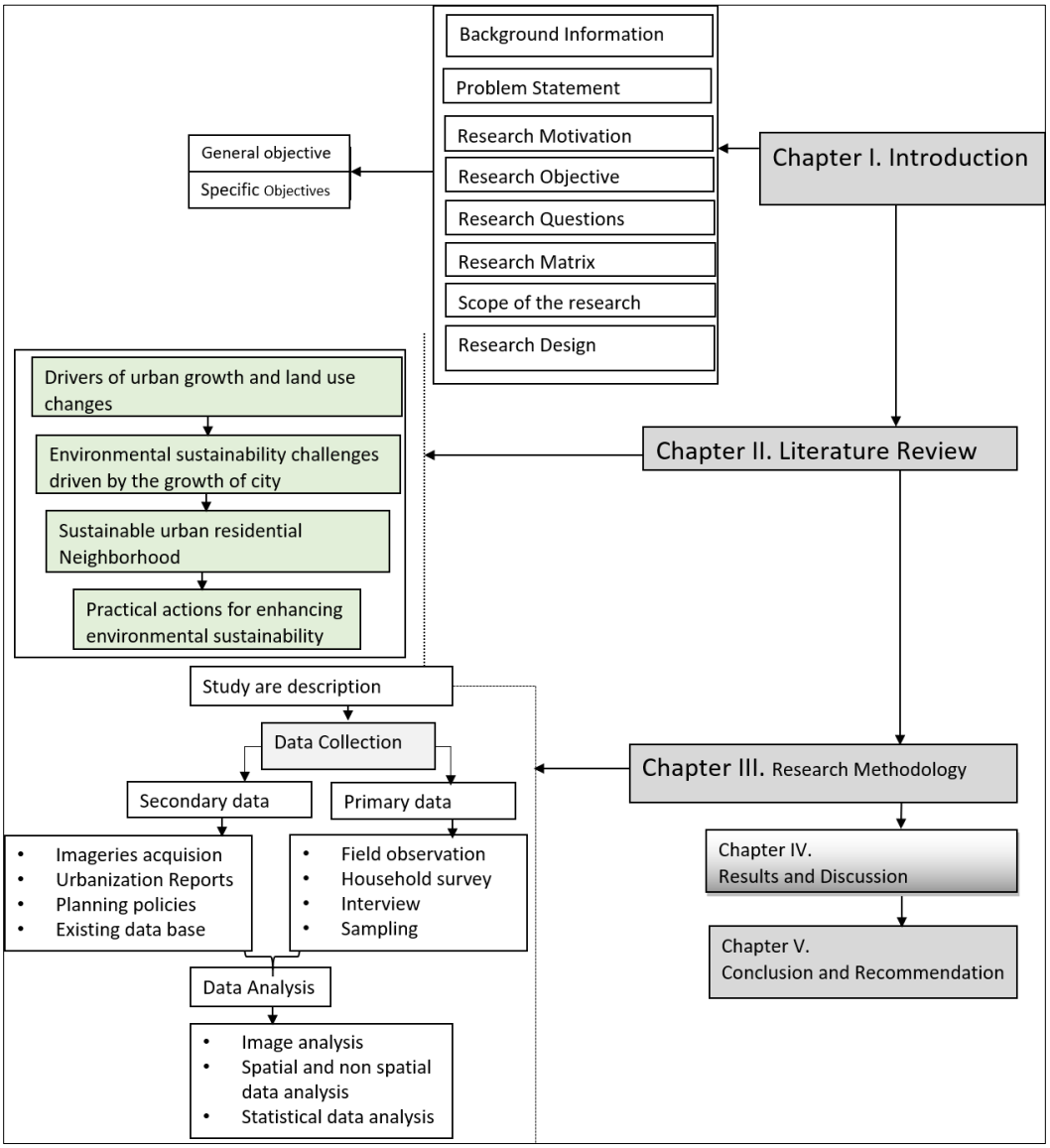
Table 1: Research Matrix

Specific Objectives	Research Questions	Data Source and Methods	Expected Result
1. To evaluate spatial temporal trends of land use/land cover changes induced by urban growth in Masaka Sector since 2008 up to 2023	1.1. How has land use and land cover in Masaka Sector changed due to 2008 to 2023, and how have these changes been influenced by urban growth?	• Satellite imagery analysis (2008-2023) from Maxar and Rwanda space agency • Image analysis and classification	• Major land use/cover changes in Masaka sector • Land use cover matrix
2. To identify the environmental sustainability challenges driven by urban growth in Masaka Sector.	2.1. What specific environmental sustainability challenges have arisen due to urban growth in Masaka Sector during the evaluated period?	• Field surveys • Field observations • Interviews with local residents and official's Environmental sustainability challenges • Environmental impact reports	• Environmental challenges resulted by urban growth
3. To propose practical actions that policymakers and urban planners may apply to enhance environmental sustainability in Masaka Sector.	3.1. How can policymakers and urban planners effectively address the environmental sustainability challenges identified in Masaka Sector?	• Policy analysis - Expert consultations	• Strategies for promoting urban development which leads to sustainability of environment in Masaka sector • Practical action and strategies for environmental preservation in Masaka sector
	3.2. What practical actions or strategies can be implemented to promote sustainable urban development in Masaka Sector, ensuring a balance between growth and environmental preservation?	• Review of best practices in Environmental sustainability	

1.7. Research Design

The research design details a cohesive strategy that connects conceptual research questions with practical empirical investigation. It precisely defines the required data and outlines the methods for data collection and analysis. The design will be presented in a structured format, including sections such as General Introduction, Literature Review, Methodology, Results and Discussion, Conclusion, and Recommendations, each contributing to a comprehensive and organized research document.

Figure 1: Research design



Chapter 2. Literature review

2.1. Introduction

Urban growth has significant implications for environmental sustainability, posing complex challenges that affect ecosystems and human well-being. As cities and towns expand an increasingly defining feature of the 21st century the pressures from rising urban populations and development intensify, leading to greater demands for land, energy, and infrastructure. This often results in environmental degradation, undermining ecological balance and the responsible use of resources.

2.2. Drivers of urban growth and land use changes

Urban growth and land use changes are influenced by a complex interplay of various drivers that shape the spatial dynamics of cities and their surrounding areas. One of the primary drivers is population growth**,** which often results from natural increase and migration (Bibri et al., 2020). As people flock to urban areas in search of better employment opportunities, improved living standards, and access to essential services, cities expand to accommodate the rising population. This influx can lead to increased demand for housing, infrastructure, and public services, prompting rapid urban development and the conversion of rural land into urban areas (Li et al., 2021).

Economic factors also play a critical role in urban growth. The transition from agrarian economies to industrial and service-based economies drives significant changes in land use patterns. Economic development often leads to increased investments in infrastructure, such as transportation networks, utilities, and communication systems, which facilitate urban expansion (Wu et al., 2021). Additionally, the growth of industries and commercial activities attracts more residents, creating a cycle of growth that can lead to the transformation of previously undeveloped land into residential, commercial, or industrial zones. This shift in land use reflects the changing economic landscape and the needs of an urbanizing population.

Social and cultural influences are equally important in shaping urban growth and land use. Changes in societal values, lifestyles, and preferences can significantly impact how land is utilized and

developed. For instance, the desire for more sustainable and livable environments has led to the emergence of urban planning concepts such as mixed-use development, green spaces, and pedestrian-friendly infrastructure (Addae & Oppelt, 2019). Moreover, cultural dynamics, including the integration of diverse communities, can influence land use decisions, promoting inclusive and vibrant urban environments. As cities evolve, the demand for spaces that reflect cultural identities and promote social interactions becomes increasingly significant.

Environmental factors also drive urban growth and land use changes. Climate change, natural disasters, and the availability of natural resources can alter patterns of urbanization. For instance, areas prone to flooding or extreme weather may see shifts in land use as communities adapt to changing environmental conditions (Dadashpoor et al., 2019). Additionally, the push for sustainable development practices emphasizes the need for green spaces, conservation of natural resources, and resilience to climate impacts, leading to innovative approaches in urban planning and land management. Together, these drivers create a dynamic and often challenging landscape for urban growth, necessitating effective policies and strategies to manage land use changes sustainably.

2.2.1 Socio-economic Factors

Economic development often acts as a catalyst for urban growth. Job opportunities, higher wages, and better living standards attract people from rural areas to urban centers. This migration leads to the expansion of urban areas into peripheral regions. In his Study Xu et al. (2020) highlights the strong correlation between economic growth and urbanization in developing countries. As cities become hubs of economic activities, they draw in a workforce seeking improved livelihoods, which in turn spurs further economic activities and infrastructure development, creating a cycle of growth and expansion.

Economic factors are also influenced by globalization and technological advancements. As industries grow and new businesses emerge, the demand for urban land increases, pushing cities outward, economic and social development are significant drivers of urban growth. We hypothesized that these socioeconomic elements would play a critical role and collectively influence urban expansion. To represent these socioeconomic factors, we selected two categories

of variables: social factors, which included overall population (Li et al., 2018). And urban population density, and economic factors, which included GDP density, primary industry added value density, secondary industry added value density and tertiary industry added value density.

Moreover, economic disparities between urban and rural areas further exacerbate urban migration. Urban centers typically offer better educational facilities, healthcare services, and social amenities compared to rural regions (Cattaneo et al., 2022). This disparity not only fuels migration but also shapes the development patterns in peripheral areas, where new residents often settle in informal or poorly planned neighborhoods. These areas, lacking in sustainable planning and infrastructure, often become hotspots for environmental degradation, highlighting the need for integrated economic and environmental planning (Jończy et al., 2021).

2.2.2 Demographic Factors

Population growth, both natural and through migration, is a significant driver of urban expansion. As urban populations increase, the demand for housing, infrastructure, and services extends the boundaries of cities. According to the Smit (2021), urban areas in sub-Saharan Africa are experiencing rapid growth on a global scale, primarily due to elevated fertility rates and migration from rural to urban areas. This influx is driven by the pursuit of improved healthcare, education, and employment opportunities that are often lacking in rural settings, thereby contributing to the expansion of urban sprawl into peripheral regions.

High population growth rates in urban areas place immense pressure on land and resources. As cities expand to accommodate growing populations, they often encroach on agricultural lands, forests, and other natural habitats (Kumar, 2024). This urban expansion not only contributes to environmental degradation but also poses threats to food security and biodiversity. Many regions have undergone substantial land use changes driven by population pressures, which have led to environmental issues such as deforestation and soil erosion.

The demographic shift from rural to urban areas also alters the social fabric and economic dynamics of peripheral regions, the new urban residents often bring different lifestyles and consumption patterns, which can lead to increased resource use and waste generation (Ravetz et

al., 2012).Inadequate infrastructure in rapidly growing peripheral neighborhoods often exacerbates these issues, leading to pollution and other environmental problems. Sustainable urban planning must consider these demographic trends to mitigate adverse environmental impacts and promote resilient, livable communities.

2.2.3 Policies and Planning regulations factors

Government policies and urban planning strategies play a critical role in shaping urban growth, zoning regulations, land-use planning, and infrastructure development can either encourage or limit urban expansion. In many developing countries, inadequate urban planning and governance can lead to uncontrolled urban growth (Domingo et al., 2021). Effective policy frameworks and strategic planning are essential to manage urban growth sustainably, preventing environmental degradation and ensuring that development meets the needs of the growing population.

Effective urban planning involves creating comprehensive plans that integrate economic, social, and environmental considerations. Policies advocating for mixed-use development, high-density housing, and efficient public transportation can effectively mitigate urban sprawl and alleviate associated environmental impacts. However, in many cases, such policies are either lacking or poorly implemented. For instance, different cities' urban planning efforts have faced challenges in keeping pace with rapid growth, resulting in environmental sustainability challenges peri urban areas of a city (Mouratidis, 2021).

The role of governance is also crucial in implementing sustainable urban planning. Strong institutional frameworks and effective enforcement of regulations are necessary to manage land use and development effectively. In regions where governance is weak, urban growth often proceeds unchecked, leading to the proliferation of informal settlements and environmental degradation. Studies by Parnell and Robinson (2017) Good governance plays a pivotal role in achieving sustainable urban development by ensuring coordinated efforts among diverse stakeholders.

2.2.4. Environmental factors

Environmental factors significantly influence urban growth and land use changes, shaping the way cities develop and adapt to various ecological conditions. One of the most prominent environmental factors is climate change, which affects urban areas through rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events(Yang et al., 2020). As cities experience these changes, they must reassess their infrastructure and land use practices to mitigate potential impacts. For example, urban planners may need to incorporate flood-resistant designs, green infrastructure, and sustainable drainage systems to manage stormwater effectively. Consequently, climate change not only poses risks but also presents opportunities for creating more resilient urban environments (Zhong et al., 2020).

Another critical environmental factor is the availability and quality of natural resources, including land, water, and energy. The accessibility of these resources can dictate urban growth patterns, as cities often expand into areas that offer abundant resources for development. For instance, regions with fertile land may attract agricultural expansion, while areas with significant water resources might foster industrial growth (Roy et al., 2022). Additionally, the quality of these resources plays a vital role; contaminated land or polluted water sources can hinder development efforts and necessitate cleanup and restoration initiatives. Urban planners must consider resource availability and sustainability to ensure that growth does not compromise the environment or public health.

Biodiversity and ecological considerations are increasingly influencing urban growth and land use changes. Urban areas are often located near important natural habitats and ecosystems, which can become fragmented or degraded due to urban expansion. Recognizing the value of biodiversity, many cities are adopting strategies to protect green spaces, conserve natural habitats, and enhance ecological connectivity (Long et al., 2021). Integrating nature into urban planning not only helps preserve biodiversity but also provides benefits such as improved air quality, enhanced urban aesthetics, and increased recreational opportunities for residents. As environmental awareness grows, cities are increasingly tasked with balancing development demands with the need to protect and restore the ecological integrity of their surroundings.

2.3. Environmental sustainability challenges driven by urban growth

Urban growth presents numerous challenges to environmental sustainability, particularly in rapidly developing urban areas, the pressure on natural resources and ecosystems intensifies, leading to a variety of environmental issues that require urgent attention. This section aims to identify and analyze the key environmental sustainability challenges associated with urban development (Elmqvist et al., 2019). These transformations disrupt local ecosystems, escalate pollution levels, and diminish the quality of life for residents. Recognizing these challenges to environmental sustainability is essential for formulating effective urban planning and policy strategies that foster sustainable development.

this section examines the specific challenges that urban growth poses to environmental sustainability by exploring the inadequacies of existing drainage systems in managing increased stormwater runoff, the inefficiencies in waste management that lead to pollution, and the loss of green spaces and forest cover, the threats to wetland and slopping areas due to urban expansion. By identifying these challenges, and aiming at to highlight the importance of integrating sustainable practices into urban planning and development.

2.3.1. Wetland pollution

Wetland pollution is a significant environmental sustainability challenge driven by urban growth. As cities expand, land development often encroaches upon wetlands, which serve as critical ecosystems for biodiversity, water filtration, and flood control. Urban expansion increases surface runoff from roads, construction sites, and industrial areas, carrying pollutants like heavy metals, oils, and chemicals into nearby wetlands. The influx of these pollutants degrades water quality, disrupts aquatic life, and reduces the wetlands' natural ability to filter contaminants, ultimately compromising their ecological functions (Javan et al., 2023).

The conversion of wetlands for urban uses such as residential, commercial, or industrial development further exacerbates the problem. These conversions often involve draining or filling wetlands, leading to habitat loss and fragmentation, which directly threatens the species that rely on these environments for survival (Wantzen et al., 2019). Pollutants from urban waste, untreated sewage, and industrial effluents can accumulate in wetland sediments, affecting the entire food

chain. The degradation of wetlands thus diminishes their role in maintaining ecological balance, with long-term consequences for both the environment and human health.

Moreover, the loss of wetland areas due to urban growth reduces their capacity to act as natural buffers against climate change impacts. Wetlands help regulate local microclimates and store carbon, playing a crucial role in mitigating greenhouse gas emissions. When they are polluted or destroyed, their ability to sequester carbon diminishes, contributing to increased atmospheric carbon levels and exacerbating global warming. Addressing wetland pollution through sustainable urban planning and effective environmental policies is essential to preserving these valuable ecosystems and ensuring long-term urban resilience (Verma & Raghubanshi, 2018).

Currently, wetland resources face threats from drainage and fragmentation due to water supply diversions and infrastructure construction, including unmanaged storm water from residential housing in the study area. Protecting wetlands requires a combination of regulatory measures and community involvement. Establishing protected areas and enforcing land use regulations can help prevent further encroachment. Furthermore, community education and engagement initiatives can play a crucial role in increasing awareness about the significance of wetlands and promoting local conservation efforts (Brinkmann et al., 2020).

2.3.2. Construction on Steep Slopes

Urban growth in sloped areas presents significant challenges to environmental sustainability due to increased erosion, landslides, and habitat degradation. When infrastructure development extends into hilly or mountainous regions, natural vegetation is often cleared, weakening soil structure and reducing its ability to retain moisture. As a result, surface runoff increases, leading to soil erosion and sedimentation in nearby water bodies, which degrades water quality and aquatic ecosystems (Sestras et al., 2021).

Additionally, the removal of vegetation eliminates the protective cover that stabilizes the soil, increasing the likelihood of landslides, especially during heavy rainfall. These landslides not only pose risks to human safety and infrastructure but also disrupt local ecosystems, emphasizing the need for careful land-use planning and vegetation preservation in sloped area, Moreover, urban

development on slopes alters natural water runoff patterns, exacerbating flooding risks in low-lying areas (Guzzetti et al., 2020).

The introduction of impervious surfaces, such as roads and buildings, prevents water absorption into the ground, leading to excessive surface runoff that can overwhelm drainage systems. This runoff often carries pollutants, contaminating local waterways and negatively impacting aquatic ecosystems. The increased demand for resources in these areas further intensifies sustainability challenges, making it essential to implement effective stormwater management systems and sustainable urban planning strategies to balance development with environmental preservation (Zhou et al., 2021).

2.3.3. Urban sprawl and informal settlement development

Urban sprawl and the development of informal settlements are closely interlinked, with significant implications for environmental sustainability. Urban sprawl refers to the uncontrolled expansion of urban areas into peripheral regions, often characterized by low-density, car-dependent development (Msuya et al., 2022).

This phenomenon frequently leads to the rise of informal settlements, particularly in developing countries, where rapid urbanization outpaces the provision of formal housing and infrastructure. Informal settlements, also known as slums, are typically characterized by inadequate access to basic services, insecure land tenure, and substandard housing. The relationship between urban sprawl and informal settlements is complex, as the latter often emerge on the fringes of sprawling cities where land is cheaper and more accessible, albeit lacking in proper planning and services(Dovey et al., 2020).

The environmental impacts from urban sprawl and informal settlements are profound and multifaceted. One significant issue is the loss of natural habitats and green spaces, which are often converted into residential areas without adequate planning. This encroachment on natural ecosystems leads to biodiversity loss and disrupts local wildlife. Additionally, the spread of urban areas increases the impervious surface area, contributing to higher runoff and the potential for flooding (Canton, 2021).

Urban sprawl and informal settlement development strain existing infrastructure and resources, undermining efforts towards sustainable urban development. The decentralized nature of sprawl makes it challenging to provide efficient public transportation, leading to increased energy consumption and greenhouse gas emissions. Informal settlements often lack access to reliable water supply, sanitation, and waste management services, resulting in improper waste disposal and environmental contamination. Addressing these challenges requires integrated urban planning that promotes compact, sustainable growth, and the formalization of informal settlements through improved infrastructure and services (Yasin et al., 2021).

Urban sprawl presents a paradoxical phenomenon in political terms, as it is credited with fostering global economic growth and stability, yet it is also identified as a significant contributor to climate change (Silva & Ma, 2021). Mostly peri urban areas are grappling with the evolution of urban sprawl, which has shifted from residential communities to more intricate environments characterized by diverse land-use functions, industry decentralization, polycentric structures, and alternative forms of suburban governance.

2.3.4. Lack of solid waste management

Solid waste management in peri-urban areas faces significant challenges due to rapid population growth and urbanization. These regions often lack adequate waste management infrastructure, leading to the accumulation of waste in open areas and waterways. The sudden increase in waste generation surpasses the capacity of existing systems, resulting in inefficient waste collection and disposal (Warunasinghe & Yapa, 2016). This Urban growth increases the volume of waste generated, posing challenges for waste management systems. Effective waste management practices, including collection, disposal, and recycling, are essential for reducing pollution and promoting environmental sustainability (Vardoulakis et al., 2016).

Solid waste management has emerged as a critical environmental and public health issue in numerous countries, where systems for managing waste from its origin to its ultimate disposal, typically in landfills or through processing, remain inadequate and unsustainable. In an effective solid waste management system, the final step involves the disposal of solid waste generated within a community. Advanced technologies for solid waste management typically involve

engineering processes such as sorting, volume reduction, and possibly recycling prior to disposal are needed to curb this problem (Iraguha et al., 2022).

2.3.5. Lack of drainage system

In rapidly urbanizing areas, drainage systems frequently struggle to keep pace with the surge in stormwater runoff generated by the increased number of impervious surfaces, such as roads, parking lots, and rooftops. These surfaces prevent water from naturally infiltrating into the ground, leading to more surface runoff (Lourenço et al., 2020). When drainage infrastructure is insufficient or outdated, it often results in flooding and water pollution, which can cause significant disruptions to communities and ecosystems. Therefore, implementing effective drainage infrastructure is essential for managing stormwater, reducing flood risk, and maintaining water quality in urban areas, especially those with inadequate drainage systems (Anim et al., 2021).

The challenge of designing and implementing an efficient drainage system is further compounded by the combined effects of climate change and urbanization. Climate change intensifies rainfall patterns, leading to more frequent and severe storm events (Francisco et al., 2022). At the same time, urban growth continues to replace natural landscapes with impervious materials, increasing the volume and velocity of stormwater runoff. Together, these factors can exacerbate the frequency and severity of urban flooding, posing a growing threat to both infrastructure and human safety in many regions worldwide.

Moreover, urbanization not only impacts the volume of runoff but also degrades water quality. As water flows over impermeable surfaces, it picks up a range of pollutants, including oils, heavy metals, nutrients, and debris. This contaminated runoff is often discharged into water bodies without adequate treatment, leading to the accumulation of pollutants that can harm aquatic life, disrupt ecosystems, and pose health risks to humans. Urbanization thus introduces a complex array of water quality issues by increasing the diversity and concentration of pollutants that find their way into rivers, lakes, and other water sources (Zhou, 2014).

Stormwater management is essential for mitigating these issues. Traditional drainage systems are often designed to quickly remove stormwater, but they do not address the root causes of flooding

and pollution. Sustainable urban drainage systems offer a more holistic approach, integrating features like permeable pavements, green roofs, and retention ponds to manage runoff more effectively Implementing in the developing areas to significantly reduce flood risks and improve water quality (Muwafu et al., 2024).

2.3.6. Limited development of Green Spaces, parks and open space

Green spaces act as lung of the city and natural buffers that help mitigate the effects of urbanization by absorbing rainfall, reducing surface runoff, and mitigating the urban heat island effect (Handayani et al., 2018). The limited development of green spaces, parks, and open spaces in urban areas poses significant challenges to environmental sustainability by reducing the ecological benefits.

When cities lack adequate green spaces, rainwater is less able to infiltrate into the ground, and leading to increased stormwater runoff and a higher risk of urban flooding. Furthermore, the absence of vegetation and open areas exacerbates the heat retained by buildings and pavements, resulting in elevated temperatures that worsen heat stress and increase energy demands for cooling, thereby contributing to greater greenhouse gas emissions (Kabisch et al., 2015).

Green spaces offer ideal conditions for relaxation, whether in small squares or expansive urban parks. They serve as hubs for recreation, providing opportunities for rest, leisurely walks, games, and sports (Holt et al., 2019). Without sufficient greenery, cities struggle to manage air pollution effectively, resulting in poor air quality that negatively impacts public health, with increased risks of respiratory illnesses. Green spaces also help to sequester carbon, and their absence means fewer opportunities for carbon dioxide absorption (Wang & Foley, 2021).

The social and psychological benefits of green spaces further underscore their importance for sustainable urban development. Parks and open spaces provide places for recreation, social interaction, and physical activity, which are essential for the well-being of urban residents. When urban development neglects these spaces, it limits access to natural environments, which has been linked to increased stress levels, reduced mental health, and lower overall quality of life. This not

only affects individuals but also places a burden on public health systems as cities are forced to deal with higher rates of stress-related illnesses and lifestyle diseases (Puchol-Salort et al., 2021).

2.3.6.1. Lack of urban forestation and urban trees plantations

Urban forests and trees offer numerous environmental benefits and ecosystem services critical to urban sustainability. They improve air quality by absorbing pollutants such as nitrogen dioxide, sulfur dioxide, and particulate matter, while also sequestering carbon dioxide, which helps mitigate climate change. Urban trees provide shade and reduce the urban heat island effect, leading to lower energy consumption for cooling buildings. Additionally, they enhance stormwater management by intercepting rainfall, reducing runoff, and promoting groundwater recharge. These ecological functions contribute to the overall health and resilience of urban areas (Nyelele & Kroll, 2020).

Urban forests also support biodiversity by providing habitats for various species, contributing to urban ecological networks. They improve soil quality and prevent erosion through root systems that stabilize the soil. Furthermore, urban trees and green spaces offer recreational and aesthetic value, promoting mental well-being and physical health among residents. They create pleasant environments that encourage outdoor activities and social interactions, fostering community cohesion (Chen et al., 2020).

The protection and conservation of urban forests and trees are essential to counteract the adverse effects of urban growth. Studies by Laurance (2014) and Güneralp et al. (2017) have documented the adverse effects of the loss of forests and vegetation from urban expansion leads to several environmental challenges, such as increased air pollution, higher temperatures, and reduced biodiversity. Without adequate tree cover, cities are more susceptible to the urban heat island effect, which can exacerbate heat waves and increase energy demands for cooling.

Furthermore, the removal of trees and green spaces diminishes the city's ability to manage stormwater effectively, leading to increased flooding and water pollution. The loss of vegetation also impacts the mental and physical health of residents, reducing opportunities for recreation and social interaction. Preserving urban forests and trees is therefore vital for maintaining a high quality of life in urban areas. Policies that promote the conservation of existing green spaces and

the creation of new ones can help mitigate the negative impacts of urbanization and ensure sustainable urban development, atmosphere, intensifying global warming (Kobayashi, 2024).

2.4. Sustainable urban residential neighborhood

A sustainable urban residential neighborhood is designed to balance development with the environment, fostering communities that thrive without depleting natural resources or compromising future generations' well-being (Dalampira & Nastis, 2020). This concept integrates environmentally friendly building practices, efficient resource management, and green infrastructure to reduce the neighborhood's ecological footprint. For example, using renewable energy sources like solar or wind, implementing rainwater harvesting systems, and adopting sustainable building materials can significantly cut down on energy consumption and waste production. In this way, sustainable neighborhoods contribute to a reduction in greenhouse gas emissions, aiding in the fight against climate change (Chan, 2016).

Environmental sustainability is a core component of sustainable urban neighborhoods, as it aims to maintain a healthy balance between human activities and the ecosystem. Green spaces such as parks, community gardens, and green roofs not only provide recreational areas but also contribute to biodiversity, air purification, and temperature regulation. Urban planning that promotes walkability, cycling, and public transportation reduces reliance on private vehicles, subsequently lowering air pollution and conserving natural resources. By designing residential neighborhoods that prioritize green infrastructure and resource efficiency, cities can significantly lessen their environmental impact while improving the quality of life for their residents (Purvis et al., 2019).

Sustainable urban residential neighborhoods also align with several United Nations Sustainable Development Goals (SDGs), particularly SDG 11, which aims to make cities and human settlements inclusive, safe, resilient, and sustainable. These neighborhoods support SDG 6 (clean water and sanitation) by utilizing efficient water management practices, and they contribute to SDG 7 (affordable and clean energy) through the integration of renewable energy technologies. Additionally, promoting sustainable urban development can help achieve SDG 13 (climate action) by mitigating urban sprawl's adverse effects, such as deforestation and loss of agricultural land, which exacerbate climate change (Xie et al., 2022).

The implementation of sustainable urban residential neighborhoods presents an opportunity to reshape urban growth in a way that supports long-term environmental health and resilience. Through innovative urban planning and design, cities can address the challenges of rapid urbanization, such as increased waste, pollution, and resource depletion (Ali et al., 2019). This approach not only enhances environmental sustainability but also fosters social and economic benefits by creating livable, inclusive communities with access to essential services and opportunities. Ultimately, sustainable urban neighborhoods are a critical strategy for achieving a more sustainable and equitable future, aligned with global sustainability goals (Enrico Morriello et al., 2020).

2.4.1. Indicators of Sustainable urban residential neighborhood

Indicators of a sustainable urban residential neighborhood provide measurable criteria to assess the extent to which these areas achieve environmental, social, and economic sustainability. These indicators include energy efficiency, water management, waste management, air quality, and green space availability (Mindrinos & Panagiotopoulos, 2023). For instance, energy efficiency can be measured through the percentage of buildings that use renewable energy sources, such as solar panels, or energy-saving technologies like LED lighting. The amount of energy consumed per household or the carbon footprint per capita can also serve as quantitative benchmarks for evaluating progress toward sustainability. These metrics not only guide policymakers but also help residents and developers understand the impact of their choices on the environment (Meijering et al., 2018).

Water management is another critical indicator that involves assessing water consumption levels, rainwater harvesting practices, and the implementation of water-efficient appliances. Measurement can include the percentage of households using water-saving fixtures, the volume of rainwater collected and reused, or the reduction in stormwater runoff through permeable surfaces and green infrastructure. Waste management indicators can be assessed through recycling rates, the amount of waste generated per capita, and the proportion of waste diverted from landfills. These measurements help track progress towards a circular economy, reducing resource extraction and landfill dependency while promoting recycling and composting initiatives (Commission & Environment, 2018).

Air quality and green space availability are equally important indicators of sustainable urban neighborhoods. Air quality can be measured by monitoring levels of pollutants like particulate matter (PM2.5 and PM10), nitrogen dioxide (NO2), and carbon monoxide (CO). Lower levels of these pollutants indicate better air quality and a healthier living environment. The availability of green space is assessed by the amount of public green areas per capita, the proportion of land designated as parks or natural reserves, and the connectivity of green spaces to promote biodiversity. The presence of tree-lined streets and urban gardens also supports these indicators, contributing to climate regulation, pollution reduction, and residents' mental and physical well-being (Xie et al., 2022).

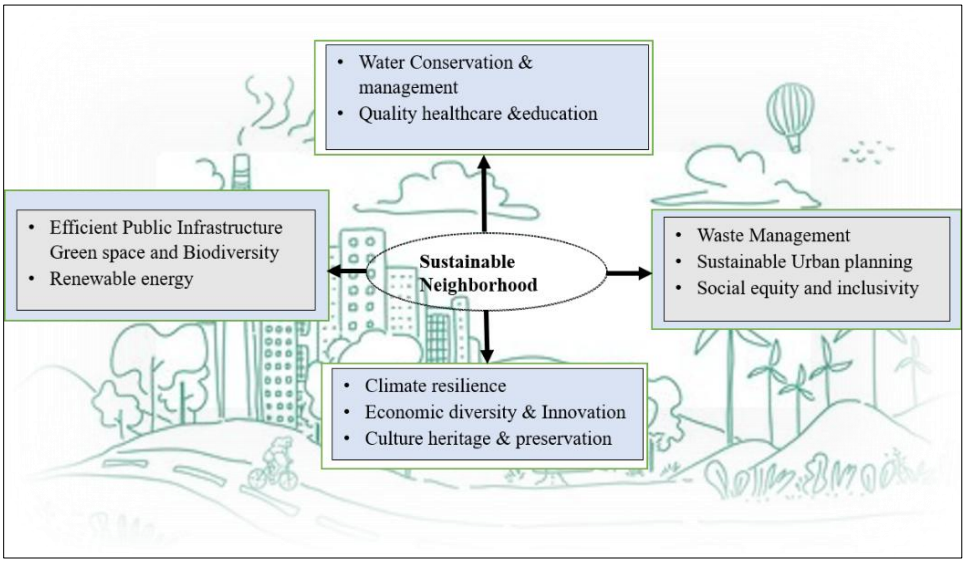
Social and economic indicators, such as access to public transportation, affordability of housing, and community involvement, complete the picture of a sustainable urban neighborhood. Public transportation accessibility can be measured by the percentage of households within a certain distance from transit stations or bus stops, while housing affordability is evaluated through metrics like the ratio of housing costs to household income. Community involvement indicators, such as participation rates in local sustainability initiatives or neighborhood associations, offer insights into social cohesion and resident engagement. Together, these indicators provide a comprehensive framework to assess and enhance the sustainability of urban residential neighborhoods, ensuring that progress is measured and achievable targets are set (Xie et al., 2022).

2.4.2. Factors leading to sustainable urban residential neighborhood

Several factors contribute to the development of a sustainable urban residential neighborhood, starting with effective urban planning and land use management. Thoughtful planning ensures that residential areas are designed to maximize space while minimizing environmental impacts. Strategies like mixed-use development, which combines residential, commercial, and recreational spaces, can reduce the need for long commutes, thus lowering transportation-related emissions (Nabil et al., 2023). Integrating zoning policies that encourage higher density in appropriate areas helps to curb urban sprawl and protect natural habitats and agricultural land. Additionally, planning that incorporates green infrastructure such as parks, green roofs, and rain gardens supports environmental sustainability by managing stormwater and enhancing urban biodiversity (Xie & Jamaani, 2022).

Energy efficiency is another crucial factor, with sustainable neighborhoods focusing on reducing energy consumption and promoting renewable energy use. Incorporating energy-efficient building materials, insulation, and technologies in construction can significantly decrease energy demands for heating, cooling, and lighting. On a larger scale, adopting district heating and cooling systems that utilize renewable energy sources like solar, wind, or geothermal can provide neighborhoods with cleaner, more sustainable energy. Incentives for households to install solar panels or adopt energy-efficient appliances further contribute to reducing the overall carbon footprint of urban areas. (Habitant, 2014).

Figure 2: Factors leading to Sustainable city



Source: (Xie & Jamaani, 2022)

Transportation and mobility options also play a significant role in achieving sustainability. Sustainable neighborhoods promote non-motorized transportation by prioritizing walkability, cycling infrastructure, and accessible public transportation. Ensuring that daily needs and amenities, such as schools, grocery stores, and medical facilities, are within walking or cycling distance helps reduce the reliance on private vehicles. Investing in public transportation infrastructure, including electric buses or light rail, not only reduces air pollution but also provides equitable access to mobility, especially for those without cars. Shared mobility services, like bike-sharing and car-sharing programs, further support sustainable and flexible transportation choices (Khan et al., 2022).

Community engagement and social inclusivity are equally important in fostering sustainable urban residential neighborhoods. Active involvement of residents in decision-making processes encourages sustainable behavior and promotes social cohesion. Engaging communities in local sustainability initiatives, such as urban gardening, waste reduction programs, or energy conservation campaigns, empowers residents to take ownership of their environment (Semeraro et al., 2021). Inclusivity ensures that housing and services are affordable and accessible to all, fostering equity and resilience within the neighborhood. This social fabric not only supports sustainable development but also ensures that the benefits are distributed across different social groups, enhancing the neighborhood's overall quality of life (Bueno-Suárez & Coq-Huelva, 2020).

2.5. Policy and regulatory framework for enhancing environmental sustainability

Policies and regulations aimed at enhancing environmental sustainability in peri-urban areas often focus on land use planning, waste management, and pollution control. These frameworks typically include zoning laws, building codes, and environmental impact assessments (EIAs) that govern development activities. For instance, policies may restrict construction in ecologically sensitive areas or mandate green building practices (Yasmeen et al., 2020). regulations promoting integrated land use planning can help manage the spatial growth of peri-urban areas, ensuring a balance between development and environmental conservation.

The effectiveness of these policies often depends on enforcement and community participation. Regulatory bodies, such as local governments and environmental protection agencies, play a crucial role in monitoring compliance and implementing penalties for violations (Faezah et al., 2022). Public awareness and stakeholder involvement are essential to ensure that local communities understand the regulations and participate actively in sustainable practices, such as waste recycling programs or tree planting initiatives. This helps foster a sense of ownership and encourages behaviors that align with sustainability goals

Moreover, the implementation of regulatory frameworks such as building codes, energy efficiency standards, and water conservation policies also supports sustainability objectives. Zoning regulations help guide development towards less ecologically sensitive areas while promoting the

efficient use of urban space. Governments often collaborate with local authorities to implement and monitor these regulations, ensuring that developers comply with environmental standards. Compliance with international agreements, such as the Kyoto Protocol and the Paris Agreement, further fosters sustainable urban development by aligning national policies with global sustainability goals (Barnes et al., 2021).

2.5.1. Development Strategies for Sustainability

Development strategies in peri-urban areas often aim to promote sustainable land use and efficient resource management while accommodating population growth. These strategies can include densification policies, mixed-use zoning, and investment in public transport systems to reduce urban sprawl and limit car dependency. Integrating green belts or buffer zones around peri-urban areas can also help preserve biodiversity and provide ecosystem services such as water filtration and air quality improvement (Ruggerio, 2021).

Strategies also emphasize the sustainable management of natural resources and the use of adaptive planning approaches for areas at risk of environmental hazards. Guidelines for stormwater management during site development and restrictions on construction in high-risk zones (e.g., slopes with high gradients) can help mitigate risks such as landslides and floods (Zhou et al., 2021). These measures are designed to ensure a balanced approach between development and ecological preservation, promoting long-term sustainability.

2.5.2. Green growth strategies

Green growth focuses on balancing economic development with environmental protection and sustainability. Key challenges include managing the environmental impacts of rapid urbanization, such as deforestation, pollution, and the loss of agricultural land (Jiang et al., 2023). Policies to promote green growth often emphasize the adoption of clean technologies, renewable energy, and sustainable agricultural practices. Investments in renewable energy sources, such as solar and hydropower, can help reduce greenhouse gas emissions while meeting growing energy demands.

However, implementing green growth strategies in peri-urban areas can be challenging due to financial constraints and limited access to green technologies. Bridging the financing gap through public-private partnerships, grants, and international aid can support the adoption of sustainable practices Moreover, integrating environmental considerations into economic planning can drive green innovation and create jobs in sectors such as clean energy and sustainable agriculture (Cruz-Bello et al., 2023).

2.5.2. Green Infrastructure in Peri-Urban Areas

Green infrastructure refers to natural and semi-natural systems that provide environmental, social, and economic benefits through ecosystem services. Urban green infrastructure (UGI) plays a crucial role in balancing biodiversity preservation with sustainable urban growth by utilizing adaptive management strategies (Feingold et al., 2018). Green infrastructure can include urban forests, wetlands, green roofs, and sustainable drainage systems that help manage stormwater, reduce heat islands, and improve air quality. For example, Singapore's extensive network of green corridors and rooftop gardens offers a model for integrating green infrastructure into urban planning, enhancing biodiversity while providing recreational spaces for residents.

Implementing green infrastructure requires cross-sectoral collaboration and long-term investment. Planning authorities, environmental agencies, and private developers must work together to incorporate green infrastructure into urban development projects. Incentives, such as tax breaks for developers who include green features in their projects, can stimulate investment. Additionally, green infrastructure can be part of climate adaptation strategies, helping urban areas cope with extreme weather events and changing environmental conditions.

Chapter 3. Research Material and Methodology

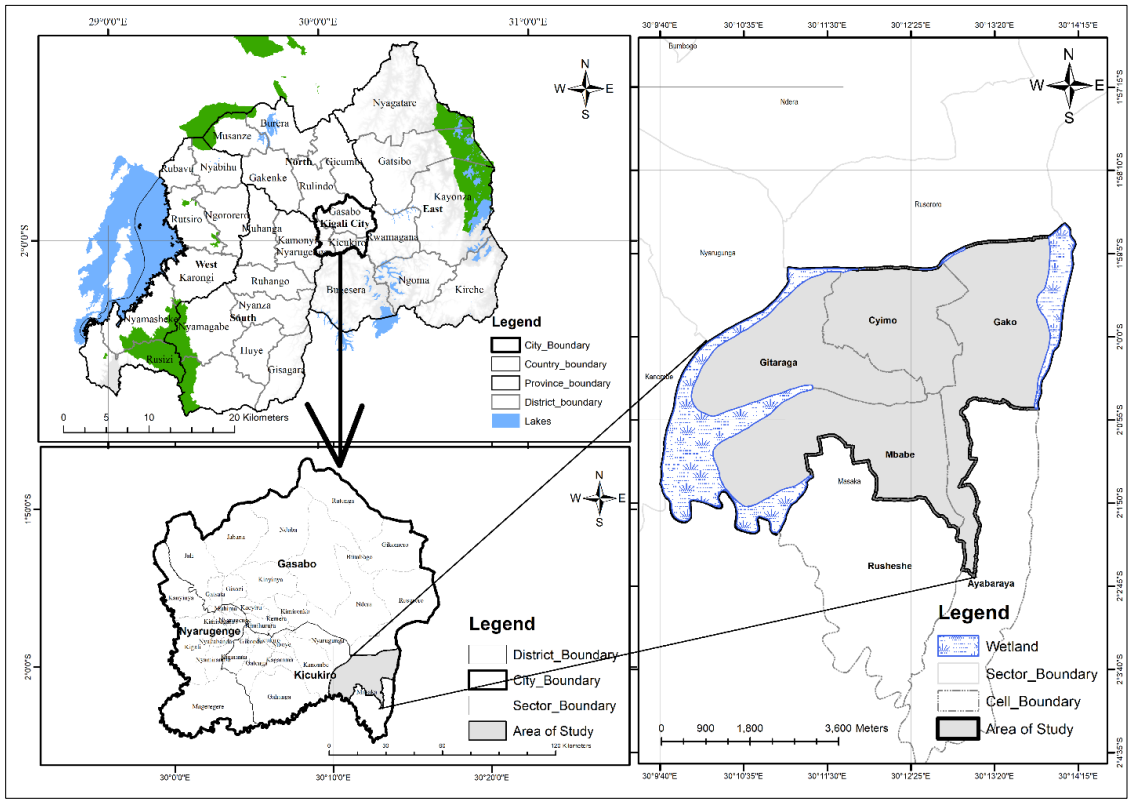
3.1.Introduction

This chapter aims to assess the methods and techniques used in evaluating urban growth trends and their impact on environmental sustainability in the Masaka sector. It also outlines the types of data used and their sources. Additionally, it describes the tools utilized for data analysis and details the procedures and methods applied in the analysis.

3.2.Study area description

The study area is located in the Masaka sector in Kicukiro District in the city of Kigali. It has 3178.55 hectares and it includes the Mbabe, Gitaraga, Cyimo, and Gako Cells. The geographic coordinates are 01°59'44.0"S latitude and 30°11'30.0"E longitude (-1.995556, 30.191667). it is bordered in the South of the study area are Rusheshe and Ayabaraya Cells, to the West are Kanombe and Nyarugunga Sectors, to the North is Rusororo Sector, and to the East are Nyakariro and Muyumbu Sectors.

Figure 3: Study are location

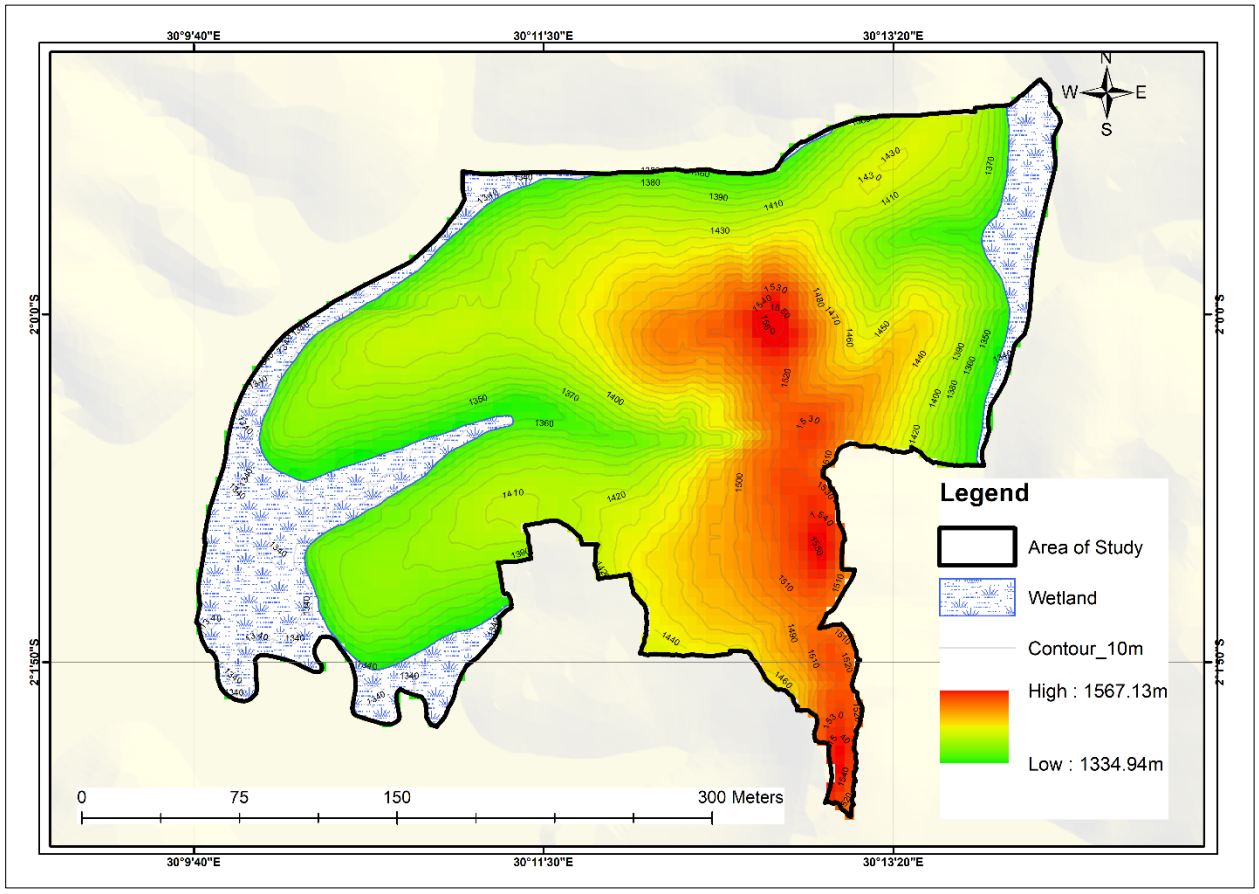


Source: (NISR, 2022)

3.3. Topography of the study area

The topography of study area ranges between 1334.94 and 1567.13 meters above sea level, as shown in *Figure 4*. This terrain characteristics make much of Masaka Sector suitable for infrastructure development, particularly areas with slopes of around 33% found in Gitaraga, Mbabe, and Gako cells. However, some area of steeper areas recommended for afforestation to enhance forest cover.

Figure 4: topographic map of the study area



Source: (NISR, 2022)

3.4. Data source

This section offers an in-depth overview of the data collection methods utilized in this research. A variety of techniques were employed to gather primary data, including interviews with key stakeholders involved in the elaboration of Kigali city master plan, such as community leaders and government officials. Surveys were administered to a sample of residents from the Masaka sector

within the selected study area, providing diverse perspectives and comprehensive data, household surveys, and field observations.

Additionally, direct field observations were made to capture valuable insights into the physical changes occurring in the settlements and built environment due to the growth of Masaka sector. These observations allowed for a detailed understanding of the impact of the environmental sustainability resulted from the growth of Masaka. By combining these methods, the research ensured a thorough and multi-faceted approach to data collection, enabling a robust analysis of the research objectives outcomes.

3.5. Spatial and non-spatial Data collection

Spatial data, also known as geospatial data, is a term used to describe any data related to or containing information about a specific location on the Earth's surface. Non-spatial data, on the other hand, is data that is independent of geographic location (Song et al., 2020). In this study all types of data will be used to understand the physical changes of the city, spatial data in this study it includes satellite imagery, and data from field surveys. whereas non-spatial data include existing literature, field observation, and sampling. All the data are categorized in primary and secondary data sources.

3.5.1. Primary data source

Primary data collection entails gathering information directly from original sources, by passing reliance on pre-existing research conducted by others. This approach involves methods such as field observations, household surveys, and interviews. These techniques are instrumental in gathering both qualitative and quantitative data necessary for analyzing the growth dynamics of Masaka sector. The primary data collected is also utilized to assess the progress of physical plan implementation, evaluate environmental impacts resulting from land use planning, and formulate strategies and recommendations based on the study's findings

3.5.1.1.Field observations

Field observations were conducted as a crucial part of the data collection process to gather firsthand insights into the physical changes and on-ground realities of the Masaka sector. These observations involved systematically documenting the infrastructure improvements and environmental sustainability conditions in the area.

Through these field observations, the research aimed to understand the practical implications of the urban growth, such as in waste management systems, water drainage, and overall environmental quality. This method allowed for a more nuanced and comprehensive analysis, complementing the data obtained from surveys and interviews, and providing a holistic view of The impact of urban growth on the environmental sustainability to the community.

3.5.1.2.Demographic Data

The demographic data utilized in this study were collected from the National Institute of Statistics of Rwanda (NISR). These data provided population figures for the selected sites, enabling the evaluation of urbanization trends within Masaka sector. By comparing data across different years, the study identified and analyzed changes occurring in the study area, offering valuable insights into demographic shifts and urban development dynamics over time.

3.5.1.3.Spatial Data

Spatial data used in this study include: Satellite Imagery Data which was obtained from Rwanda Space Agency and Charis UAS, due to the availability of imageries which have high resolution of 30cmx30cm were used from the range of years 2008-2013-2018-2023 to detect the change in urbanization of Masaka sector whereby five classes including water, wetland, forest, vegetation and built up were used because there are the main classes that are mostly observed in the study area. Other spatial data like land use master plan from Nation Land use Authority, forest cover from ministry of environment, Administrative boundary and household data from National Institute of Statistics of Rwanda.

3.5.2. Secondary data source

Secondary data refers to information that has been collected, analyzed, and published by someone other than the original researcher by reviewing existing documents like scientific reports, websites, and theses related to urbanization growth. This approach used the integration of data from multiple sources, providing a reliable foundation of both qualitative and quantitative information.

3.5.2.1.Library research

Valuable information in this study were sourced from different books, scientific journal articles, and official reports including Kigali master plan, national land use and development plan, Rwanda building code and others which were collected from credible institutions both in Rwanda and globally.

To gather information on the implementation of land use plans, published materials were reviewed. This included various web documents and resources found in libraries and documentation centers of public organizations such as the National Land Authority (NLA), Rwanda Housing Authority (RHA), Ministry of Infrastructure (MININFRA), Kicukiro District, and the City of Kigali.

3.5.3. Sampling techniques

The method of selecting the sample is known as sampling, which involves choosing a portion of the population to represent the entire population. To obtain the necessary information, it is essential to determine the number of respondents. This quantity is referred to as the sample size.by applying the formula, the study uses to determine the sample size is the equation below, given the population size of the study area is of 3555 households,

This type of selection is known as purposive sampling, as the cells were intentionally chosen based on the earlier implementation of the master plan in those areas compared to others. The sample size was determined using the following formula.

$$n = \frac{N(Z_{\alpha/2})^2}{4(N-1)l^2+(Z_{\alpha/2})^2}$$

Whereby

 n represents the sample size

 N represents the sampling frame, which is 3555 for this study

 Zα/2 is the value from the normal distribution for a 95% confidence interval, which is 1.96 for this study, selected based on the desired precision

 α denotes the significance level

 l signifies the tolerable error, which is 10% in this study

The total number of households in the selected cells was 3555, are distributed as follows: 1145 in Gako cell (32.01%), 1056 in Cyimo cell (29.70%), 745 in Mbabe Cell (20.96%), and 609 in Gitaraga cell (17.13%). Using the formula provided above, the sample size was calculated as follows.

$$n = \frac{3555(Z0.05)^2}{4(3555-1)*(0.1)^2+(Z0.05)^2}$$

$$= \frac{3555(1.96)^2}{4(3555-1)*(0.1)^2+(1.96)^2}; \quad = \frac{3555(1.96)^2}{4(3554))*(0.1)^2+(1.96)^2}; \quad \underline{n = 347}$$

This sample size of 347 households includes 112 from Gako cell and 11 households per village, 103 from Cyimo cell and 11 households per village, 72 from Mbabe cell and 12 households per village, and 59 from Gitaraga cell with 8 households per village. These samples were proportionally selected based on the number of households in each cell.

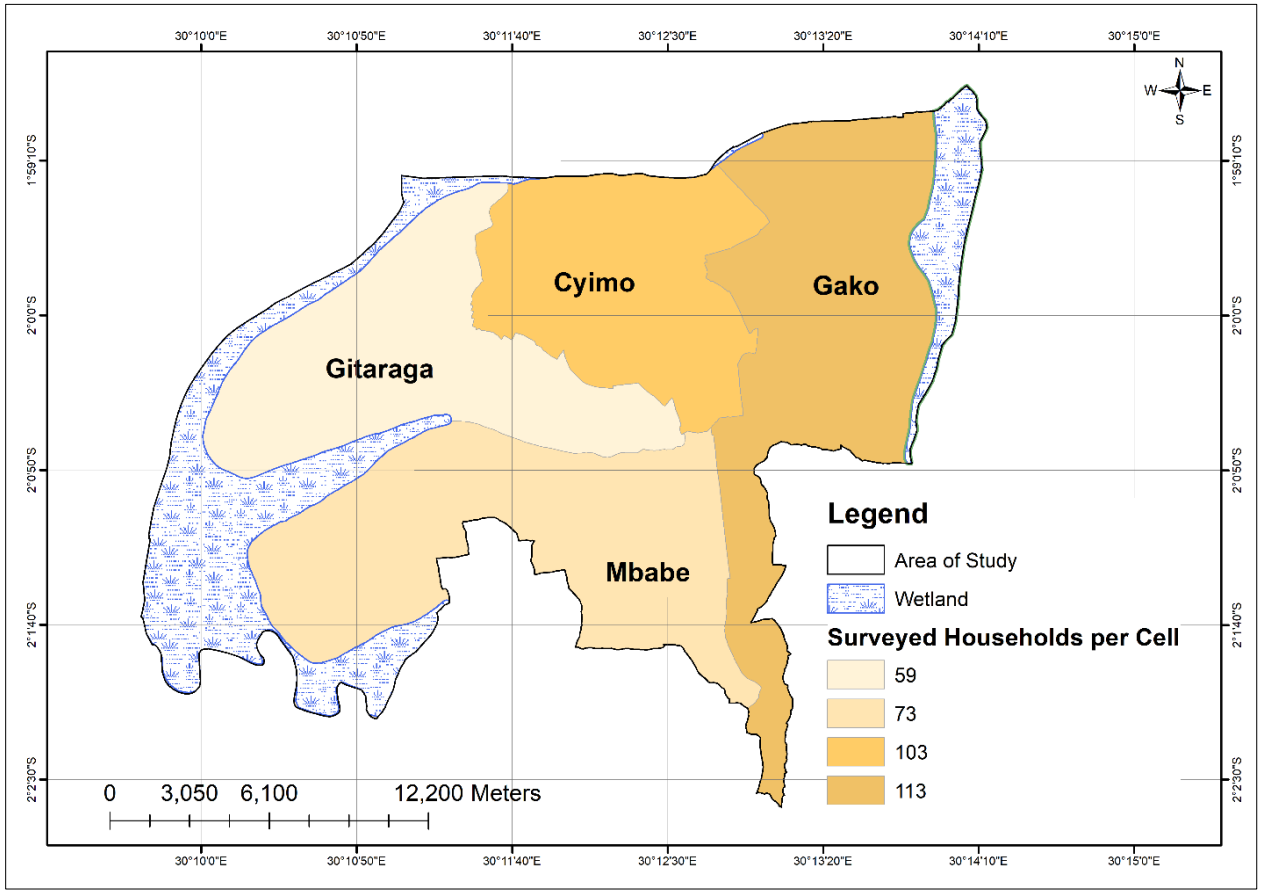
3.5.3.1.Household survey

The household survey was an essential part of this study, providing valuable insights into the direct beneficiaries of the growth of Masaka sector. During the survey, residents were asked to share information about how urbanization growth impacts their lives covering the environmental aspects. The study involved a sample size of 347 households, ensuring a representative and comprehensive understanding of these impacts.

Subsequently, the systematic random sampling method was used to accurately identify the households to be surveyed This method was chosen because, according to Rahman et al. (2022) it is easy to implement and does not require a complete listing frame, the respondents this takes to distribute sample size. Consequently, it found that one at every 10^{th} Household could participate

in a survey before surveying the next one, ensuring the geographical coverage of the entire study area.

Figure 5:Spatial distribution of respondents



Source: (NISR 2022 and Field Survey, 2024)

3.5.3.2.Interview with key informant

For the interviews, purposive sampling was used to select interviewees who are responsible for urban planning and the implementation of the master plan at both the Kigali City level, Ministry of Infrastructure, Rwanda Housing Authority, Rwanda Environmental Management Authority, National Land Authority and the local level. This sampling method was chosen because the necessary information about master plan implementation can only be provided by these specific authorities. The targeted interviewees include the urban planners, Environmentalist experts and housing development experts working at these institutions.

These interviewees were expected to offer valuable insights into several key aspects, including the extent of infrastructure improvements achieved in the Masaka sector due to the project and the environmental challenges faced during its execution. Additionally, they shared lessons learned from the development, contributing to a comprehensive understanding of the project's impact and the obstacles encountered along the way.

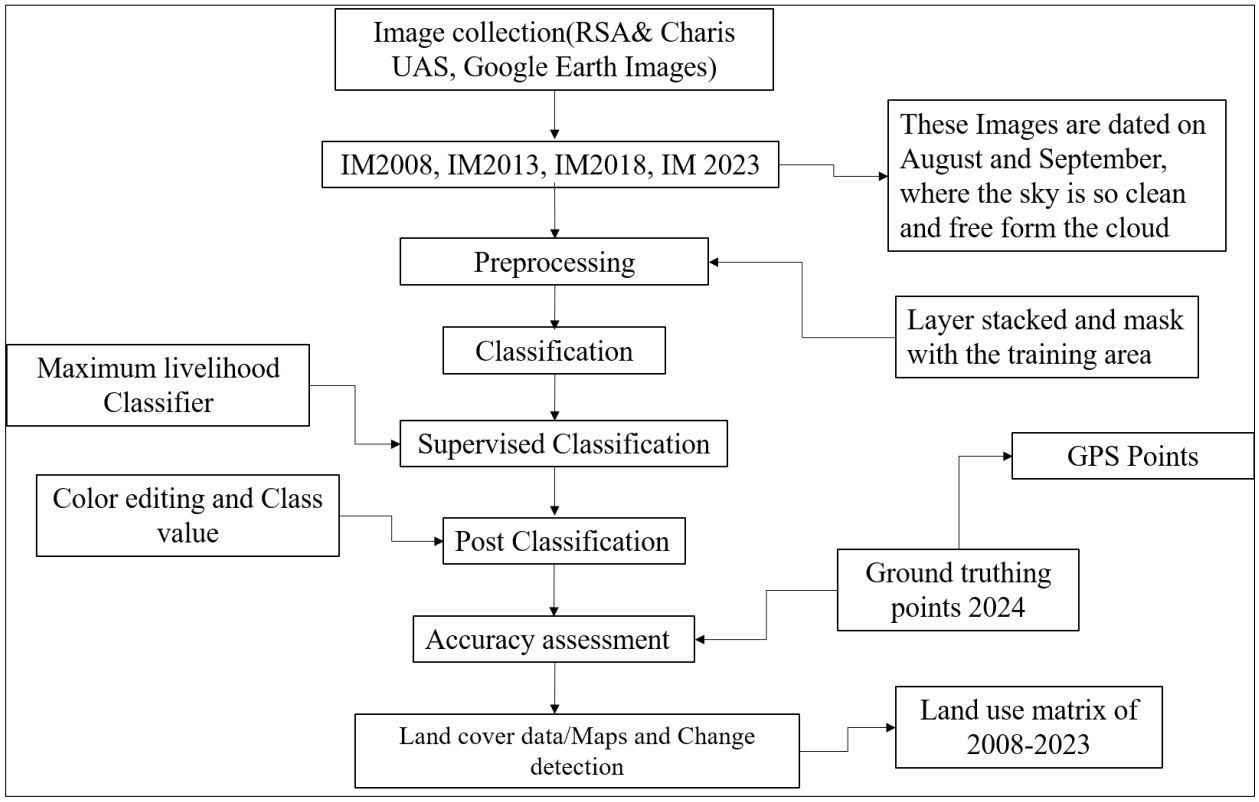
3.6.Image processing and analysis

All obtained data, either spatial or non-spatial data was analyzed in this research. In fact, this research used satellite images to obtain the classification of land use and change detection. This is due to the research focus on spatial temporal trend in urbanization in Masaka Sector from 2008 to 2023, their change over time and the corresponding impacts on environmental sustainability. The methodology focused on evaluating spatial temporal changes in land use cover, employing ArcGIS software (specifically ArcGIS Pro) for image analysis, classification and mapping.

The image classification was done using supervised classification, where Georeferenced Images are inserted in software, all required band are stacked together, then the subset is performed to remain with Area of interest. During the study, bands were initially combined to identify specific land cover classes such as built-up areas, forests, and agriculture. Training samples representing these classes were selected using polygon tools to capture pixels with specific reflectance characteristics from the combined bands, ensuring they accurately represented each class. This systematic approach facilitated detailed analysis and mapping of land use patterns based on spectral data.

After refining results by eliminating small patches or merging similar classes is done to combine all trained samples into one class. After repeating the same procedure for all classed, then validation and assessment of accuracy using ground truth data and confusion matrices is done, to determine accuracy of all classification. During the image classification, the supervised classification method was used, by selecting "training samples," which are specific areas on the map to accurately represent particular land cover types. The software analyzes the spectral signatures of the pixels within each training area to establish the average and variability (mean and variance) of these classes across all input bands or layers.

Figure 6: Image processing and analysis



Source: (Mohamed, 2019)

To quantify land use changes, a land use conversion matrix is created. This matrix compares classified land use maps over different time periods and identifies transitions between different land use categories. The matrix consists of rows representing initial land use classes (wetland, forest, agriculture, and built-up area) and columns representing the final land use classes. By calculating the area of land that has transitioned between these categories, the matrix provides a comprehensive overview of land use changes, highlighting the extent and nature of conversions between wetlands, forests, agricultural lands, and built-up areas.

3.7. Analytical Framework

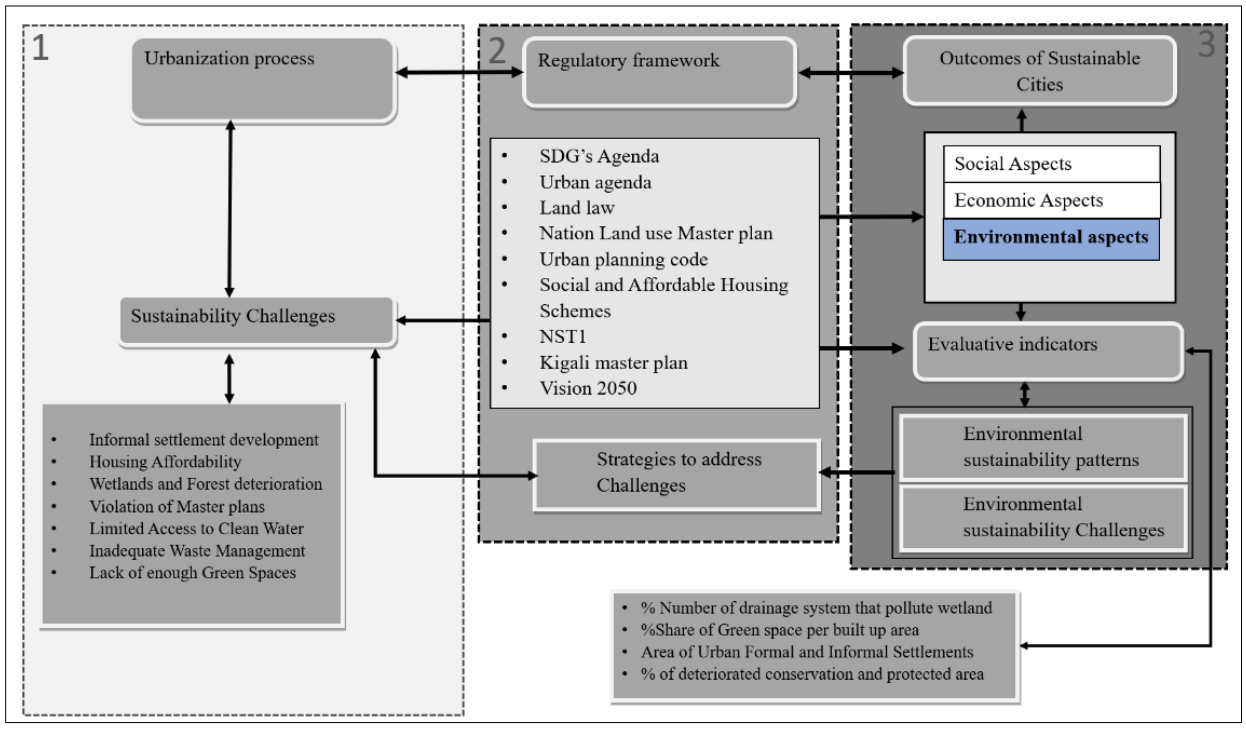
This framework helped in explaining how the certain analysis of the growth of Masaka sector were conducted. The block one examines the urbanization process where an increasing percentage of a population live in Masaka sector has led to various challenges, including the proliferation of informal settlements, housing affordability issues, and the deterioration of vital ecosystems such

as wetlands and forests. As Masaka expand rapidly, the pressure on land resources intensifies, often leading to violations of established master plans. This unchecked urban sprawl contributes to a host of environmental issues, including inadequate waste management, limited access to clean water, and the encroachment on green spaces. The rapid growth of urban populations exacerbates these challenges, making it increasingly difficult to maintain a balanced and sustainable urban environment.

The block two examines how these challenges posed by urbanization, by whereby a robust regulatory framework is essential. In Masaka, various laws and plans have been implemented to guide urban development and mitigate its adverse effects. The Nation Land Use Master Plan and the Urban Planning Code are key components of this framework, setting the standards for land use and urban development. These regulations aim to control the spread of informal settlements and ensure that housing projects comply with sustainability criteria. Additionally, social and affordable housing schemes have been introduced to tackle the issue of housing affordability, ensuring that even the lower-income population can access decent housing. The enforcement of these regulations is crucial in maintaining the balance between urban growth and environmental conservation.

The block three give the expectation from urban process and the regulatory framework to have a sustainable residential neighborhood in Masaka sector, these outcomes of sustainable residential neighborhood are classified in social aspect, economic aspects and ultimately environmental aspects which is the main aspect to be discussed in this study, to evaluate if Masaka sector is growing in sustainable way, However, this study will focus primarily on the environmental aspect, using evaluative indicators from the environmental perspective.

Figure 7:Analytical Framework



Source: (Nieuwenhuis et al., 2021)

Chapter 4: Results and discussions

4.1. Introduction

This chapter provided a comprehensive discussion of the findings. The first segment delved into the growth analysis of Masaka Sector since 2008 until 2023. Following the challenges encountered during the implementation of Master plan will be discussed. Subsequently, the study will include a descriptive analysis of the respondents. Additionally, it also will provide in-depth exploration of recommendations for policymakers aimed at improving urban planning implementation and enhancing the living conditions of urban dwellers within Masaka Sector.

4.2. Analysis of the growth of Masaka sector

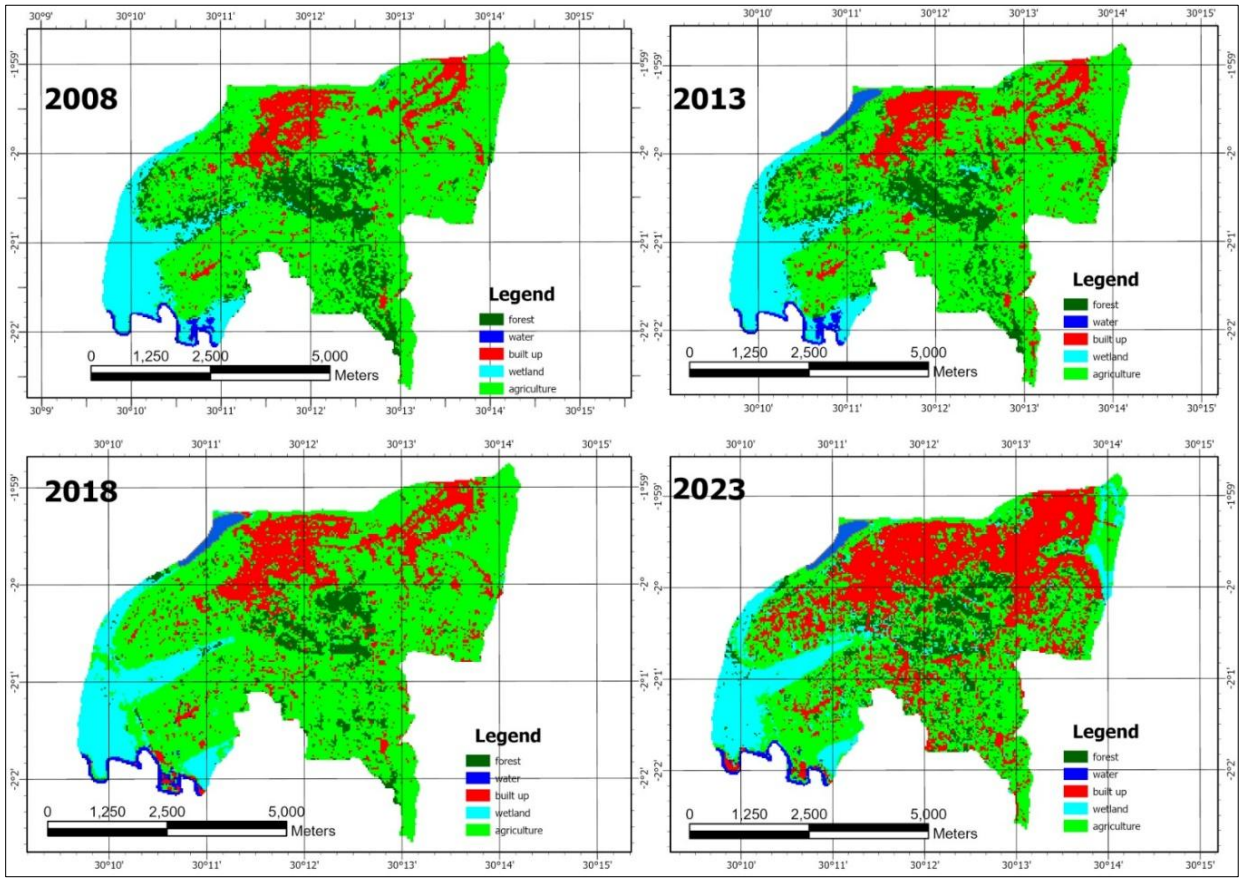
The analysis of the satellite images provided reliable information to generate the spatial temporal land use land cover map in this research Since 2008 up to 2023 meaning 15 years. Masaka Sector has undergone substantial changes in land use and land cover due to the rapid growth. Classifying land use and land cover into agriculture, built-up, forest, wetland, and water are essential for evaluating spatial temporal dynamics of urban growth.

The results of image analysis revealed a notable shift from agricultural and natural landscapes to urban areas characterized by residential, commercial, and some small industrial developments. According to 80% of respondents and expert from Masaka Sector, Kicukiro District, RHA, CoK and RHA said that this expansion in Masaka has primarily been driven by population growth, economic development, and the shift of individuals who were expropriated from the city center and sought land in the peri-urban areas. This shift has led to the conversion of agricultural areas into residential zones to accommodate the increasing population. Commercial activities have also expanded, resulting in the establishment of shopping centers, markets, and other business ventures. These transformations not only alter the physical landscape but also disrupt the ecological balance of the region.

"The Masaka site has grown significantly over the past 15 years, and it is now experiencing rapid development due to its proximity to essential infrastructure and its status as a *Kigali Health City namely IRCAD Africa, Relocation of CHUK which is under construction, My Heart Care Centre*

and the Head Quarters of University of Global Health Equity planned to be at Masaka. These have led to an influx of people moving there and others investing in accommodation businesses."[1]

Figure 8:Urban growth of Masaka Sector



*Source: (**https://earthexplorer.usgs.gov and NISR ,2022**)*

The *figure 9, figure 10 and table 2* illustrates the changes where the vegetation cover from 2008 to 2023, highlighting significant shifts in land use within the study area. Over the 15-year period, agricultural cover exhibited a marked decline, decreasing from 62% of the total area in 2008 to 43.5% in 2023. This downward trend indicates a reduction of nearly a half of agricultural land, likely due to various factors such as urbanization, changes in land management practices, and economic pressures. The decrease in agricultural land is significant as it reflects a potential impact on local food production and rural livelihoods.

[1] Interview with CoK, RHA, Kicukiro District and Masaka sector

The built-up area in Masaka Sector has experienced significant changes over the years, reflecting the urbanization and development trends in Kigali. In 2008, the built-up area constituted 11.22% of the sector's total land, indicating a relatively low level of urban development at the time. This period was characterized by the initial stages of urban expansion, with a modest increase in built-up areas due to the gradual growth of the population and economic activities in the region.

By 2013, the built-up area had increased to 13.31%, coinciding with the launch of Kigali's first master plan. This period marked a more structured approach to urban planning and development, with the master plan guiding the expansion of infrastructure and residential areas. The slight increase in the built-up area during this period reflects the early impacts of the master plan, as the city began to implement more organized and sustainable urban growth strategies.

The built-up area saw a significant jump to 17.63% in 2018, following the 2013 master plan's initial implementation phase. The revision of the master plan in 2020 and the introduction of detailed physical plans accelerated this growth, with the built-up area reaching 32.08% by 2023. This period also saw the development of major infrastructure projects, including the Kigali Health City in Masaka, which contributed to the rapid urbanization. The increase in built-up areas during this time highlights the influence of comprehensive planning and strategic infrastructure development in shaping the urban landscape of Masaka Sector.

Table 2:Statistical analysis of land use change

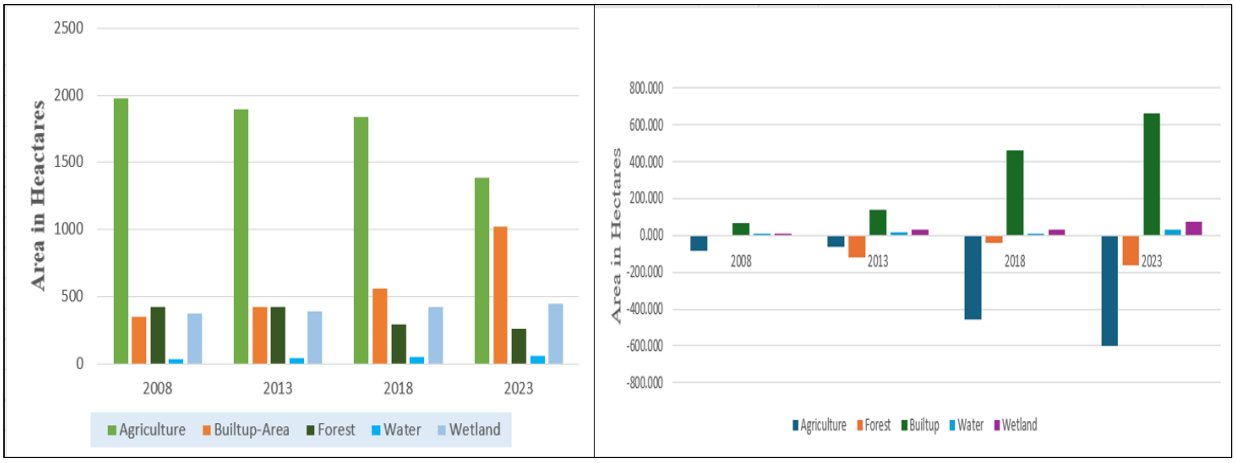
	2008		2013		2018		2023	
Class	**Area/Ha**	**Area%**	**Area/Ha**	**Area%**	**Area/Ha**	**Area%**	**Area/Ha**	**Area%**
Built-up-Area	356.746	11.22%	423.166	13.31%	560.246	17.63%	1019.696	32.08%
Wetland	379.876	11.95%	391.486	12.32%	422.946	13.31%	453.496	14.27%
Agriculture	1979.882	62.29%	1898.252	59.72%	1857.702	58.44%	1382.642	43.50%
Forest	424.876	13.37%	423.166	13.00%	300.146	9.44%	289.866	9.12%
Water	37.17	1.17%	42.48	1.34%	37.51	1.18%	32.85	1.03%
Grand total	**3178.55**	**100%**	**3178.55**	**100%**	**3178.55**	**100%**	**3178.55**	**100%**

*Source: (**https://earthexplorer.usgs.gov and NISR, 2022**)*

Similarly, the dynamics of forest cover in the Masaka sector experienced notable fluctuations. Forest cover slightly decreased from 13.37% in 2008 to 9.12% in 2023. This reduction is primarily

attributed to the conversion of forested areas into built-up regions, highlighting the pressure on natural habitats due to expanding urban infrastructure.

Figure 9: Land use land cover and net change statistics per period



*Source: (**https://earthexplorer.usgs.gov and NISR,2022**)*

The study revealed that these changes occurred due to the increased demand for land for construction. the wetland behind the Inyange Industries has been transformed into a small lake, and other parts of the wetland have been managed, which is why we observe changes in the wetland. 57% respondents said that, the classes of agriculture, vegetation, and forest exhibited the most significant shifts in land use conversion because of the development of settlement, as shown in the appendix (***appendix 1 and 2)*** tables of land use change matrix.

4.3 Environmental Challenges induced by the growth in Masaka Sector

Despite the established measures to regulate the human settlement, the rapid growth of the Masaka sector from 2008 to 2023 has induced different environmental challenges, particularly concerning deforestation purposively to land for settlements. As the population increased and urbanization intensified, there were a substantial rise in the demand for land for residential, agricultural, and commercial purposes. This expansion led to extensive clearing of forests, which in turn resulted in the loss of urban forest, the loss of urban forested areas reduced the natural carbon sequestration capacity of the region, contributing to higher local carbon emissions and climate change impacts in coming years.

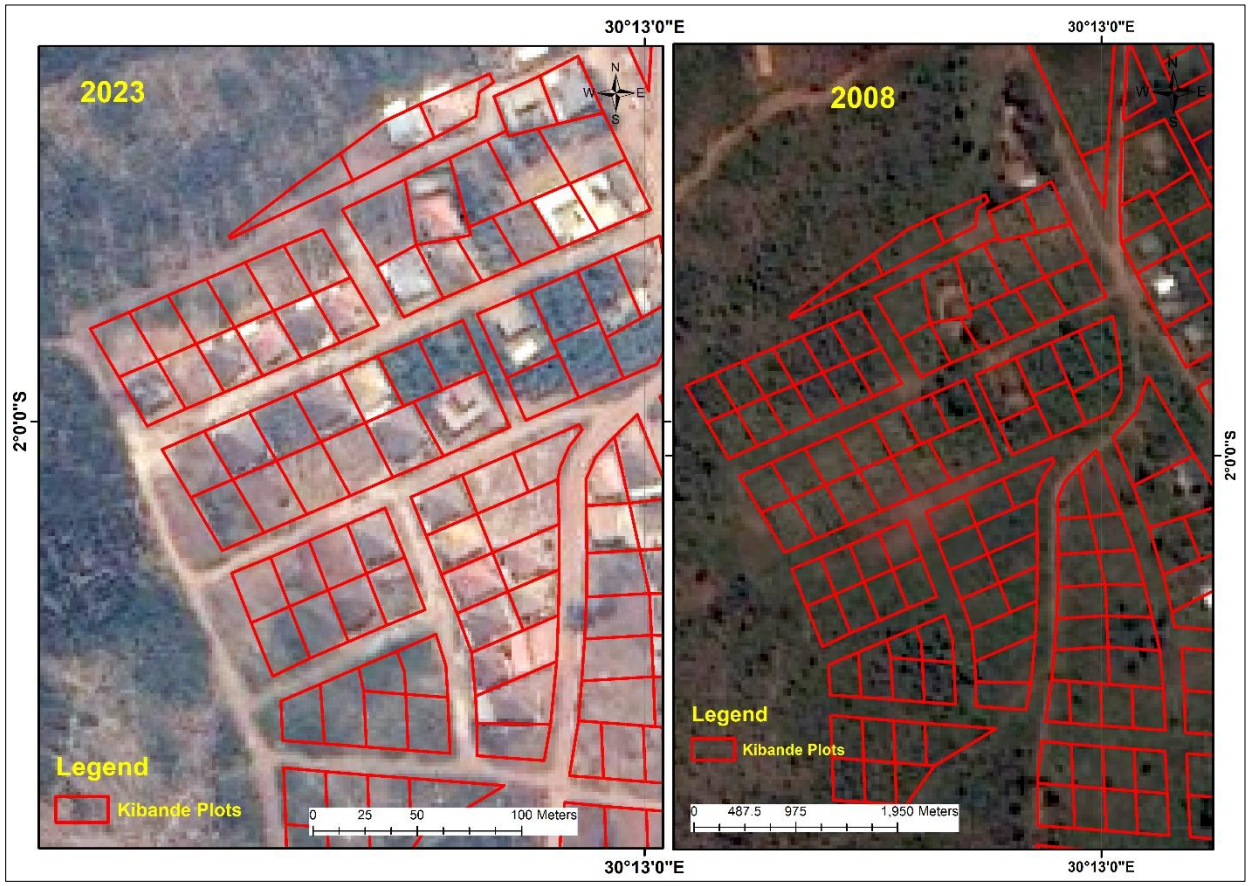
4.3.1. Loss of forest cover

According to standard size of forest as stated in Rwanda Forest Cover Mapping in November 2019, where it defined a forest size that should be having minimum size of 0.5 hectares, as shown on *figure 20* about how the growth of Masaka is encroaches the forest area and despite the measures taken regarding to urbanization in Masaka sector, the reduction in forested areas, alongside the expansion of urban development, raises significant concerns regarding environmental degradation.

In 2008, forests covered 13.37% of the entire study area. By 2013, this percentage had slightly decreased to 13%. However, by 2018, forest cover had significantly dropped to 9.44%. This decline is largely attributed to the implementation of the Kigali City Master Plan, which led to the conversion of forested areas into residential zones. By 2023, forest cover had further reduced to 9.12%. In Masaka, urban expansion has been steadily increasing, but this growth has come at the expense of forested areas.

This decline can be attributed to the conversion of vegetation cover into built-up areas as urbanization continues to expand. *The figure20* also shows how the forest was replaced by the settlement. The loss of forest covers due to urbanization growth have profound impacts on environmental sustainability and they play a crucial role in filtering pollutants and maintaining water quality, particularly concerning wetlands pollution, drainage systems, green spaces, and open spaces. As urban areas expand, the natural landscapes that once served as vital ecosystems were replaced by buildings and infrastructure.

Figure 10: Replacement of urban forest by settlements



Source: (CoK, 2020 and Google Earth Image of 2008-2023)

Environmental experts from NLA and the Rwanda Housing Authority argued that the transformation of forest into built up areas leads to the degradation of wetlands. Without the natural filtration provided by wetlands, urban runoff, often laden with pollutants. Moreover, the destruction of vegetated areas increases the likelihood of soil erosion and sedimentation in drainage systems, resulting in frequent blockages, flooding, and reduced efficiency of stormwater management infrastructure.

The removal not only diminishes these critical functions but also reduces recreational areas that contribute to the physical and mental well-being of urban populations. The absence of these natural spaces leads to a decrease in biodiversity and disrupt local ecosystems, making the urban environment less resilient to environmental changes. Thus, the unchecked loss of vegetation and forest cover due to urbanization poses a severe threat to the sustainability and livability of urban

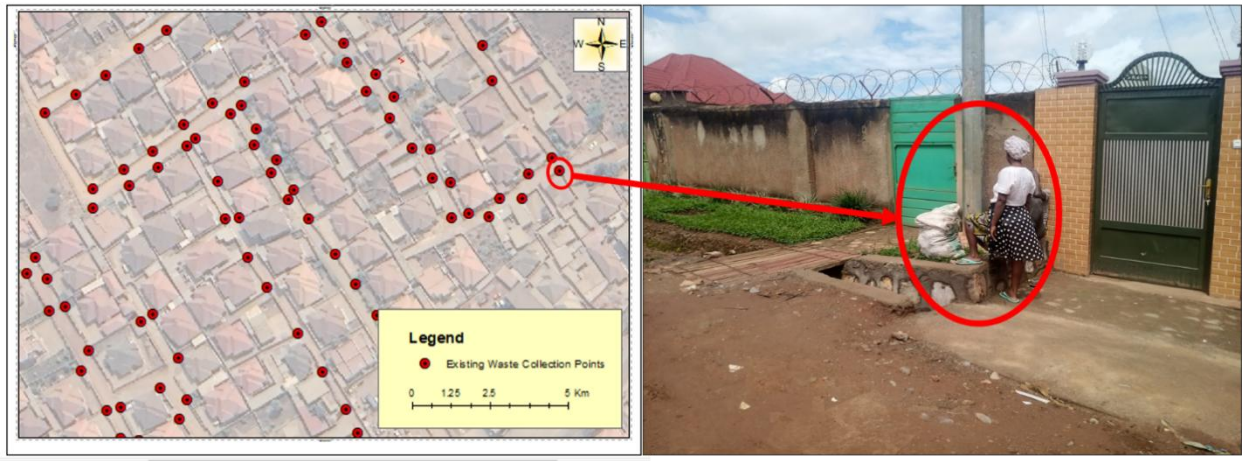
areas, necessitating comprehensive planning and conservation strategies to mitigate these adverse effects.

4.3.2. Lack of Solid Waste Management

The growth of Masaka Sector has resulted in population growth and the rate of solid waste production has been gone far in high productivity rate, which needs the effective management The Masaka Sector faces significant challenges of waste management, which are worsened by rapid population growth and increased urban activities. Meaning that, the study revealed that the current waste management practices are outdated, and the Masaka dwellers are still relying on traditional methods such as dumping waste on agricultural lands. This practice has become increasingly unsustainable with the sector's growth, resulting in improper waste disposal and accumulation in open areas.

"In Masaka site, despite how it is being developed faster, but the issue of solid waste management remains substantial. Some people are still dumping waste into drainage channels and other areas not designed for waste disposal. Additionally, companies responsible for waste collection are often delayed, which could lead to the emergence of new diseases."[2]

Figure 11: Distribution of Waste in sacks during the collection



Source: (Google Earth image, 2023 and Field Survey, June 2024)

[2] Interview with Masaka residents, 2024

According to 55% of respondents, argued that the waste management is a significant problem. The respondents noted that most residents store their waste in sacks and wait for collection by the waste collection service company they subscribe to. They also highlighted that waste collection is inconsistent; it can sometimes take more than two weeks for collection, and when collection does occur, residents are expected to deposit their waste at their gates. This irregularity leads to illegal dumping practices as indicated on *figure 12*. This infrequent disposal underscores severe issues in the study area's primarily due to the absence of designated collection points. The lack of proper disposal stations results in waste ending up in open dumps or drainage systems.

As shown on *Figure 12*, the red points illustrate how during the waste collection, the entire neighborhood venues become congested with sacks of waste. This accumulation not only creates an unsightly environment but also poses health and safety risks to the community. The congestion indicates the urgent need for more efficient and frequent waste collection services to mitigate these issues.

Figure 12: Illegal dumping

Source: (Field survey,2024)

4.3.3. Limited Open and Green Spaces

Green space and open space, while often used interchangeably, have distinct definitions in urban planning and development. Green space specifically refers to areas covered with vegetation, such as parks, gardens, and natural reserves, which provide environmental benefits like air purification, temperature regulation, and habitats for wildlife.

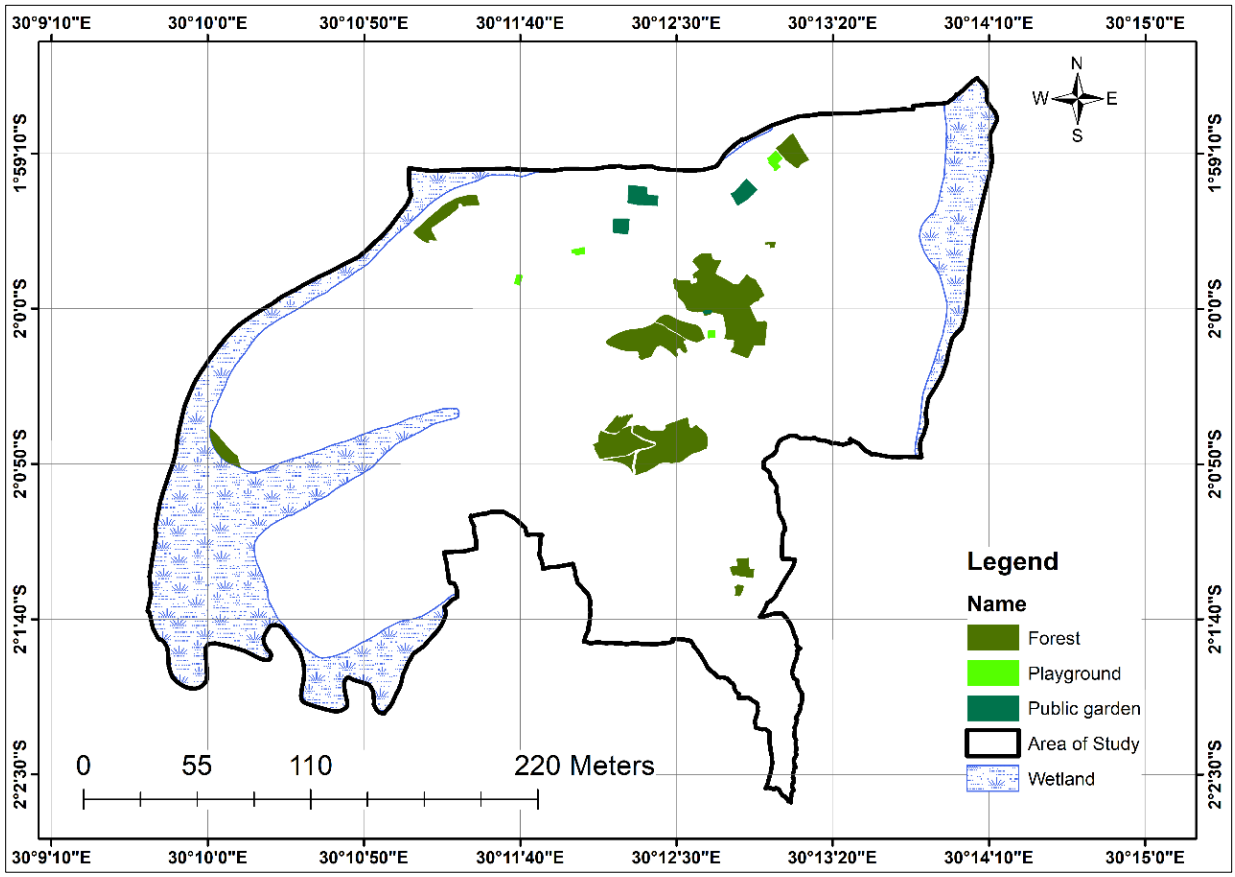
Open space, on the other hand, encompasses a broader category that includes not only green spaces but also other types of undeveloped land such as plazas, sports fields, and vacant lots. Open spaces can be paved or unpaved, vegetated or barren, and are generally intended for public use, recreation, and community activities. While all green spaces are open spaces, not all open spaces are green, highlighting the nuanced difference between these two important urban elements.

In the context of the Masaka sector, the distinction between green space and open space becomes particularly relevant. Masaka, like many urbanizing areas, is experiencing rapid growth, which poses challenges to maintaining environmental sustainability. In this sector, green spaces such as community parks and tree-lined streets are crucial for mitigating the urban heat island effect and providing residents with recreational areas.

"When we are granted construction permits, aspects related to landscaping are often neglected. As a result, people build structures as they requested in their permit, and even during inspections, green spaces are not considered. It is important that these aspects are also addressed, as they benefit the city[3]"

[3] Interview with Masaka residents

Figure 13:Existing of forest, green and Open spaces



Source: (NISR and Field Survey, 2024)

According to the respondents, 55% identified that the lack of green spaces and open areas is a critical issue. This indicates that in the Masaka sector, the limited development of green and open spaces reflects inadequacies in physical planning, resulting in limited recreational opportunities for residents.

Table 3:Analysis of green spaces availability in the study area

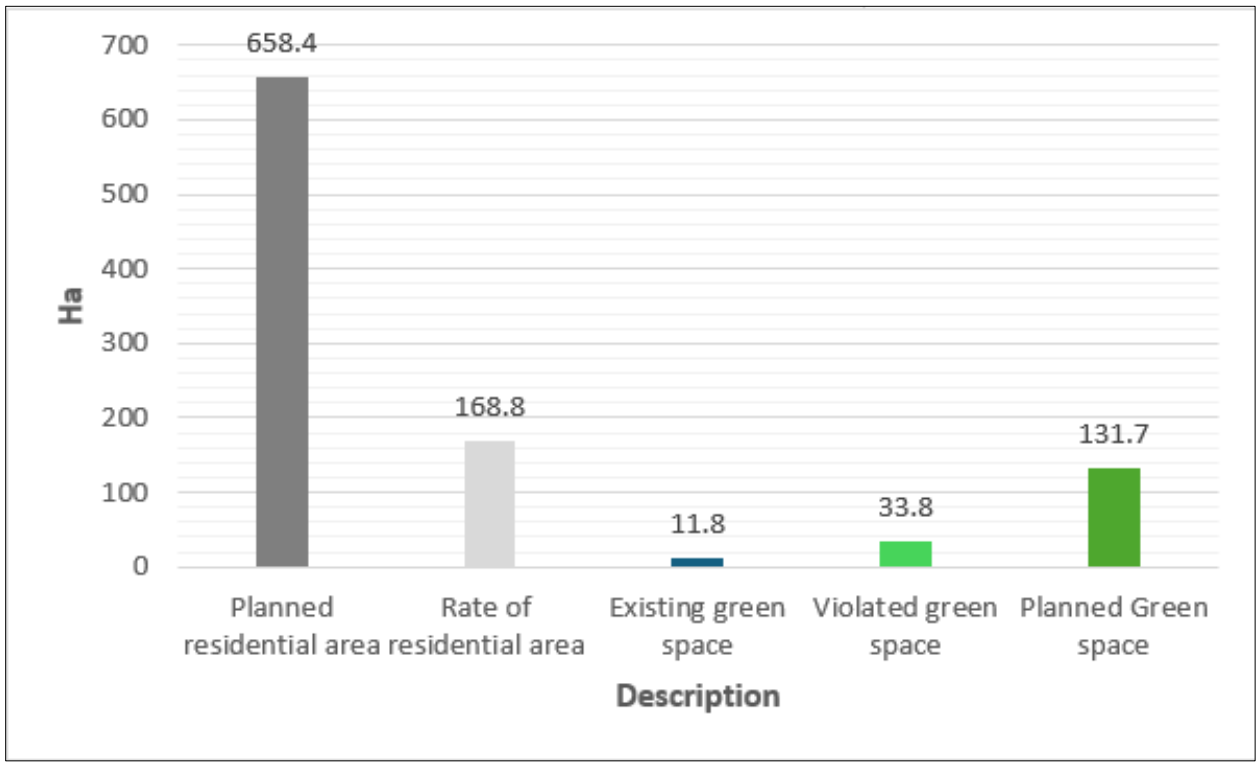
Description	**Quantity (Ha)**	**Percentage**
Planned residential area (Total area according to the Physical plan and Master plan)	658.4	
Current share of residential area	168.8	25.64 %
Current share of the green space	11.8	8.97 %

Share of green space used for residential house development	33.8	25.64 %
Planned Green space as per zoning regulation	131.7	

Source: (NISR,2022 CoK and Field survey)

The research analysis reveals that the average amount of green space per parcel is estimated to be 7%, significantly lower than the minimum 20% standard per parcel that required by zoning regulations. This discrepancy indicates that zoning regulations are not being consistently adhered to. The area designated for settlement covers 658.4 hectares, including 131.7 hectares of green spaces. However, the area that has already been settled is 168.8 hectares, which should correspond to 33.8 hectares of green space. But the study shows that only 11.8 hectares of green space have been realized. This shortfall is due to residents not complying with the legal requirements. Consequently, the target of achieving 131.7 hectares of green space across the entire site may not be met unless action is taken.

Figure 14: Availability of Green spaces availability status comparing with master plan



Source: (NISR, CoK and Field survey, 2024)

Furthermore, the current green space situation shows that only 8.97% of the area is dedicated to green spaces, whereas it is supposed to be 25% considering the rate of settlement in the study are, highlighting a considerable shortfall in the provision of green spaces in the Masaka sector while the growth continues.

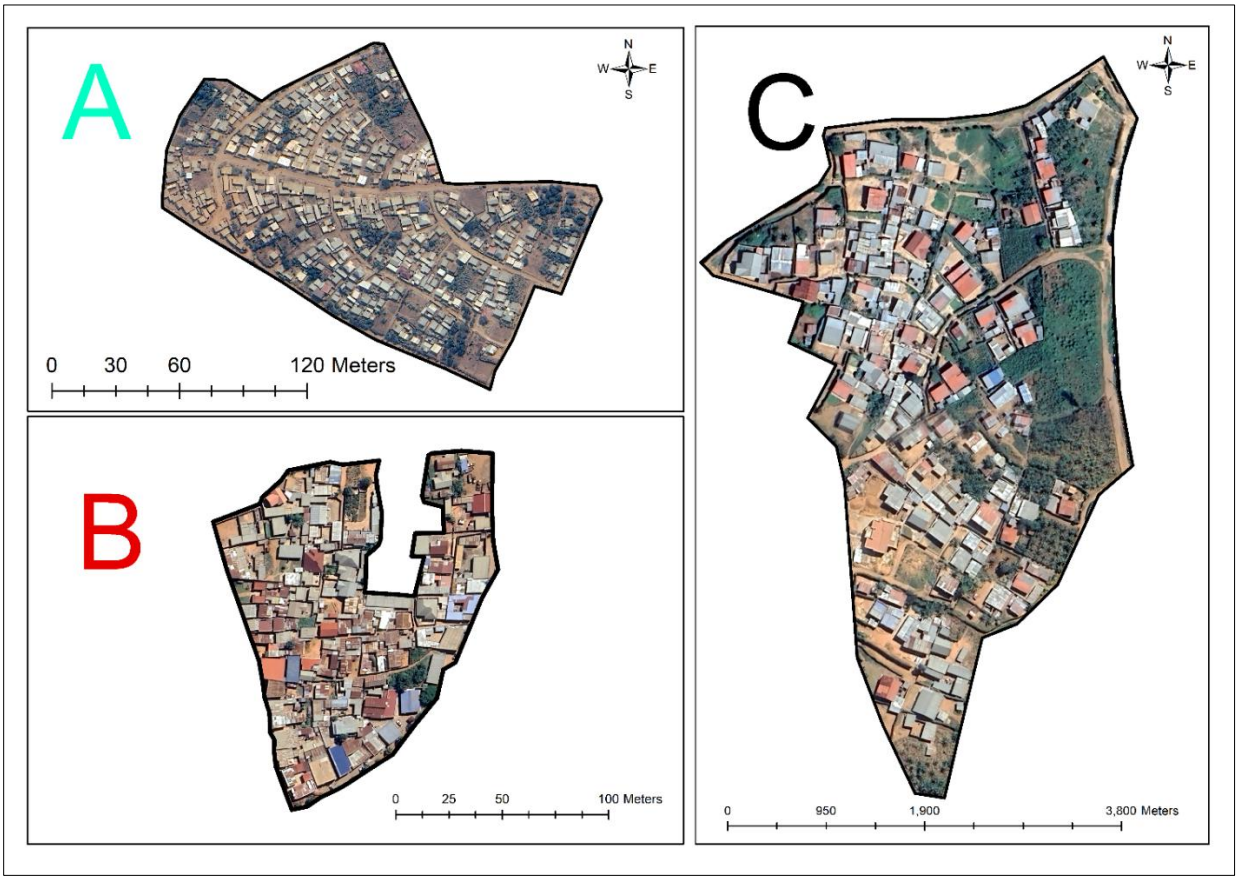
Figure 15:Measurement of Green space availability in Masaka per Households

Source: (Field photo, 2024)

4.3.2. Informal settlements development

Informality areas in the context of the Masaka Sector refer to regions where buildings and settlements are developed without adherence to zoning regulations, the master plan, and Rwandan building codes. These areas typically feature substandard housing and are often established by individuals seeking to create small rental housing without following official guidelines.

Figure 16: Distribution of informal settlements based on the satellite images



Source: *(Google Image 2024 and Field photo, August 2024)*

The development of informal areas in the Masaka Sector are being developed and impacting its neighboring communities in several ways, as noted by 65% of respondents argued that these problems are being caused by those who want to develop small housing for rent another highlighted informality are those who settle in area without respecting the master plan. This study had mapped the areas that have congested with substandard house based on the Rwandan building code and land use regulations as mapped on the *figure 13* and these informality areas are characterized by:

Table 4: Characteristics of informal areas in the study area in comparison to planned areas.

Informally developed Areas	**Areas developed according to zoning regulations**
• Buildings are developed without respecting zoning regulations	• Buildings are developed in accordance with zoning regulations
• Lack of access to servicing like roads, drainage system	• Houses are developed according to Rwandan building code and land use regulations
• Congestion of small houses for rent in one plot plus the main house and those houses are substandard • Small shops are dispersed within the neighborhood	

Source: (Field observation, 2024)

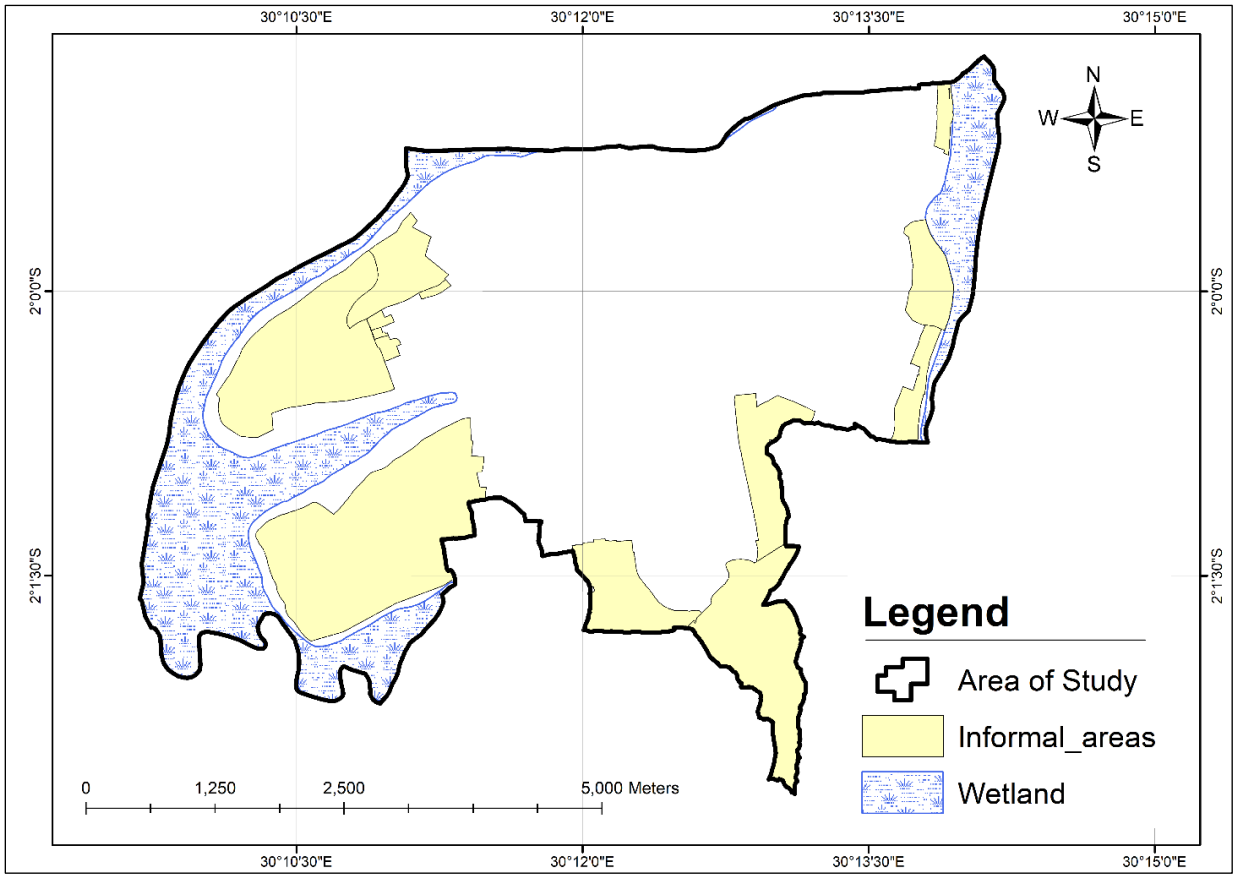
The primary effects of informality settlement are the strain on existing infrastructure and public services. Masaka Sector's informal settlements typically lack the drainage system, and waste management systems. This are leading to increased unsanitary pressure on neighboring areas' resources. As these informal areas grow, they are causing pollution wetland. These areas usually lack formal waste collection and disposal services, leading to the proliferation of illegal dumping sites. The presence of large amounts of waste in informal areas lead to the spread of diseases and adversely affect the health of residents in both informal and adjacent formal neighborhoods.

"Residents say that substandard houses that are being built in a chaotic manner because those who want to build modest houses often negotiate with the village or cell leader, who then turns a blind eye. Additionally, even if someone has obtained all the necessary construction permits, they often want to build a shop as well, which also contributes to the disorder in the city."[4]

[4] Summary of dwellers' arguments, compiled during the household survey

As shown in the figure 13. People are moving to settle far from the planned designated sites, leading to the continued growth of informal settlements. These houses often lack access to water, have limited electricity, and some areas, like Rusheshe, have no electricity at all. This situation also causes security issues due to poor lighting.

Figure 17:Location of informal settlements in Masaka Sector



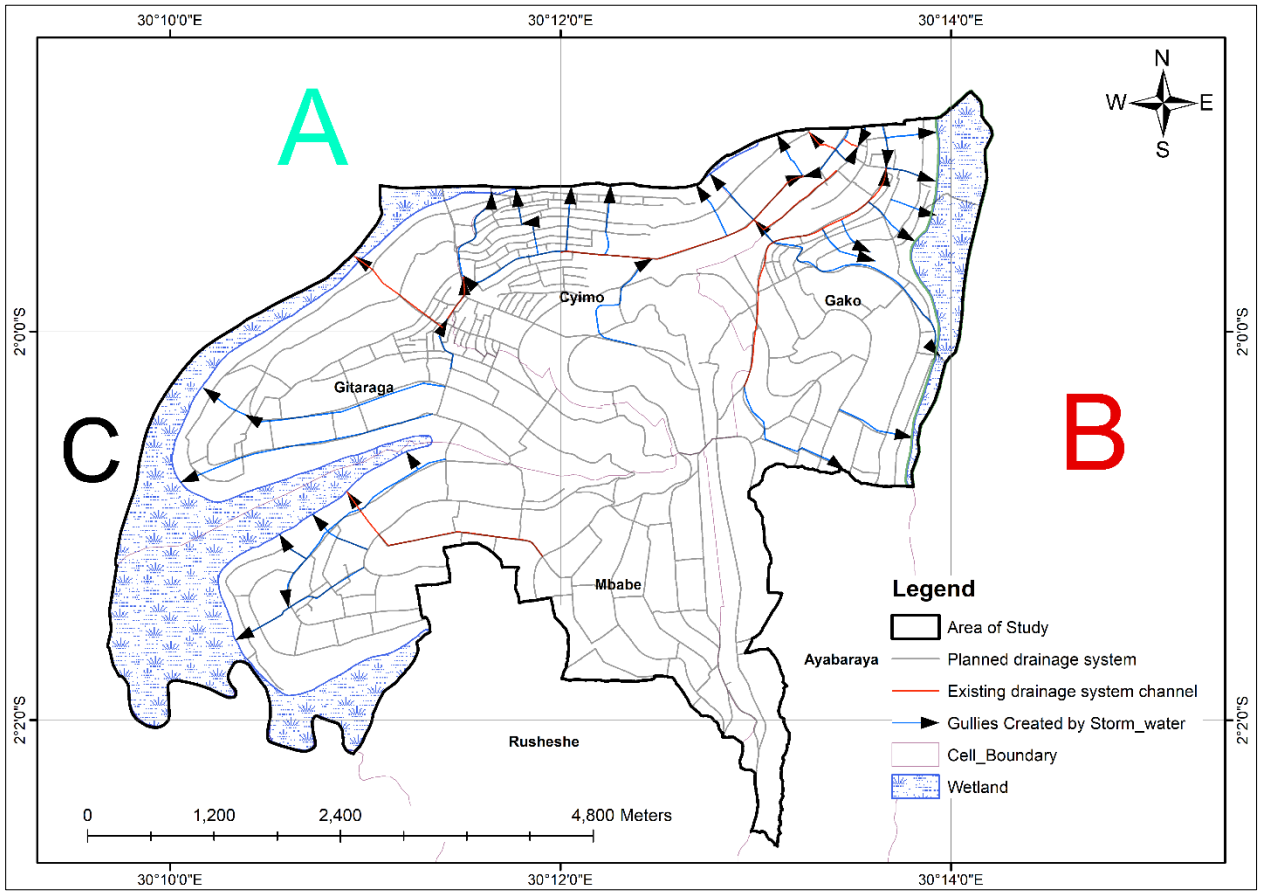
Source: (NISR,2022 and Field survey,2024)

4.3.4. Lack of Drainage System

Stormwater in a residential area of Masaka sector comes from multiple sources, including rooftops, paved surfaces, and roads during rainfall. The amount of stormwater generated is influenced by the rainfall's intensity and the type of surface it contacts. Vegetated surfaces reduce runoff by allowing rainwater to soak into the soil. In contrast, impermeable surfaces prevent infiltration, leading to higher volumes of runoff. This increased runoff from impermeable surfaces can contribute to various problems, such as flooding, erosion, and water pollution.

Managing stormwater effectively requires incorporating green infrastructure, such as rain gardens, permeable pavements, and green roofs, which help to absorb and filter rainwater. These measures can mitigate the adverse effects of stormwater runoff, promoting a more sustainable and resilient residential environment. The rapid urban growth of Masaka Sector has brought several drainage system challenges. 75% of respondents highlighted that the drainage system is problematic since Masaka started being developed. The finding shows that 10.6 % are only the drainage system available within the site and 38.9 % are formed by the heavy rainfall, the residents argued for the necessity of constructing a common drainage system that can serve the entire neighborhood, rather than small, individual sections. They believe that a collective approach would provide a more sustainable solution compared to the fragmented systems currently in place.

Figure 18: Drainage System in Masaka



Source: (NISR,2022; OSM, 2024 and Field Survey, 2024)

As shown in ***Figure 14*** above there are existing drainage system and drainages created by the heavy rainfall near and the center of the roads, Letter **A** indicates the surveyed downflow direction

where all water accumulated from drainages created by the heavy rainfall and the flows carrying debris pollute the wetland. Additionally, Letter **B** also indicates the surveyed downflow direction occurring on the right side of the figure and **C** indicates the surveyed downflow direction occurring on the left side.

Figure 19:Gullies resulting from the rain water

Source: (Field photo, 2024)

These have resulted in frequent flooding, especially during heavy rains, as the existing drainage systems are overwhelmed by the volume of water. The respondents also said that the runoff also carries pollutants from urban areas into wetlands. The combined effects of inadequate drainage infrastructure and extensive impervious surfaces necessitate urgent attention to sustainable urban planning and effective water management strategies to mitigate these adverse impacts.

4.4. Practical actions for enhancing environmental sustainability

The rapid urban growth in Masaka Sector has significantly altered its landscape, the findings shows that different actions that could be made so far to enhance the environmental sustainability. The study identified a substantial shift from agricultural and natural landscapes to urban areas, driven primarily by population growth, economic and social development. This transformation has led to the conversion of large swathes of agricultural land into residential and commercial zones, resulting in a marked reduction in green spaces and open areas. the control should be made in order to control this growth without hampering the surrounding, also urban dwellers should be enforced in introducing urban agriculture to keep having the balance of ecosystem.

4.4.1. Practical actions for development of Green spaces

The loss of green spaces and forest cover in the Masaka sector have been found as problematic, whereby the study revealed the current green space provision of 8.97% is significantly below the required 25%, and the average green space per household stands at only 7%, far less than the mandated 20% per residential plot. There is a practical necessity for ensuring that what is planned during development is executed as intended, these will result in having the balance of green space and built up.

The Urban planners should take actions on policies that incentivize the creation and maintenance of green spaces within the planned site by not making the parcellation only as shown on ***figure 21*** but also including all aspects based on the neighborhood requirements. Additionally, initiatives such as urban reforestation and the establishment of community gardens can help restore ecological balance, enhance biodiversity, and provide recreational areas for residents. The study has revealed that most people they don't know or aware on how these green spaces should be implemented.

Other action is when the site is to be implemented by the consultant, it is necessary to recommend that they plant trees along the planned roads. Once the site is handed over to the owners, they should improve and maintain existing green spaces by upgrading facilities and ensuring regular upkeep of the planted trees along the roads. Additionally, they should ensure that these new green spaces are evenly distributed across the community and establish volunteer programs for the upkeep of green spaces, such as tree planting alongside the roads and maintenance.

4.4.2. Proposed actions for solid waste management

waste management is a critical area that requires urgent attention in the Masaka Sector. The current practices, which rely on infrequent and inadequate waste collection, lead to significant environmental pollution. To enhance sustainability, it is essential to establish efficient waste management systems that include regular waste collection services and designated disposal sites within the neighborhood by establishing waste collection stations.

"Residents say that the waste collection company takes too long just for 3 weeks or 4 weeks to come because there is no set schedule for waste collection, which causes hygiene issues in their

homes. Additionally, some people who have not subscribed to waste collection services also contribute to the problem by dumping waste in drainages and other places. However, the company explains that the city is growing rapidly, so there are not enough trucks to cover all areas. Sometimes, they even knock on the gate, but no one opens, leaving the waste in the homes. Therefore, it is necessary to consider establishing waste collection points to make it easier for the waste collectors and to ensure that residents do not miss out."[5]

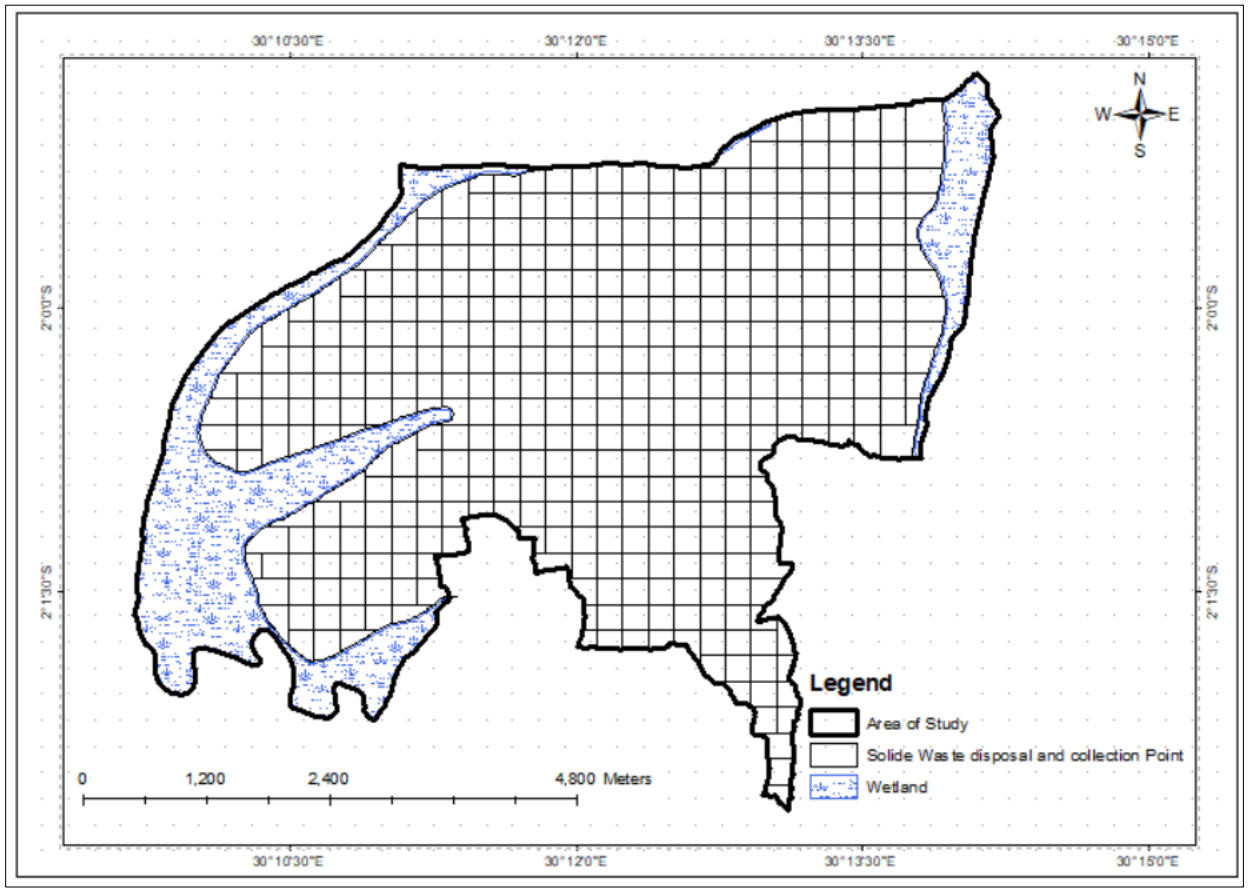
Referring to the Experts from RHA, REMA and NLA all they emphasized on the Rwanda urban planning code gazette on 16/04/2019which is now under revision chaired by MININFRA and RHA with other stakeholders, in its chapter two *section 2.2.1*, it recommends that the maximum travel to solid waste point should not exceed 250m, by the analysis made during the study it shows that the waste disposal point that have standards are 422 as distributed on the *figure 22*.

Each box represents where a waste collection point would be placed, allowing residents to bring their waste there. The company they subscribe to would then come and collect the waste from these points, instead of waiting for them to pick it up from individual homes and potentially missing some when people aren't available. The solution of establishing waste collection points in communities of Masaka sector can significantly improve public health and waste management efficiency.

These waste collection points help prevent the accumulation of waste in households, reducing the risk of disease by providing a designated area for regular disposal. Additionally, centralizing waste collection simplifies management, transport, and processing, while also encouraging recycling. The temporary and space-efficient design of these collection points makes them easy to implement without disrupting the community. The Public education campaigns on waste management can also foster community involvement and reduce the environmental impact of waste.

[5] Interview with Masaka residents and waste collection service company

Figure 20: Spatial distribution of waste collection point the study area



Source: (NISR,2022 and Field Survey, 2024)

4.4.3. Practical actions for Drainage system Development and wetland Management

To solve the issues of drainage system to manage surface runoff that are polluting the wetland. The findings highlight the need for more extensive and efficient drainage systems. The practical action proposed is to establish the necessity of constructing a common drainage system that can serve the entire neighborhood, rather than small individual sections and establishing vegetative buffer zones around wetlands that can help to filter out pollutants from runoff before they reach the wetland areas.

This can be done during Umuganda or through financial contributions. This approach would provide a more sustainable solution compared to the fragmented systems currently in place. Urban planners should also integrate green infrastructure solutions such as rain gardens, bioswales, and

permeable pavements. These measures facilitate natural infiltration and filtration processes, thereby reducing the gullies that damage the roads. Policymakers must ensure that these solutions are incorporated into urban development plans and that regulations are strictly enforced.

"In areas where residential sites are being developed, there is often no drainage system, and sometimes builders forget to include drainage. Occasionally, when drainage systems are constructed, they do not meet quality standards. This issue could be addressed by raising awareness about the requirements for building in drainage systems, as many studies now require showing where water will flow based on specific sites, rather than just clearing plots for housing. And they advised also to have vegetative buffer around the wetland which will help to curb the pollution of wetland ecosystem"[6]

An effective drainage system is crucial for managing stormwater, preventing flooding, and ensuring public health and safety. In Masaka sector, where current drainage systems need to be improved, addressing these issues is essential. Constructing the existing systems will improve their capacity to manage increased water flow during heavy rains, thus reducing the risk of waterlogging and property damage.

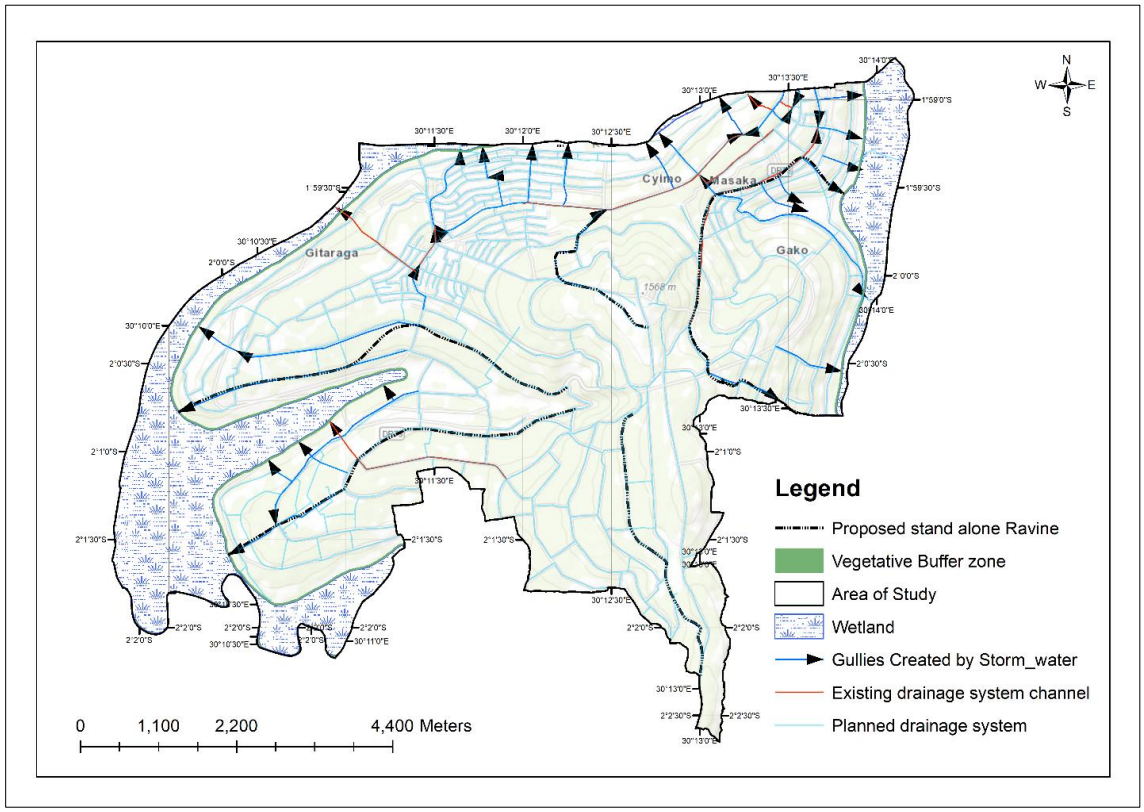
Figure 21: Gullies deteriorating Roads within the study area

[6] Interviews with local leaders, Kigali city authorities and Experts form central Government 2024.

Source: (Field photo, April 2024)

Additionally, developing new drainage infrastructure in areas without, it is necessary to prevent erosion, avoid stagnant water accumulation, and reduce health risks associated with standing water. This could be done through community education and awareness campaigns. *The figure 23* shows the proposed standalone drainage ravine the could be constructed in supporting the planned drainage system, these all will help to manage the storm water management within the all site and channeled into vegetative buffer.

Figure 22: Proposed ravine comparing with the planned drainage system and Vegetative buffer to retain stormwater



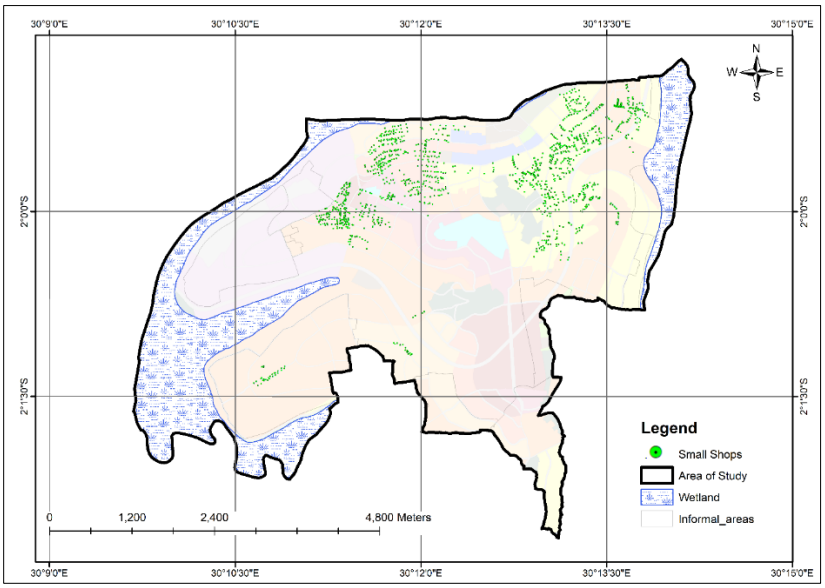
Source: (NISR, 2022 and Field survey, 2024)

4.4.4. Practical actions for preventing the informal settlements development

To tackle the issues of substandard small housing and the proliferation of small shops in Masaka, a multi-faceted approach is essential. Strengthening Rwanda urban planning code and zoning regulations, along with enforcing regular inspections, can ensure that new housing and small shops adhere to safety and quality standards, these will help manage the types of developments allowed in different areas, and creating designated commercial zones with respect to Rwanda urban planning code as stated in Official Gazette of 16/04/2019, where it states that the Minimum servicing requirements with facilities for upgraded neighborhoods retail shop should be within 500 m if these followed it will help to prevent the encroachment of small shops into residential neighborhoods.

Improving housing quality and infrastructure is also crucial. By promoting affordable housing programs and supporting the renovation of existing substandard homes, the overall quality of living can be enhanced. Additionally, upgrading utilities and public spaces will support better housing and commercial developments. Developing new infrastructure where it is lacking will help mitigate issues related to erosion, stagnant water, and health risks.

Figure 23: Location of informal settlement zones and small in the study area



Source: (CoK, 2020; NISR, 2022 and Field Survey, July 2024)

It is also essential to educating residents and potential developers about the importance of adhering to building codes and the long-term benefits of formal development, communities can become more proactive in supporting regulatory measures. Additionally, developing affordable housing programs in new developed site can provide viable alternatives to informal areas. It is also needed to establish small markets within the site that can serve the community where these can alleviate informal constructions of small shops that are being developed within neighborhood.

"The issue of informal settlements is often caused by people fleeing areas that are undergoing significant development. They tend to move to more remote areas where it is easier to farm and build without many restrictions. To address this, Mixed use, incremental housing and affordable housing should be constructed in these developing zones, and residents should be prevented from building without proper permits".[7]

This approach reduces the need for long commutes, encourages local economic activities, and creates vibrant, self-sustaining communities. By providing residents with access to essential services and employment opportunities within their neighborhoods, mixed-use developments can discourage the spread of informal settlements, as people are less likely to seek cheaper, unregulated housing in remote areas.

Incremental housing offers a flexible and cost-effective solution for addressing the housing needs of low-income populations in Masaka Sector. This approach allows residents to build their homes in phases, starting with a basic, affordable unit and gradually expanding or improving it over time as their financial situation allows. By providing secure land tenure and basic infrastructure, incremental housing enables people to invest in their homes without resorting to informal settlements. This strategy not only improves living conditions but also promotes social stability and long-term urban planning in Masaka.

Affordable housing is crucial in preventing the proliferation of informal settlements. By constructing affordable housing units in strategically planned areas, the government and private developers can provide low-cost, decent housing options for low- and middle-income families. Affordable housing, combined with policies that prevent unpermitted construction, ensures that

[7] Interview with Government Institutions Experts from MININFRA and RHA

residents have access to legal, safe, and sustainable housing solutions. This approach reduces the incentive for people to settle informally, contributing to the overall orderly development of Masaka and enhancing the quality of life for its inhabitants.

Community engagement and economic incentives can further support these efforts. Educating residents and developers about the benefits of adhering to building standards and involving the community in planning processes will ensure that developments meet local needs. Providing financial assistance for housing upgrades and supporting small businesses in designated commercial areas will contribute to a more organized and sustainable urban environment in Masaka.

Chapter 5: Conclusion and Recommendations

5.1. Conclusion

Urban growth plays a crucial role in shaping economic development, infrastructure expansion, and social dynamics in cities. It can drive progress and innovation, but it also presents challenges such as environmental impact, resource management, and the need for sustainable planning in Masaka Sector. This study aimed to assess the spatial-temporal dynamics of urban growth in Masaka Sector and its impact on the environmental sustainability. By evaluating land use and land cover changes; identifying the challenges to environmental sustainability driven by urban growth; and proposing practical actions for policymakers and urban planners, this research provides a comprehensive analysis of the impacts of urbanization in Masaka Sector.

Based on the findings, the present study achieved its specific objectives. Firstly, the study successfully evaluated the spatiotemporal dynamics of land use/land cover changes in Masaka Sector. The findings revealed with a notable expansion of built-up areas and a corresponding reduction in agricultural and forest cover. This growth has resulted in key environmental sustainability challenges, including inadequate waste management, informality developments, poor stormwater management, loss of green and open spaces, and the wetland pollution. The urban growth of Masaka sector over the 15-year period has been systematically documented, demonstrating how the area has evolved in response to increasing population and urban pressures.

Secondly, the research identified key environmental sustainability challenges associated with the observed urban growth. These challenges include the violation of open and green spaces from what master plan designated too, loss of urban forest due to the high pressure of needing the lands for residential, increased environmental degradation, heightened pollution of wetland due to unconstructed drainage system and the gullies created by the heavy rainfall, problems of solid waste management and drainage system and the strain on essential resources such as water and energy. The study highlighted the adverse effects of these challenges on both the environment and the quality of life for residents in the sector.

Lastly, the study proposed practical actions to address these challenges. These actions include integrating green infrastructure into urban planning, promoting sustainable land use practices, enforcing environmental protection regulations such as establishing vegetative buffers to protect wetlands from pollution, improving drainage systems, establishing waste collection points, creating market areas within neighborhoods, introducing mixed uses and affordable housing, and developing incremental housing to curb the proliferation of informal areas. Additionally, implementing continuous monitoring systems will guide future urban development. These recommendations aim to mitigate the negative environmental impacts and foster a more sustainable urban environment in Masaka Sector.

In conclusion, the study achieved all of its specified objectives. It provided a comprehensive analysis of land use changes, identified critical environmental sustainability challenges, and offered actionable solutions for enhancing environmental sustainability in the face of ongoing urban growth. These findings and recommendations serve as a valuable resource for policymakers and urban planners striving to ensure a balanced and sustainable development path for Masaka Sector.

5.2. Recommendations

Based on the findings, the following recommendations are proposed to address the identified environmental sustainability challenges and promote sustainable urban development in Masaka Sector these recommendation goes to City of Kigali and Rwanda Environmental Management Agency:

- **The City of Kigali**

The city of Kigali as mandated to prepare the master plan of the City of Kigali, specific master plans and to ensure their implementation, should enforce strict land use regulations to control urban growth by Conducting regular land use assessments to monitor changes and address any unauthorized developments promptly. This will help to manage urban growth more effectively and prevent unsustainable expansion. By implementing these recommendations, Masaka Sector can navigate urban growth more sustainably, balancing development with environmental preservation and enhancing the quality of life for its residents.

The city of Kigali should engage the community to construct a common drainage system that can serve the entire neighborhood, rather than small and individual sections. This collective approach would provide a more sustainable solution compared to the fragmented systems currently in place construct and maintain efficient drainage systems to manage stormwater effectively, thereby reducing the risk of road destruction and wetland pollution. These could be done by establishing rain gardens and permeable pavements, to enhance water absorption and reduce runoff. These measures can help prevent erosion and waterlogging, contributing to better urban resilience.

The city of Kigali should also ensure that the implementation of planned green spaces and urban forest adheres to zoning regulations, rather than solely focusing on inspecting construction structures. It is crucial that green space planning is integrated into the regulatory framework to promote environmental sustainability and enhance urban livability. The study recommends also to establish small markets within the site that can serve the community where these can alleviate informal constructions of small shops that are being developed within neighborhood.

- **Rwanda Environmental Management Agency**

It is necessary to develop and implement a robust waste management system to ensure proper disposal by establishing waste collection station within the neighborhood instead of putting the sacks of waste along the roads and gates. This should include increasing public awareness about waste collection management and effective waste management is crucial to minimizing environmental impact. The study recommends also to establishing vegetative buffer zones around wetlands that can help filter out pollutants from runoff before they reach the wetland areas.

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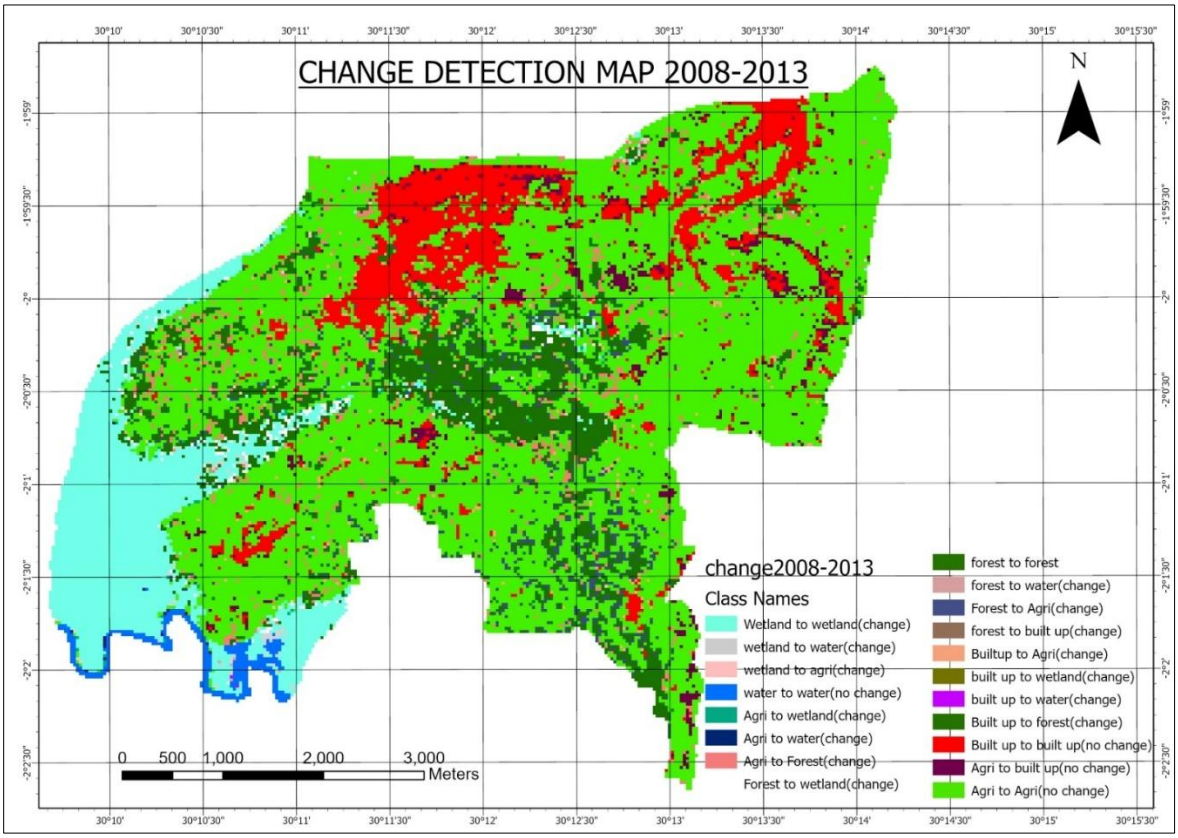
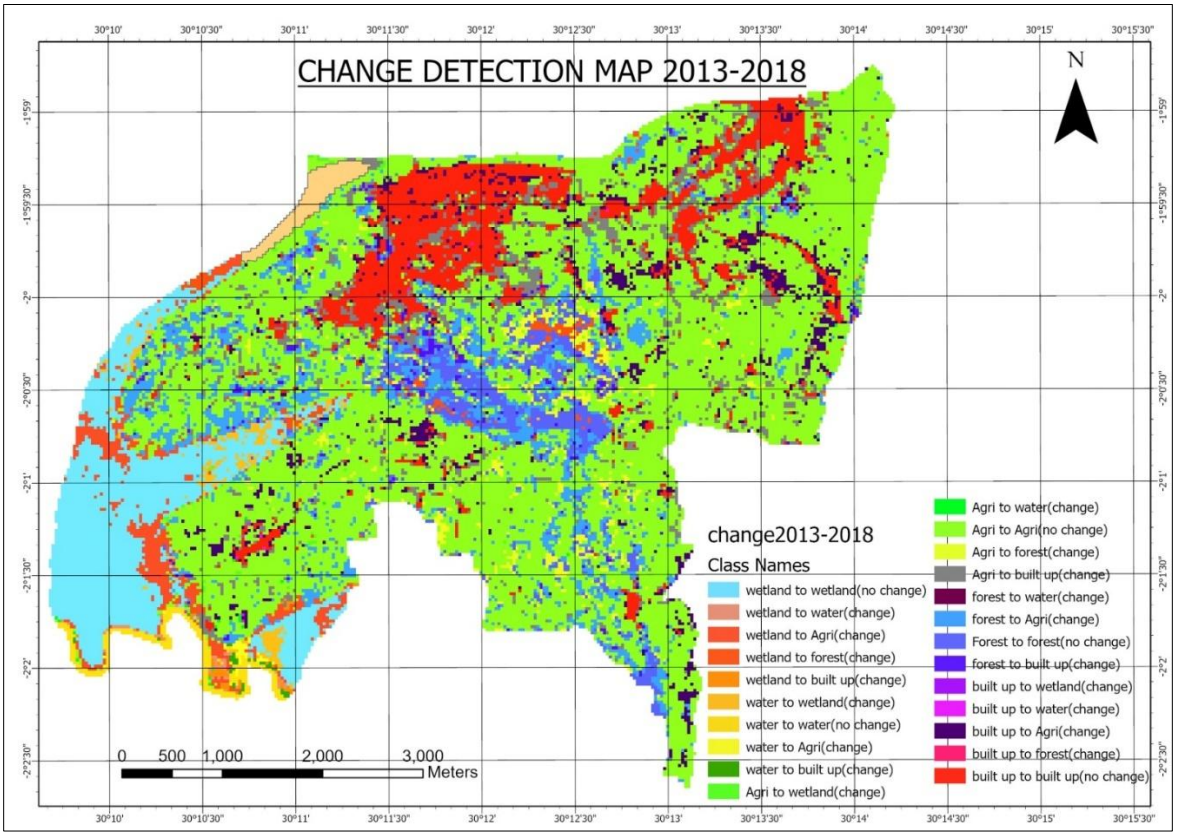
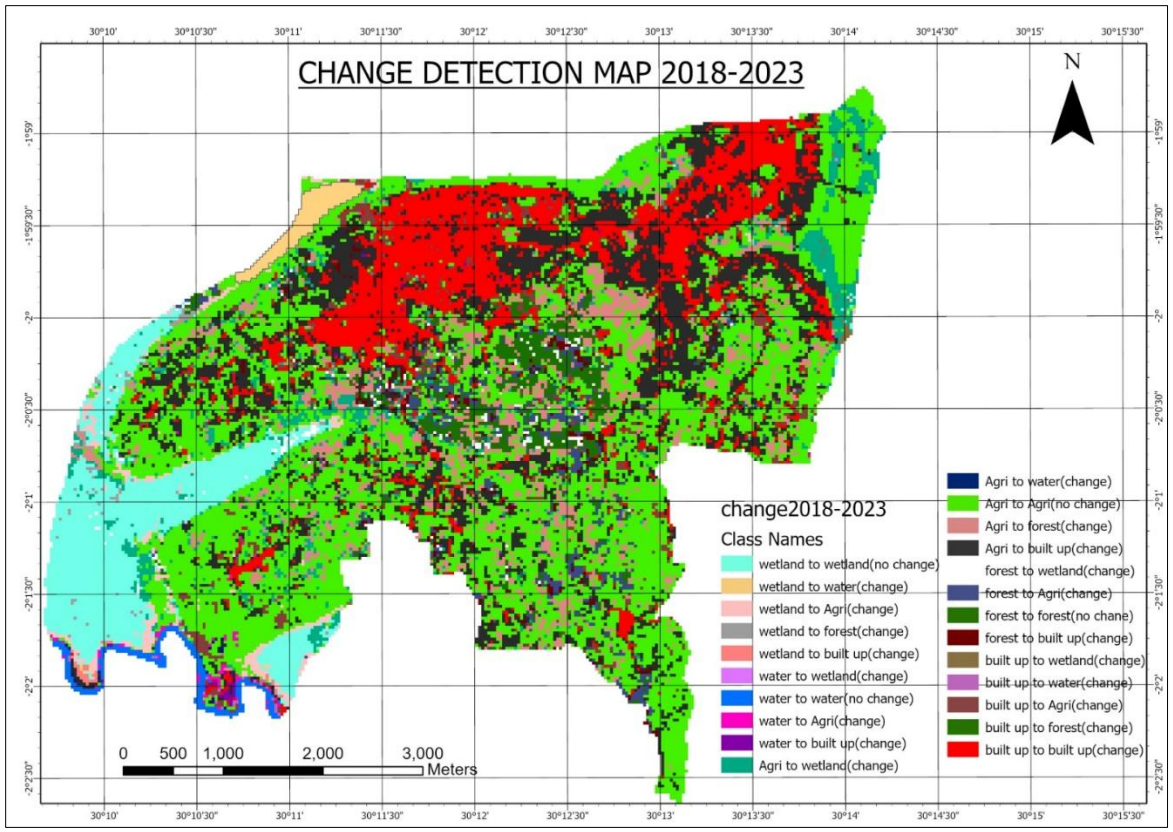
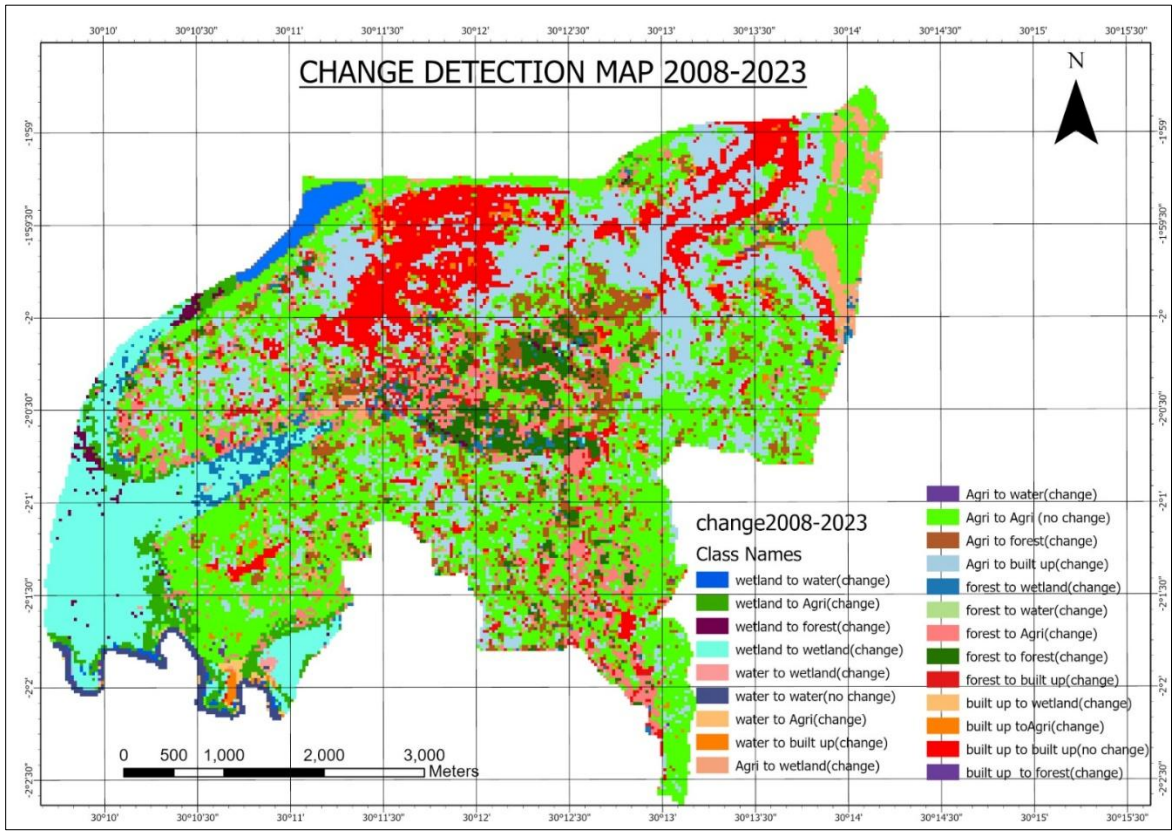
Appendix1: change detection






CHANGE DETECTION MAP 2018-2023
N
change2018-2023
Class Names
wetland to wetland(no change)
wetland to water(change)
wetland to Agri(change)
wetland to forest(change)
wetland to built up(change)
water to wetland(change)
water to water(no change)
water to Agri(change)
water to built up(change)
Agri to wetland(change)
Agri to water(change)
Agri to Agri(no change)
Agri to forest(change)
Agri to built up(change)
forest to wetland(change)
forest to Agri(change)
forest to forest(no chane)
forest to built up(change)
built up to wetland(change)
built up to water(change)
built up to Agri(change)
built up to forest(change)
built up to built up(change)
0 500 1,000 2,000 3,000
Meters


CHANGE DETECTION MAP 2008-2023
N
change2008-2023
Class Names
wetland to water(change)
wetland to Agri(change)
wetland to forest(change)
wetland to wetland(change)
water to wetland(change)
water to water(no change)
water to Agri(change)
water to built up(change)
Agri to wetland(change)
Agri to water(change)
Agri to Agri (no change)
Agri to forest(change)
Agri to built up(change)
forest to wetland(change)
forest to water(change)
forest to Agri(change)
forest to forest(change)
forest to built up(change)
built up to wetland(change)
built up toAgri(change)
built up to built up(no change)
built up to forest(change)
0 500 1,000 2,000 3,000
Meters

Appendix2: Land use cover matrix

Year	2008		2013		2018		2023
	Area/Ha	Area%	Area/Ha	Area%	Area/Ha	Area%	Area/Ha
Built-up-Area	356.746	11.22%	423.166	13.31%	560.246	17.63%	1019.696
Wetland	379.876	11.95%	391.486	12.32%	422.946	13.31%	453.496
Agriculture	1979.882	62.29%	1898.252	59.72%	1837.702	57.82%	1382.642
Forest	424.876	13.37%	423.166	13.00%	300.146	9.44%	261.866
Water	37.17	1.17%	42.48	1.34%	57.51	1.81%	60.85
Study Area	**3178.55**	**100%**	**3178.55**	**100%**	**3178.55**	**100%**	**3178.55**

LULC changes matrix as observed between 2008-2023

	2008-2023 Area change in Hectares						
	Classes 2023	Built up	Wetland	Agriculture	Forest	Water	**Total**
Classes2008	built-up	304.65	6.38	17.22	74.34	0	**402.59**
	wetland	6.03	334.34	110.236	56.79	2.52	**453.126**
	Agriculture	212.2	78.48	1500.716	185.476	0.63	**1976.872**
	forest	18.45	4.95	108.18	177.29	0.462	**309.332**
	water	0	4.41	3.33	0.09	28.89	**36.63**
	Total	**541.33**	**428.56**	**1808.792**	**493.986**	**32.04**	**3178.55**

LULC changes matrix as observed between 2008-2013

	2008-2023 Area change in Hectares						
	Classes 2013	Built up	Wetland	Agriculture	Forest	Water	**Total**
Classes2008	built-up	330.016	0	93.06	0.09	0	**423.166**
	wetland	0.18	369.076	4.95	35.956	15.01	**425.172**
	Agriculture	25.02	5.67	1600.422	571.1	0	**2202.212**
	forest	1.35	1.71	80.19	17.28	0	**100.53**
	water	0.18	3.42	1.26	0.45	22.16	**27.47**
	Total	**356.746**	**379.876**	**1779.882**	**624.876**	**37.17**	**3178.55**

LULC changes matrix as observed between 2013-2018

	2013-2018 Area change in Hectares						
	Classes 2013	Built up	Wetland	Agriculture	Forest	Water	**Total**
Classes2013	built-up	291.046	8.19	4.82	2.67	3.42	**310.146**
	wetland	0.27	284.026	29.9	30.18	28.26	**372.636**
	Agriculture	129.96	75.96	1788.112	249.106	3.87	**2247.008**
	forest	0.63	18.54	72.36	119.7	0	**211.23**
	water	1.26	4.77	3.06	0	28.44	**37.53**
	Total	**423.166**	**391.486**	**1898.252**	**401.656**	**63.99**	**3178.55**

LULC changes matrix as observed between 2018-2023							
	2018-2023 Area change in Hectares						
	Classes 2013	**Built up**	**Wetland**	**Agriculture**	**Forest**	**Water**	**Total**
Classes2018	**built-up**	**443.446**	**4.41**	**9.986**	**7.63**	**4.14**	**469.612**
	wetland	**32.4**	**265.846**	**35.99**	**39.08**	**0.18**	**373.496**
	Agriculture	**99.54**	**41.76**	**1772.776**	**72.54**	**7.11**	**1993.726**
	forest	**12.51**	**9.18**	**195.196**	**91.98**	**0**	**308.866**
	water	**2.25**	**1.26**	**3.06**	**0**	**26.28**	**32.85**
	Total	**590.146**	**322.456**	**2017.008**	**211.23**	**37.71**	**3178.55**

	Net change in 2008-2013		**Net change in 2013-2018**		**Net change in 2018-2023**		
LULC Class Years	**Area in Ha**	**Area %**	**Area in Ha**	**Area %**	**Area in Ha**	**Area %**	**Area in Ha**
	2008		**2013**		**2018**		
Agriculture	-81.630	-2.57%	-60.550	-1.90%	-455.060	-14.32%	-597.240
Forest	-1.710	-0.05%	-123.020	-3.87%	-38.280	-1.20%	-163.010
Built-up	66.420	2.09%	137.080	4.31%	459.450	14.45%	662.950
Water	12.310	0.39%	15.030	0.47%	3.340	0.11%	30.680
Wetland	11.61	0.37%	31.46	0.99%	30.55	0.96%	73.62

Appendix3: Proposed Solution that can be model to curb these issues

These map shows the proposed waste disposal stations where the collection service could pick waste.

Appendix4: Questionnaire and Interview guide

I am students from university of Rwanda (UR), College of Science and Technology, School of Architecture & Built Environment, Department of Geography and Urban Planning, MSc in Geo-Information Sciences for Environmental and Sustainable Development, I am carrying out my final research project on topic entitled

"Thesis Title: Evaluating trends of urban growth and its impact on environmental sustainability in Kigali peri-urban areas: A probe from Masaka Sector"

This research is objectively to:

- To evaluate trends of land use/ land cover changes induced by urban growth in Masaka Sector the since 2008 up to 2023.
- To identify the environmental sustainability challenges driven by urban growth in Masaka Sector,
- To propose practical actions that policymakers and urban planners may apply to enhance environmental sustainability in Masaka sector.

And You have been selected as one of the respondents for this study and the information you will give, will be treated with utmost confidentiality and used purely for academic purposes. I hereby requesting you to help me by answering these questions that will guide us to find answers to the research questions. Feel free to respond all the questions and I promise you that the information provided will be confidential.

Organization/Affiliation	***Role/Position***
Ministry of Environment	*Environmental Protection Department*
Ministry of Infrastructure	*Human Settlement and Urbanization Directorate*
Rwanda Environmental Authority	*Environmental protection Unit*
Local Resident	*Resident*
City of Kigali (CoK)	*Urban Planner*
Rwanda Housing Authority	• *Social and Affordable Housing Department* • *Social Safeguard Specialist* • *Green and smart cities specialist*
Business Owner	*Owner/Manager*
National Land Authority	*Urban Planning Department*

Balancing Urban Expansion: Assessing Environmental Impacts and Sustainability Strategies in Kigali City Specifically in its Periphery"

Qs No	Category	Questions	Answers/Responses	
I.	**Questionnaire that was used in interview with Public Servants**			
			Range of Respondent years	**Use tick √**
		Male ☐	**20 to 30**	
		Female ☐	**30 to 40**	
			40 to 50	
			50 to Above	
		1. Occupation:		
		Student ☐ Private worker ☐		
		Government worker ☐ Other ☐		
		For other, please specify: ……		
		2. Educational level:		
		None ☐ Primary ☐ Secondary ☐ University ☐		
		Others ☐		
		For Others, then specify, ……		
1	Urban Planners/Environmental Experts	1. What are the primary drivers of urban growth of peri-urban areas		Are you satisfied with the given

2	Urban Planners/Environmental Experts	2. How does urbanization growth impact local ecosystems and biodiversity?		answer to how (1-5) score
3	Urban Planners/Environmental Experts	3. What are the most significant environmental challenges associated with rapid urban growth?		
4	Urban Planners/Environmental Experts	4. Are there successful strategies or initiatives that have effectively mitigated the environmental impact of urban expansion?		
5	Urban Planners/Environmental Experts	5. How do planning policies or regulations influence the balance between urban development and environmental conservation?		
6	Government Officials/Policy Makers	1. How does urban growth align with existing environmental policies or sustainability goals?		
7	Government Officials/Policy Makers	2. What measures or initiatives has the government undertaken to manage the environmental impact of urban expansion?		
8	Government Officials/Policy Makers	3. How does the allocation of resources and infrastructure development factor into sustainable urban growth?		
9	Government Officials/Policy Makers	4. What challenges do policymakers face in balancing urban development with environmental conservation?		
10	Government Officials/Policy Makers	5. In your opinion, what improvements or changes could enhance the sustainability of urban growth?		

II. Questionnaire for household survey

Male ☐

Female ☐

3. Occupation:

Range of Respondent years	**Use tick √**
20 to 30	
30 to 40	
40 to 50	
50 to Above	

Student ☐ Private worker ☐

Government worker ☐ Other ☐

For other, please specify: ……

4. Educational level:

None ☐ Primary ☐ Secondary ☐ University ☐

Others ☐

For Others, then specify, ……

11	Community Members/Residents	1. How has urban growth affected your immediate environment or neighborhood?		Are you satisfied with the given answer to how (1-5) score
12	Community Members/Residents	2. Are there specific environmental concerns you've noticed due to urbanization growth?		
13	Community Members/Residents	3. Do you believe community involvement is crucial in mitigating the environmental impact of urban growth? Why or why not?		
14	Community Members/Residents	4. Have you seen any positive initiatives or changes aimed at making urban growth more sustainable?		
15	Community Members/Residents	5. What role do you think residents should play in promoting environmentally friendly practices in urban areas?		