

BINDURA UNIVERSITY OF SCIENCE EDUCATION
DEPARTMENT OF NATURAL RESOURCES MANAGEMENT



**Urbanization-Driven Land Use Change and Its Impact on Biodiversity and Ecosystem
Functioning in Harare, Zimbabwe (2013-2025)**

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REQUIREMENTS OF THE BACHELOR OF SCIENCE (HONOURS') DEGREE IN
NATURAL RESOURCES MANAGEMENT**

30 MAY 2026

DECLARATION

I, Njani Pride Tanaka, declare that this project is my piece of work and I did not use any information from sources without crediting the owner

DEDICATION

I want to dedicate this project to my mother Tracy Njani, Brother Derek Njani and my uncles. I would have not made it this far without their unwavering support and motivations

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I want to acknowledge God for the gift of life and guidance throughout my career. I would also like to recognize my supervisor, Mr. T Chisova, for making sure I am knowledgeable in this project, his patience and desire to see me succeed and all the other lecturers of Bindura University of Science Education Faculty of Agriculture and Environmental science

My gratitude goes to all my family members for their financial and moral support throughout my university journey.

RELEASE FORM

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ABSTRACT

Urbanization has emerged as a major driver of land use and cover change in many African cities resulting in environmental issues. The study investigated the effects of urbanization driven land use change on biodiversity and ecosystem functioning in Harare between 2013 and 2025. This study aimed at analyzing spatio-temporal land use changes, assess their implications for biodiversity and evaluate the resulting impacts on selected ecosystem services. Landsat imagery was processed and classified using supervised classification techniques in QGIS version 3.4.4.1 whilst landscape patterns were analyzed using FRAGSTATS.

The findings reveal transformation of Harare's landscape over the study period. Vegetation cover fell from 767.9 km² to 214 km² which is a loss of 72.1% whilst water bodies fell by 10.3%. Bare land increased by 129.3% showing extensive land clearing associated with urban development. Spatial analysis reveals that urban growth occurs predominantly along major transport corridors and peri urban zones therefore resulting in increasing habitat fragmentation and loss of ecological connectivity.

Reduction of vegetated land has important implications for biodiversity conservation. Habitat destruction and fragmentation have diminished the capacity of urban ecosystems to support diverse plant and animal communities especially species reliant on wetlands and natural vegetation. Land use change was further established in this study by adversely affecting ecosystem functioning through the degradation of key ecosystem services. Conversion of natural landscapes into impervious surfaces has reduced flood regulation capacity and contributed to environmental degradation within the city.

The study concludes that rapid urban expansion is reshaping Harare's ecological landscape at an unprecedented rate with significant consequences for biodiversity and ecosystem sustainability. Urban planning strategies should prioritize the protection of wetlands, preservation of remaining green spaces and integration of ecological considerations into land use decision making so as to promote environmental resilience. The findings provide valuable evidence for policy makers, environmental managers and urban planners seeking to balance development needs with long term ecological sustainability in Harare.

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List of acronyms

BUSE- Bindura University of Science Education

DSO1- Dark Object Subtraction

EMA- Environmental Management Agency

FRAGSTATS- Fragment Statistics

GBIF- Global Biodiversity Information System

GIS- Geographic Information System

IDOSR- International Doctors of Science Research

IJISRT- International Journal of Innovative Science And Research Technology

LULC- Land Use / Land Cover

MDPI- Multidisciplinary Digital Publishing Institute

MLC- Maximum Likelihood Classification

NDBI- Normalized Difference Built Up Index

NDVI- Normalized Difference Vegetation Index

NRM- Natural Resources Management

OLI-2- Operational Land Imager-2

QGIS- Quantum Geographic Information System

RMSE- Root Mean Square Error

SA- Southern Africa

SCP- Semi Automatic Classification Plugin

SPOT- Satellite Pour l' Observation de la Terre

TIRS-2- Thermal Infrared Sensor -2

USGS- United States Geological System

CHAPTER 1

INTRODUCTION

Rapid urbanization of wetlands, forests, and farmlands in Harare is endangering biodiversity and essential environmental services that support urban dependence, like air quality control, flood mitigation, and water purification. Insufficient localized data is impeding effective conservation and urban planning endeavors. The changes in land use carry significant consequences notably biodiversity decline. Habitat destruction results in a reduction in species diversity, disruption natural pathways and weakening the city's ability to withstand disturbances. However the broader trends offer only a general perspective. The issue lies in the absence of specific, localized and quantitative studies connecting land use alterations in Harare to measurable impacts on biodiversity and ecosystem functioning. This gap hinders urban planners and conservationist from accessing precise data for implementing targeted spatial interventions informed by ecology. This study seeks to address this discrepancy by employing Geographic Information Systems and remote sensing technologies to examine land use changes in Harare between 2013 and 2025. The study's findings aim to go beyond academic discussions to provide practical guidance for refining urban planning policies, shaping conservation strategies and promoting a more sustainable and resilient Harare.

1.1 Background of the study

Urbanization plays a pivotal role in driving environmental changes in today's context particularly in swiftly expanded cities in developing regions where population growth outpaces urban planning capabilities (Zhang, 2016). While urban development is essential for economic advancement and enhances service provision, unregulated expansion exerts immense pressure on natural environments resulting in habitat degradation, ecosystem decline and diminishing biodiversity (Mukherjee & Bairwa, 2025).

In Harare Zimbabwe rapid urban growth had spurred the extensive conversion of wetlands, forests and agricultural land into residential, commercial and industrial zones. These transformations occur rapidly encroaching upon environmentally sensitive areas crucial for maintaining ecological balance in the city (Marondedze & Schütt, 2019a). Urban ecosystems offer key services like flood control, water purification, air quality enhancement, microclimate

regulation and biodiversity conservation all of which are vital for urban resilience and human well-being (Yao et al., 2025).

The degradation of urban ecosystems is linked to increased environmental risks like frequent urban flooding, deteriorating water quality and heightened exposure to climate related hazards (Pizzorni et al., 2024). In Harare seasonal floods and water pollution are becoming more frequent disproportionately affecting residents in peri urban and informal settlements with limited infrastructure and services (Olanrewaju & Reddy, 2025). Despite these challenges urban expansion often prioritize immediate development needs over long term ecological sustainability.

A primary challenge in addressing these issues is the lack of site specific empirical data linking distinct land use changes to biodiversity loss and ecosystem service decline. This study aims to provide robust evidence on how urbanization induced land use alterations impact biodiversity and ecosystem functionality in Harare (Hersperger et al., 2018).

1.2 Problem statement

Rapid urban expansion in Harare characterized by the conversion of wetlands, forests and agricultural lands into residential, commercial and industrial developments is largely uncoordinated and often ignores enforcement of environmental regulation resulting in widespread degradation of ecologically sensitive zones (Andreasen et al., 2022). This transformation significantly contributes to biodiversity loss and ecosystem dysfunction in rapidly growing cities in developing regions worldwide (Marondedze & Schütt, 2019a). The loss and fragmentation of natural habitats in Harare have notably reduced the capacity of urban ecosystems to deliver critical services. Wetland degradation adds to increased flooding, declining water quality and, reduced groundwater replenishment while deforestation diminishes air purification and local climate regulation functions (Nyandwi & Ndikubwimana, 2024). These ecological shifts heighten the city's vulnerability to climate related risks disproportionately affecting low income and peri urban communities that rely on ecosystem services for health and livelihoods. Continued habitat destruction and fragmentation in Harare lead to diminished species diversity, altered species composition and compromised ecological integrity within urban and peri urban ecosystems. Despite global studies demonstrating the simplification of ecological

communities and loss of native species due to urban expansion the specific impacts in Harare are inadequately quantified hindering the understanding of measurable biodiversity loss resulting from land use changes (Mumuni et al., 2025a). The absence of localized quantitative evidence connecting land use change patterns to biodiversity decline and ecosystem service degradation in Harare poses a significant obstacle to informed decision making for balancing development and ecological sustainability (Choruma et al., 2025). Closing this knowledge gap through an integrated approach involving GIS, remote sensing and biodiversity assessment is crucial for evidence based urban planning and effective environmental management in the city

1.3 JUSTIFICATION OF THE STUDY

This study is justified by the pressing need to address the widening disparity between rapid urban development and environmental sustainability in Harare. Integrating satellite imagery with field based ecological data is crucial for comprehending the context specific ecological impacts of urban expansion and guiding targeted policy and planning interventions (James, 2023).

The study provides a valuable scientific contribution by linking urban land use changes with biodiversity metrics and ecosystem functioning in southern African cities, filling a gap in existing literature. Previous research in Harare primarily focused on changes in land cover without integrating detailed remote sensing data and on site biodiversity assessments for a comprehensive analysis of ecological impacts (Ogunbode et al., 2024). By combining GIS, remote sensing and ecological fieldwork this study addresses a critical information void and enhances our understanding of how urban growth influences ecological systems at the city level.

Findings of this research have significant implications for urban planners, environmental managers and decision makers involved in Harare's development. The current urban planning frameworks in Zimbabwe often lack updated spatial plans that consider ecosystem services and green infrastructure, leading to unplanned development decisions and increased environmental risks (Dyachia et al., 2017).

From a policy and planning perspective, the findings of this study are highly relevant to urban planners, environmental managers, and decision makers responsible for guiding Harare's development. Current urban planning frameworks in Zimbabwe often rely on outdated spatial plans that inadequately account for ecosystem services and green infrastructure, leading to ad

hoc development approvals and increased environmental risk (Dyachia et al., 2017). The evidence generated by this study will support the integration of ecological considerations insights gained from this study will facilitate the incorporation of ecological factors into land planning, zoning regulations and environmental assessments thereby strengthening urban governance and resilience. Into land-use planning, zoning regulations, and environmental impact assessment, thereby strengthening urban governance and resilience.

From a perspective of social and environmental justice changes in urban land use disproportionately impact vulnerable communities especially those in peri urban and informal settlements that bear the brunt of flooding, water contamination and heat related challenges (Nyathi et al., 2025). The deterioration of wetlands and water quality directly threatens livelihoods, public health and food security. By shedding light on the ecological repercussions of unregulated urban expansion this study advocates for the development of fair and inclusive urban policies that safe guard both natural resources and human well-being.

Ultimately the study aims to offer a coherent set of evidence based recommendations to guide sustainable urban development in Harare. By identifying critical areas of biodiversity decline and diminishing ecosystem services, the research will inform targeted conservation efforts, promote the integration of green infrastructure and ecological corridors in urban planning and enhance public awareness of environmental stewardship. In doing so, the study contributes to both national and global sustainability objectives including climate resilience, biodiversity preservation and the advancement of sustainable cities.

1.4 AIM

To determine how urban-driven land use change affects biodiversity and ecosystem functioning in Harare, Zimbabwe.

1.5 OBJECTIVES

1. To analyse spatio-temporal land use and land cover changes in Harare from 2000 to 2024.
2. To assess the relationship between land use change and biodiversity indicators in selected urban, peri-urban, and wetland ecosystems.

3. To evaluate the effects of land use change on selected ecosystem services in altering ecosystem functioning in Harare.

1.6 RESEARCH QUESTIONS

1. What are the spatio-temporal patterns of land use and land cover change in Harare between 2000 and 2024, and how has urban expansion altered the city's landscape structure?
2. How are observed land use changes associated with changes in biodiversity indicators, such as species richness, species composition, and habitat fragmentation, in selected urban ecosystems?
3. How has urbanisation-driven land use change affected key ecosystem services, particularly flood regulation and water quality, in Harare?

1.7 LIMITATIONS

- Field surveys are susceptible to seasonal variations, observer bias, and logistical challenges
- Due to differing spatial scales integrating GIS, field surveys, and interviews can be challenging

1.8 DELIMITATIONS

- Geographic scope focuses on Harare, examining representative sites within urban, peri-urban, and wetland areas. It excludes other Zimbabwean cities and rural regions to facilitate a detailed analysis of this specific urban context, which may limit its broader applicability (Marondedze & Schütt, 2019a)
- The timeframe covers from 2013 to 2025, utilizing satellite imagery from key years (2013, 2015, 2020, and 2025). This focus allows for an in-depth look at recent urbanizations trends but does not consider historical data prior to 2013 or future projections beyond 2025
- The methodological choices of the study employ specific tools, including ArcGIS/QGIS for spatial analysis. It uses sampling methods like supervised land use/ land cover

classification and transect-based surveys, excluding alternative methods such as drone imagery or advanced modeling to ensure feasibility within resource constraints

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter shows the relevant literature prior to knowing the land use changes that influence urbanization and the possible repercussions on biodiversity and ecosystem functioning, with emphasis on the cities of the Zimbabwean. This literature review is organized into a series of sectors; the section examines the global and regional patterns of urbanization and land use change, keeping in line with the unique traits of urban expansion in sub-Saharan Africa. An exploration of the impacts of land use changes on biodiversity, focusing on mechanisms of biodiversity loss and empirical evidence from urban ecosystems, follows. The third section shows ecosystem services and functions in urban scenarios, particularly those vulnerable to urbanization pressures, for instance, flood regulation and water purification. Subsequently, the review examines methodological approaches, including remote sensing and GIS techniques for land use change analysis and field-based methods for biodiversity assessments. Finally, the chapter ends by showing the critical knowledge mishaps that the research aims to address.

2.2 URBURNIZATION AND LAND USE CHANGE: GLOBAL REGIONAL PATTERNS

2.2.1 Global Urbanization Trends and Drivers

Urbanization shows the most serious and irreversible forms of land transformation that are occurring everywhere in the 21st century. 56% of the world's population lives in towns, a number projected to reach 68% by 2050(Nations et al., 2018). The expansion of these urban areas is pronounced in low- and middle-income countries, where urbanization is rapid and outpaces the development of infrastructure and regulatory frameworks. Urban sprawl has been happening since the spatial footprints of towns expand faster than the urban population itself, and this causes the conversion of agricultural land, forests, and wetlands into built environments (Muchelo et al., 2024).

Causes of urbanization are complex resulting in economic opportunities, improved access to services, and demographic transitions, which are primary pull factors drawing populations to urban centers. However, in developing countries, issues like the decline of agriculture, the impacts of climate, and the lack of rural infrastructure cause rural-urban migration (Tietjen et al.,

2023). Moreso, informal settlements and unplanned expansion, especially in areas where law framework is weak and land tenure systems are poorly enforced, then the urban growth has to occur. The unplanned growth pattern does have implications for environmental sustainability, and it occurs repeatedly in ecologically sensitive areas, even floodplains, wetlands, and forested zones, which provide crucial ecosystem services (Chhachhiya et al., 2025).

2.2.2 Urbanization Patterns in Sub-Saharan Africa

Sub-Saharan Africa experiences the world's fastest rate of urbanization, which means populations should triple between 2010 and 2050. This type of growth occurs in a context shown by few financial resources, weak institutional capacity, and inadequate urban planning systems. The difference between urbanization in Europe and North America, which was most likely linked to industrialization and economic growth, is shown by the absence of corresponding economic development through a phenomenon known as urbanization without growth (Washington et al., 2013). This presents challenges for managing urban expansion using solutions that abide by environmental quality and ecosystem integrity.

Urbanization expansion has traits of low-density sprawl, leapfrog development, and the proliferation of informal settlements on the urban periphery. The type of settlement patterns consumes land at rates disproportionate to population growth and frequently encroaches on environmentally sensitive areas (Angel, 2023). African cities have expanded their built-up areas by an average of 4.1% annually between 2000 and 2010, which is a rate higher than population growth. A combination of formal developments, informal settlements growth, and land acquisition drives spatial distribution and leads to the fragmentation of natural habitats and disruption of ecological connectivity (Forget et al., 2021a).

Urban expansion shows traits shaped by colonial legacies, especially in southern Africa. Cities like Harare, Lusaka, and Gaborone have experienced substantial spatial expansion caused by a combination of natural population growth, rural – urban migration, and formalization of previously informal settlements (Matamanda, 2020a). Poor enforcement of laws, especially environmental laws, is done because of capacity constraints, corruption, and competing development priorities. This weakness makes room for urban development to go forward in wetlands, riparian zones, and other protected areas with great consequence (Chiweshe et al., 2025).

2.2.3 Land Use Change Dynamics in Harare, Zimbabwe

The largest city of Zimbabwe, Harare, is an ideal example of the challenges of urbanization that many African cities are facing. There have been demographic pressures in the city as a result of population growth from 1.2 million in 2000 to over 2.1 million in 2024. Significant land use change has been the cause of this growth, especially in wetlands, agricultural lands, and natural vegetation, which are converted to residential and commercial uses at an accelerating rate (Marondedze & Schütt, 2019b).

Landsat imagery from 1984 to 2020 found that the built-up area has increased by 156% during that period. In the same change, there is also a change in agricultural land as it has decreased by 23%, and natural vegetation cover seems to have declined by 41% (Marondedze & Schütt, 2019a). What is most troubling is the encroachment into wetland areas, which provide vital ecosystem services, including flood regulation and water purification. 35% of the city's wetlands have been lost or degraded between 2000 and 2020 due to urban expansion and agricultural activities (Kudumba, 2022a).

The causes of land use change in Harare are multifaceted and interrelated. The growth of the population has a demand for housing and services, whilst economic pressures and livelihood needs both cause formal development and informal settlement expansion (Matamanda, 2020b). Weak enforcement of environmental regulations and unclear land tenure arrangements facilitate encroachment into protected areas. On the other hand, economic instability and informalization have led to uncontrolled urban sprawl, as formal planning systems have been unable to manage growth (Matamanda et al., 2025). Despite laws protecting protected areas like wetlands, it is quite inadequate due to resource constraints and political pressures.

2.3 IMPACTS OF LAND USE ON BIODIVERSITY

2.3.1 Mechanisms of Biodiversity Loss in Urban Environments

Urban land use change has affected biodiversity in multiple interconnected pathways, and the most direct mechanism is habitat loss, in which natural ecosystems are converted to built environments, thereby eliminating physical space that is required for species survival. (Aisha Annet, 2025). When developments occur in biodiversity areas like protected areas, it will therefore be severe. Despite habitat loss, urbanization also causes habitat fragmentation, which

divides habitats into smaller, isolated patches. (Haddad et al., 2015). Fragmentation reduces habitat quality, increases edge effects, disrupts ecological connectivity, and limits species movement and gene flow, ultimately reducing population viability and increasing extinction risk.

Habitat quality is altered by urbanization through forms of environmental degradation, for instance, pollution from industries, vehicle emissions, and domestic waste, water, and soil quality, creating stressful conditions for many species. (L. Zhang, 2025). One of the ecological consequences of urban development is that water bodies and wetlands are being disturbed when activities like building waterproof surfaces, installing drainage systems, and water abstraction are carried out.(McGrane, 2016). Moreso, the urban heat island phenomenon changes local microclimates, so that temperature differences between city centers and their outskirts may be as high as 5c that is a challenge for species that have limited temperature tolerance.(Dietzel et al., 2026). Besides, urban areas always bring unexpected disturbances like noise, lights, and invasive species, which are the main reasons for the loss of native biodiversity.

The effects of these mechanisms on different taxonomic groups are quite varied. A few species known as urban adapters or the urban exploiters can survive and prosper in urban settings where they can get anthropogenic resources and live in disturbed environments, on the contrary, the majority of species especially those which are highly dependent on certain types of habitats, have a limited capability to move, or aren't used to human disturbances, suffer loss of population or local extinction. (Marzluff & Rodewald, 2008). This variable reaction of species leads to biotic homogenization, which means that rich native communities are replaced by a few widespread generalist species, leading to loss of biodiversity and the unique features of the ecosystem.

2.3.2 Empirical Evidence from Urban Ecosystems

Urbanization is leading to the loss of biodiversity worldwide, and this is evidenced by a systematic overview of 190 studies of the topic, which showed that, on average, species richness was 50% lower in urban areas compared to natural ones (Newbold et al., 2015). Specialist species and those that require large areas for their habitat were most affected. Another study revealed that urbanization could be evidence of the reduction in the richness of native species while the non-native species contribution to the urban areas increases, thereby facilitating biotic homogenization across urban regions globally (McKinney, 2006).

In African cities, the number of biodiversity studies has risen greatly over the last few years; however, there are still major gaps in our knowledge. South African urban biodiversity indicate that large biodiversity loss was linked to the development of cities. A case in point, urbanization caused the loss of 13 plant species, and an additional 26 species became endangered in the city of Cape Town (Rebelo et al., 2011). Specialists amongst the species were rapidly declining

Wetland ecosystems in African cities like Harare occur in significant numbers and are extremely susceptible to the effects of urbanization. Research in South African urban wetlands recorded a decrease in macro vertebrate diversity and changes in community composition linked to urban land use (Gál et al., 2019). The study revealed that urbanized wetlands were primarily inhabited by pollution-tolerant taxa, whereas sensitive species typical of natural wetlands were almost completely missing. Wetland bird communities in Zimbabwe are also studied, and it was revealed that with an increase in urbanization intensity species richness and functional diversity dropped drastically, with wetland dependent specialists being the most affected (Mbiba et al., 2021).

Nonetheless, biodiversity research in Zimbabwean cities is a small fraction of global standards. Most of the studies are localized, concentrated on specific taxa or done within short periods of time, thus only providing a partial understanding of how continuous urbanization affects biodiversity patterns. In particular, there is very little research that combines remote sensing data on land use change with ground biodiversity assessments to quantify the relationships between urban growth and ecological impacts (Finizio et al., 2024). Urban planning is limited by lack of information and conservation decision-making driven by evidence.

2.4 ECOSYSTEM SERVICES AND FUNCTIONING IN URBAN CONTEXTS

2.4.1 Conceptual Framework of Urban Ecosystem Services

The benefits that humans get from nature are ecosystem services. The provisions from the ecosystems comprise of provision services, the way nature assists in regulating changes in the environment (climate regulation, flood control), nature enhancing our life, especially the spiritual and entertainment part of it (cultural services), and supporting the other three types of services (supporting services) (Ecosystems and Human Well-Being: Synthesis, 2005). Ecosystem

services are vulnerable to changes brought upon them by land use changes but they are also important for the human well-being, public health and economic systems.

In cities ecosystems like parks and wetlands provide regulating services essential for urban resilience, for instance, they reduce the urban heat island effect by cooling, improve air quality by filtering pollutants, manage storm water through infiltration and storage, and reduce noise levels (Pandey & Ghosh, 2023). Turning natural and semi natural ecosystems into built up areas the capacity of providing the ecosystem services declines therefore leading to environmental risks to the ones that reside in urban areas.

The links between biodiversity and ecosystem functioning is supported by ecological studies. Ecosystems are more resilient, stable and capable of doing a lot of things only if the biodiversity is plenty. Preservation of biodiversity in cities shouldn't be seen as a conservation target but a necessity for the continuation of the delivery of ecosystems services. This connection points to the significance of considering how urbanization impacts both biodiversity and ecosystem functioning together (Elmqvist et al., 2013).

2.4.2 Critical Ecosystem Services in African Cities

Flood regulation continues to be a main challenge, especially in cities where the combination of old and poor storm water infrastructure with a higher frequency of heavy rain results in severe floods. Urban wetlands and green spaces help in the storm water absorption and provide a temporary water holding function during storm events (Liu & Zhang, 2025). Unfortunately, even the few wetlands left are highly degraded or have been lost to urban expansion, and informal settlements tend to be also the ones most of the time affected by these phenomena without adequate infrastructure.

Urban water certification is, of course, a very important issue in cities that have a problem with water quality. Surface runoff from the cities carries pollutants and nutrients to water bodies through wetlands, which act as a natural filter of these substances. Public exposures and risk of diseases are increased due to the decrease in water quality brought about by the destruction of natural filtration systems. In Lake Chivero and the Mukuvisi River of Harare, water quality

problems owing to wetland encroachment and poor treatment of wastewater have resulted in a water crisis that has the city as a whole as its victim (Kudumba, 2022)

Evapotranspiration from plants, along with shade, is one of the sources of cooling that helps in controlling temperature and lowering heat-related health risks. Consequently, when green areas are lost to built-up areas, this results in higher urban temperatures, increased demand for energy to cool the buildings, and more heat stress among the already vulnerable populations (Zariro et al., 2025). Temperature differences of up to 7 °C have been observed in Harare between the vegetated and built-up areas, thus showing the thermal regulation benefits of green infrastructures.

2.4.3 Impacts of Land Use Change on Ecosystem Services Provision

Switching natural ecosystems to urban land uses changes how ecosystems work and what they can offer us. One of the most common ways that wetlands are being used nowadays is for urban development (Alikhani et al., 2021). It is known that wetlands serve a wide variety of functions that would be lost through their degradation and change. In African wetlands, urban wetlands have a much lower ability to retain nutrients, trap sediments, and attenuate floods, even though natural wetlands served these functions very well. Moreso, the more intensely urbanized a wetland area was, the less capable it became at providing these ecosystem services. In the same vein, covering vegetated areas with impervious surfaces inevitably results in the disruption of the hydrological cycle, with decreases in infiltration and groundwater recharge and an increase in the volume of surface runoff and hence flooding (Mumuni et al., 2025b).

The linkage between land use change and ecosystem service decline is becoming more and more recognized in Harare. Research shows that wetland encroachment and degradation have been the causes for the rise in flooding in peri-urban areas, as the studies reveal that quarters that were built on or next to wetland degradation normally have flooding that is more frequent and severe than those areas where wetlands have been preserved (Matsa & Mupepi, 2022). Regular monitoring of water quality in the rivers and reservoirs of Harare has steadily declined. At the same time, there has been a noticeable increase in urban development as well as in the loss of wetlands. These developments show quite clearly the immediate effects of the degradation of ecosystems on urban dwellers.

The loss of ecosystem services has a huge economic cost that is made worse by the fact that it is rarely fully estimated in African cities. Globally, wetlands provide ecosystem services valued at around \$25 000 per hectare each year. (de Groot et al., 2012). It is through this lens that one can estimate Harare is losing to the depletion of its wetlands, millions of dollars' worth of the city's ecosystem services yearly due to the depletion of its wetlands. The price of these damages is indirectly paid through flooding cases, water treatment costs, and health problems. Unfortunately, such environmental and economic facts are regularly ignored in urban planning, where the main focus is given to the short-term development gains while the long-term sustainability is overlooked.

2.5 REMOTE SENSING AND GIS APPROACHES TO LAND USE CHANGE ANALYSIS

2.5.1 Remote Sensing for Urban Land Use Classification

Remote sensing technology offers great opportunities for monitoring and quantifying changes in land use and land cover across the globe and over time. For instance, satellite images captured by Landsat, Sentinel, and SPOT can provide cost-effective and systematic observations that can be repeated for urban growth and land transformation. (Rogan & Chen, 2004). The Landsat collection, especially, is a goldmine for retrospective studies on urbanization as it offers uninterrupted worldwide coverage since 1972, with a 30-meter spatial resolution. The time span is a key feature that helps to reveal the long-term patterns of land use and even pinpoint ecosystem conversion.

There are a number of classification methods that can be used to get land use details from satellite images. Pixel categorization into predetermined land cover types is done through supervised classification methods like maximum likelihood classification, which rely on training data (Talukdar et al., 2020). These have also been extensively used for urban studies, and if provided with suitable data and image processing, can typically deliver classification accuracies of over 85%. On the other hand, the relatively new machine learning and deep learning techniques, which also cover convolutional neural networks, are very effective in classifying urban land cover, but they demand a large amount of computational power and training data (Southworth et al., 2024).

Remote sensing has gradually become a method to track the changing face of the city areas of Africa, for instance, Nairobi, Lagos, Addis Ababa, and Harare. Through the use of satellite imagery over different time periods, the researchers were able to calculate urban sprawl rates, recognize urban spatial growth patterns, and evaluate the effects on adjacent areas. The outcome of the researchers is the fact that there has been rapid, in most cases, unplanned urban sprawl, showing that the built-up area in most cities has been growing at a rate of 3-5% each year. Remote sensing, therefore, gives crucial primary data that makes it possible to understand the magnitude and speed of urban changes in areas that lack adequate data.

2.5.2 Change Detection Techniques and Landscape Metrics

Change detection involves identifying alterations in land cover or land use by comparing remote sensing images captured at different times. Various methods can be used for this, ranging from simple image differencing to post-classification comparison and hybrid approaches. Post-classification comparison, which involves first generating land cover classifications for each date and then comparing these maps, is the most common method because it is straightforward and provides detailed information about land use changes. This approach is particularly useful when a detailed understanding of land use change is needed. In addition to quantifying changes, landscape ecology also examines how habitats are organized and fragmented. Habitats are organized and broken up.

Landscape metrics, which are derived through programs like FRAGSTATS, measure various structural characteristics of landscapes like the size, shape, number, connectivity, and diversity of patches. These statistics are important in ecology because they closely reflect ecological processes like species movement, population sustainability, and ecosystem health.

The use of such methods in African cities has brought to light disturbing trends of ongoing habitat fragmentation resulting from urban sprawl. For example, an analysis in African cities showed that urban sprawl mainly happens through scattered, low-density housing, which fragments the natural habitats around the city more intensely than compact urban forms. (Z. Liu et al., 2016). Research in Harare revealed progressive fragmentation of farming and natural areas around the city, which would threaten biodiversity conservation and ecosystem linkages.(Marondedze & Schütt, 2019b). Therefore, landscape metrics serve to quantify aspects

that not only supplement statistics on land use changes but also provide a better understanding of the ecological implications.

2.5.3 Integration of Remote Sensing with Field-Based Data

A field survey helps to confirm remote sensing classifications, provide ecological context for the interpretation of land cover categories, and directly measure biodiversity and ecosystem functioning, which are aspects that satellites can't capture. This combination matters most in urban areas where land cover categories usually consist of a wide range of ecosystem types that differ in ecological quality and biodiversity value. Combining remote sensing and field biodiversity assessments is successful in the study of ecological patterns in cities (Rhodes et al., 2015).

Combining the methods shows the negative effects of land use change on the biodiversity than either approach alone for example in south Africa land use mapping is integrated with vegetation sampling so that different degrees of urbanization affected plant community composition and diversity can be checked. Results stress the need for attention to the spatial distribution of green areas in urban biodiversity conservation planning. Integrated methods that combine satellite based land use change analysis with structured field biodiversity survey could yield the evidence for conservation and decision making.

2.6 FIELD BASED BIODIVERSITY ASSESSMENT METHODS

2.6.1 Overview of Biodiversity Survey Approaches

Field based biodiversity examinations make use of many standardized techniques to measure species richness, community composition and species numbers. The choice of the correct method depends on the taxonomic group that's under study, research goals, spatial scale and habitat type. Urban biodiversity surveys aim on taxa that's simple to sample, sensitive to urbanization changes and ecologically informative. These usually consist of birds that are visible and sensitive to the destruction of habitats, plants that reflect the environmental conditions over a long period and macroinvertebrates in aquatic bodies that act as indicators of water quality and the state of the ecosystem (Yadav et al., 2025)

In order to get accurate and comparable biodiversity data sets is the reason by sampling methodology is very crucial. Convenience sampling minimizes bias and allow for statistical

inference hence stratified or systematic random sampling are better to use. In urban gradient investigations, the sampling is frequently divided according to different levels of urbanization intensity to reflect changes in biodiversity along the gradient. The determination of sample size has to be done by using a power analysis, when possible, to ensure that after replication, the test will have a high probability of detecting biologically meaningful differences. For doing a valid comparison of biodiversity metrics, the standardization of sampling effort across different sites is a must.

2.7 CRITICAL KNOWLEDGE GAPS AND RESEARCH JUSTIFICATION

While more studies are being conducted worldwide on urbanization and biodiversity, major gaps in knowledge remain, especially in African urban areas. For one thing, whereas many pieces of research have tracked how cities have sprawled from satellite images, only a handful have combined changes in land use patterns with field biodiversity assessments to find out which land use changes have most affected biodiversity (Knapp et al., 2021). Such a combination is indispensable for producing prediction models that can be used to advise urban planning and conservation prioritization. With respect to Harare, though land use change has been recorded and biodiversity issues have been highlighted, a thorough study connecting measurably the biodiversity patterns to the land use changes obtained from mapping still remains missing at the scale of the entire city.

The impacts of ecosystem services due to changes in urban land use in African cities have remained almost unexplored scientifically. Most of the time, land use around ecosystem services conceptual link isn't enough to determine the actual link between the changes on the ground and the ecosystem service benefits of urbanization, reference is made specifically to the services regulating the urban environment, such as flooding control and purification, whereas they remain the most inaccessible to field quantification without the prerequisites of temporal and spatial analysis (Nayak et al., 2024). Naturally, to unravel these together with the underlying mechanisms, it is necessary to use combined methods of remote sensing, field observation, data analysis, etc. Such a method has not been adopted by cities in Zimbabwe.

The prevailing knowledge about the relation of urban development patterns to biodiversity and ecosystem functioning is further lacking. Besides treating urbanization as a dichotomy (urban vs.

non-urban) or a simple gradient mostly these studies completely overlook the fact that urban landscapes are highly heterogeneous and consist of diversified land use types that have varying ecological impacts. A deeper understanding of distinguishing primary urbanization from gentrification, wetland conversion from agricultural land conversion is essential and has been lacking in existing research on Zimbabwean cities (Knapp et al., 2021)

Research on urban biodiversity in Africa has predominantly focused on large cities like Cape Town and Durban whilst cities like Harare with unique governance, economic and environmental contexts may exhibit distinct patterns of land use change and ecological impacts (Awoyemi & Ibáñez-Álamo, 2023). Therefore generating localized evidence is vital for developing tailored conservation and planning strategies to address specific challenges faced by Zimbabwean cities.

CHAPTER 3 METHODOLOGY

3.1 STUDY AREA AND DATA SOURCES

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3.1.1 Location

The study area is Harare, the capital and largest city of Zimbabwe, located in the north-eastern part of the country within the Mashonaland region at approximately 17°49'S, 31°03'E, at an elevation of about 1,490 metres above sea level. Harare forms the core of Harare Metropolitan Province and lies at the convergence of major road corridors, including the Bulawayo, Lomagundi, Mutare, Chitungwiza and Seke roads, which radiate outward from the historic city centre and structure the pattern of urban expansion examined in this study (Figure 3.1).

3.1.2 Weather and Climate

Harare experiences a subtropical highland climate, characterized by a warm, wet season from November to March/April, a cool, dry season from May to August and a short hot, dry season in September/October. Mean annual temperature is approximately 18°C, with average annual rainfall ranging from about 825 mm in the southwest to 855 mm in the higher-lying northeast of the city. The pronounced seasonality of rainfall and vegetation phenology is an important consideration when interpreting the Landsat-derived classifications used in this study, particularly for images acquired during the dry season.

3.1.3 Management Authority(ies)

Harare falls under the jurisdiction of the Harare City Council, a local authority headed by an elected Mayor and Council responsible for urban planning, land-use management and municipal service provision within the city boundary. The Council operates under the oversight of the Ministry of Local Government and Public Works, which sets national frameworks for physical planning. Peri-urban and satellite areas bordering the study extent, including Chitungwiza, fall under separate municipal authorities, a fragmentation of governance that has been associated with uneven enforcement of land-use regulations across the wider urban fringe.

3.1.4 Vegetation

The natural vegetation of the Harare area is open miombo woodland, dominated by Msasa (*Brachystegia spiciformis*), which colours the landscape with reddish new leaf growth toward the end of the dry season. Remnant woodland and grassland patches persist within protected or undeveloped areas such as the Mukuvisi Woodlands and along the Mukuvisi River corridor, while exotic species introduced during the colonial era, notably Jacaranda and Flamboyant, are prominent in older residential and avenue plantings within the built-up core. Much of the original woodland outside protected areas has been progressively cleared for agriculture and more recently urban development which forms the central concern of this study.

3.1.5 Population

According to the 2022 national census, the city of Harare had a population of approximately 1.85 million within the city proper, with the wider Harare metropolitan area estimated at approximately 2.49 million. Population growth and associated housing demand, including extensive informal settlement, are widely cited as key drivers of the peri-urban expansion and land cover change documented in this study.

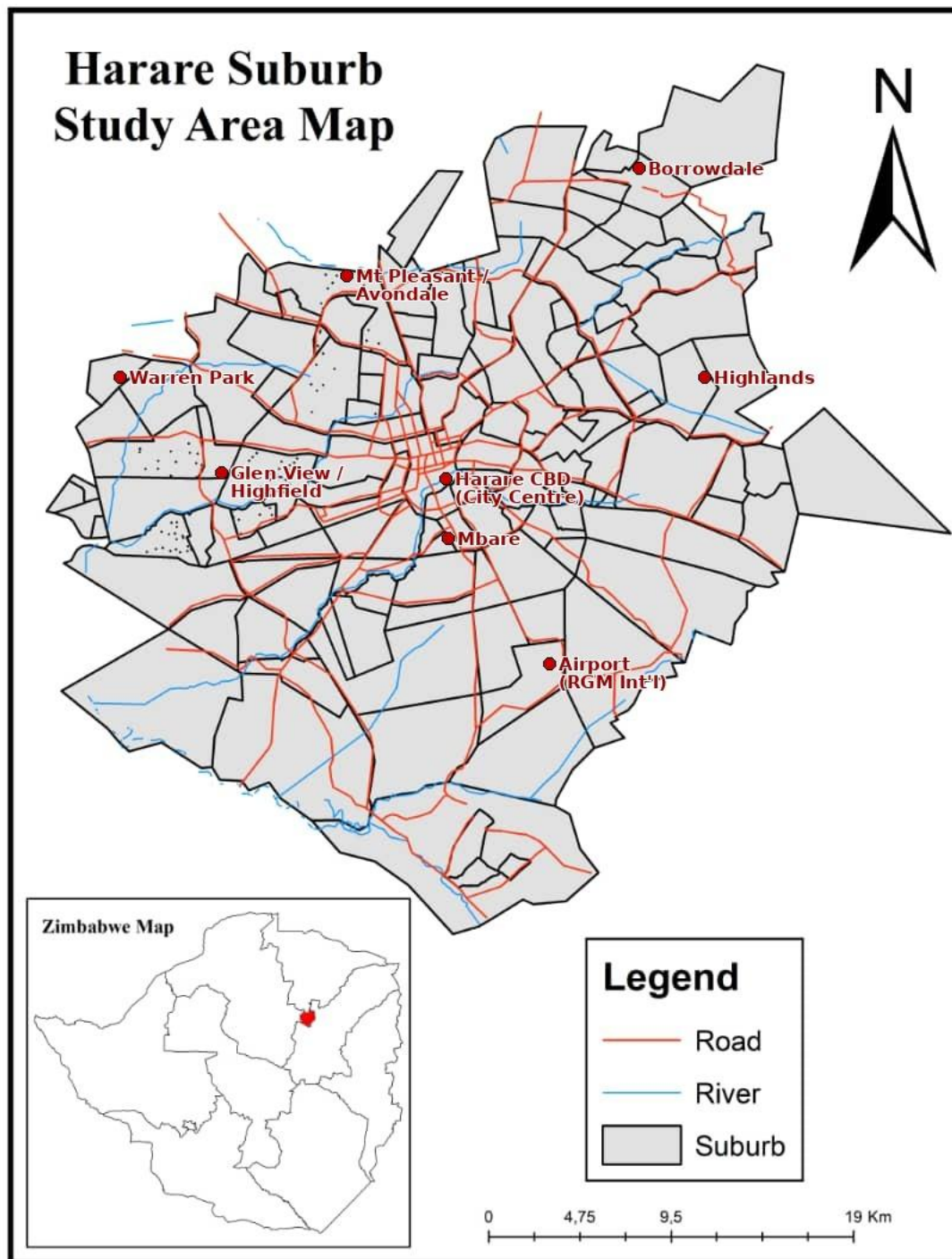


Figure 3.1: Study area

3.2 TOOLS, SOFTWARE AND MATERIALS

Various open sources and proprietary geospatial and statistical software programs were utilized for data processing, analysis and visualization. Software applications employed were as follows:

- QGIS (open source): this software was utilized to check spatial data initially, carry out vector overlay operations, and produce cartographic outputs
- FRAGSTATS 4.2: They run a spatial pattern analysis to calculate world metrics such as patch density, edge density, largest patch index, mean patch size, and Shannon Diversity Index from classified land use/ land cover raster outputs.
- Microsoft Excel: it stores initial data, allows inspection, and tabulates accuracy assessment results and biodiversity occurrence summaries.

3.3 DATA COLLECTION

Satellite images for the analysis were sourced from the United States Geological Survey (USGS) Earth Explorer platform (earthexplorer.usgs.gov) that offers free and open access to the entire Landsat archive. Landsat 8 OLI/TIRS images for the base years 2013-2025. Images were chosen based on less than 10% cloud cover and acquisition dates during the dry season to ensure spectral consistency of the classification years (Talukdar et al., 2020). All of the scenes belong to WRS -2 path 170, Row 072 that covers Harare.

Landsat 8/9 OLI data consist of seven fundamental multispectral bands that were utilized and each isolated a different segment of the electromagnetic spectrum and playing a certain part in land cover analysis

- Band 1 (coastal/ aerosol, 0.43-0.45m) was implemented to assist atmospheric correction and aerosol detection during preprocessing so as to get better surface reflectance values in general.
- Band 2 (blue, 0.45-0.51m) was most helpful in differentiating soil and vegetation and giving boundaries to water bodies

- Band 3 (green, 0.53-0.59m) it corresponded to the wavelengths at which vegetation reflectance peaks; this was used to measure plant health and distinguish vegetation types in the study area.
- Band 4 (red, 0.64-0.67m) this marks the region where chlorophyll absorption occurs and was extremely important in changing vegetated surfaces to bare land and built-up areas
- Band 5 (near infrared/NIR, 0.85-0.88m) this is greatly reflected by healthy green vegetation and the band was used mainly in calculating the NDVI, the NDVI was obtained from the formula $(\text{band 5} - \text{band 4}) / (\text{band 5} + \text{band 4})$ and was used to measure and map vegetation cover in the four study years
- Band 6 (SWIR-1, 1.57-1.65m) this reacts to soil moisture and vegetation water content. It was the main spectral channel used to better distinguish different classes of soil, vegetation and built up area during the classification phase
- Band 7 (SWIR-2, 2.12-2.29m) this was used to penetrate atmospheric haze, and it was mostly at detecting urban materials and impervious surfaces ; together with band 5 it was used to measure NDBI

The spectral bands 1-7 were integrated into a composite as primary spectral features for supervised image classification with additional NDVI and NDBI layers used to enhance the distinction between different land classes i.e. bare area, vegetation, water bodies and built up areas

3.4 DATA PROCESSING

All satellite images were processed regularly before the study. Radiometric correction and atmospheric correction were done with the Dark Object Subtraction (DSO1) technique in QGIS, changing raw digital numbers to surface reflectance values. To ensure the accuracy of geometric correction, ground control points taken from high-resolution Google Earth images were used, and the root mean square error (RMSE) was kept under 0.5 pixels. Composites without clouds were made for each base year (2013, 2015, 2020, and 2025) using Google Earth Engine's median compositing. To improve the differentiation of land cover, spectral indices were calculated for every composite image. Vegetation characterization was done by calculating the Normalized Difference Vegetation Index (NDVI), impervious surface mapping using the Normalized

Difference Built-Up Index (NDBI). These indices, plus the original spectral bands, constituted the inputs for image classification. Biodiversity records from GBIF were cleaned by removing duplicate entries and records with coordinate uncertainty greater than 1km. The cleaned data were spatially linked with the classified LULC raster's so that each species occurrence was associated with the land cover class and year of recording

3.5 LAND USE/ LAND COVER CLASSIFICATION

Supervised image classification was carried out using the Maximum Likelihood Classification (MLC) method, which is available at QGIS through the Semi-Automatic Classification Plugin (SCP). Accuracy assessments are conducted for each classified image using stratified random sampling. LULC change detection is performed using post-classification comparison, whereby classified raster's from successive time periods were overlaid to produce change matrices quantifying the area of conversion between each class pair.

3.6 LANDSCAPE METRICS AND BIODIVERSITY ANALYSIS

Landscape fragmentation and spatial arrangement are measured using FRAGSTATS 4.2 running on classified LULC raster images at both the class and landscape levels. Metrics calculated included: Patch Density, Edge Density, Largest Patch Index, Mean Patch Size, and Shannon's Diversity Index. These landscape structure indicators were then used to analyze changes in habitat fragmentation and landscape heterogeneity over the study period. Biodiversity evaluations used species records from GBIF, along with field transect surveys that were done in the areas around Harare peri-urban zones. The association between landscape fragmentation metrics and biodiversity indices was determined by the Spearman rank correlation method, conducted in Python.

3.7 RATIONALE FOR SELECTED METHODS

Remote sensing was employed to map urban changes in Harare, providing insights into long-term land use changes that field surveys alone may not capture. The analysis included measuring fragmentation using FRAGSTATS and ground verification through field transects to validate historical records and observe current patterns. The integration of historical Global Biodiversity

Information Facility (GBIF) data and current observations enabled a comprehensive analysis of how development has impacted Harare's land cover from 2013 to 2025.

CHAPTER 4: RESULTS

4.0 INTRODUCTION

In this chapter presents the outcome of the analysis of the land use and land cover (LULC) change data collected for Harare, across the study years which are 2013, 2015, 2020, and 2025. The analysis draws on supervised image classification of Landsat satellite imagery processed using QGIS. The focuses on how the four LULC classes of vegetation, water areas, bare areas and built-up areas have changed in spatial extent. The data is presented through tables, graphs and map interpretations to reveal both the magnitude and direction of these land cover changes. The data will be organized by class, followed by an integrated discussion of overall LULC transformation trends and their implications for urban land management in the study area (Marondedze & Schütt, 2019c)

4.1 Overall LULC Area Statistics 2013-2025

The data reveals significant shifts in land cover composition over the years, most notably the progressive expansion of built-up areas and the corresponding fluctuation and overall decline of the land that's vegetated Table 4.1

Table 4.1: LULC Harare Area Statistics (km²)

LULC CLASS	2013	2015	2020	2025
VEGETATION	767.9	87.7	541.5	214
WATER AREA	5.75	47.1	5.10	5.16
BARE AREA	88.5	405.9	229	202.97
BUILT UP AREA	758.6	1109	805	1199.5

TOTAL	1620	1649.7	1581.43	1621.6
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Built-up area has consistently held the largest share of land cover in Harare across years in question, with the exception of 2013 when vegetation was marginally dominant. The dramatic reduction in vegetation cover from 767.9 km² in 2013 to just 214.0 km² in 2025 is a notable observation, representing a net loss of 553.9 km². On the other hand, the built-up area grew from 758.6 km² in 2013 to 1,199.5 km² in 2025 a net increase of 440.9 km² (Figure 4.1). The patterns point to an ongoing and accelerating process of urbanization that is progressively consuming Harare's natural land cover.

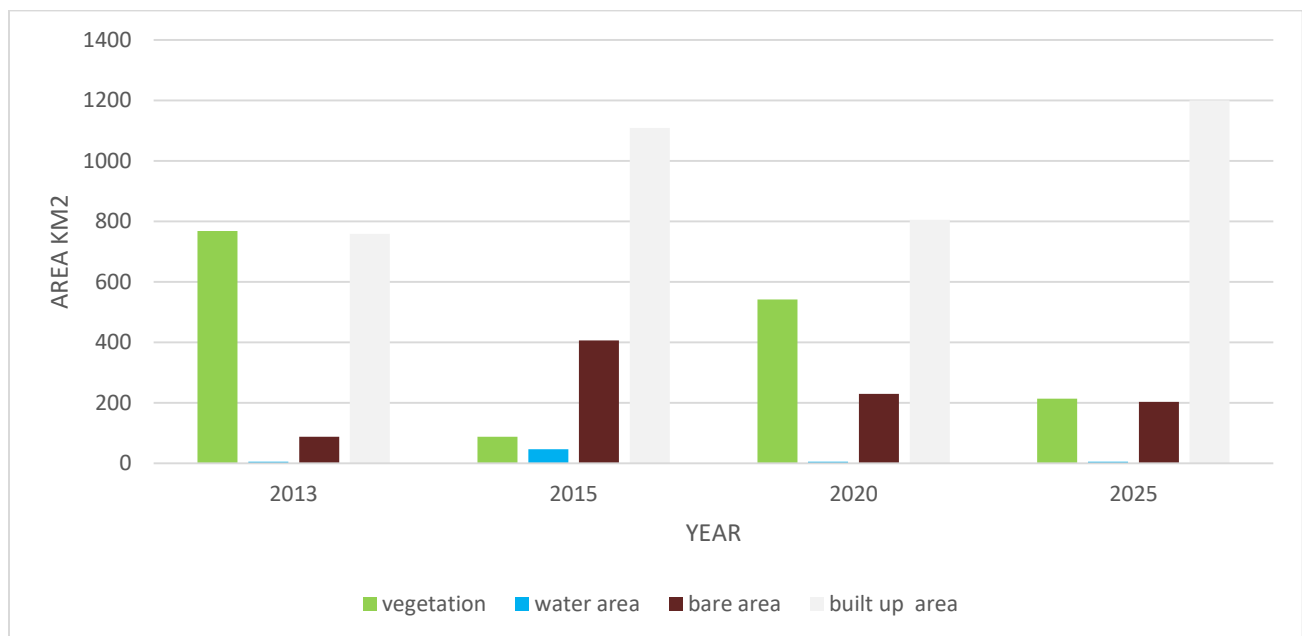


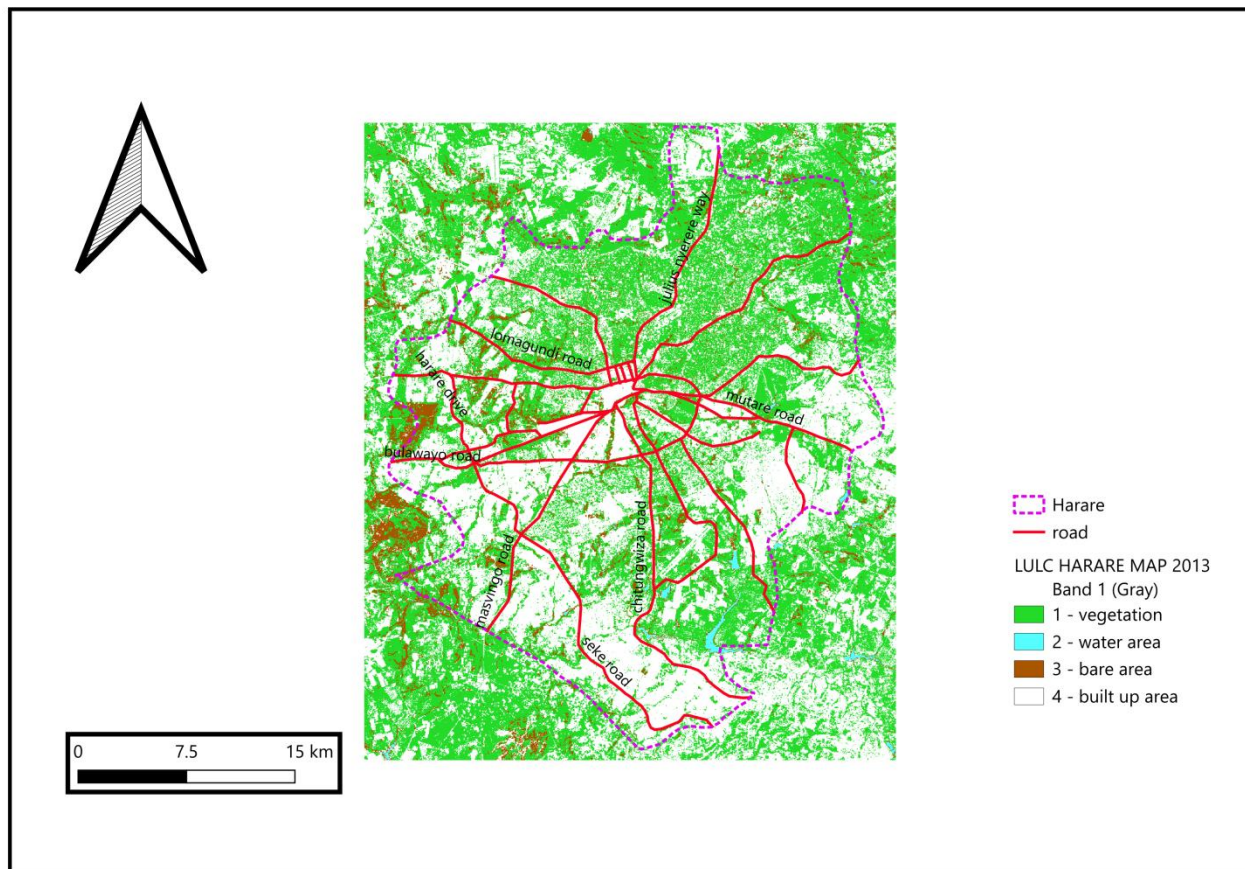
Figure 4.1 Land Use Land Cover Classification- Harare (2013-2025)

Most notable feature is the dramatic variability in the vegetation and built-up area categories, while water areas remain relatively stable and modest throughout the study period. Built-up area bar consistently towers above most other categories, and its growth between 2020 and 2025 is particularly pronounced.

4.2 ANALYSIS OF VEGETATION COVER CHANGE

The vegetation cover in Harare shows dramatic and non-linear change across the study years. In the Table 4.1 and Figure 4.1, vegetated areas started at 767.9 km² in 2013, collapsed sharply to just 87.7 km² in 2015, partially recovered to 541.5 km² by 2020, and then declined again to 214.0 km² in 2025.

Vegetation was the dominant in 2013 land cover class, covering 767.9 km², which represented approximately 47.4% of the total classified area. As shown in the 2013 LULC map, green (vegetation) dominated both within and around the Harare city boundary, with significant vegetated patches extending across peri-urban zones along all major road corridors, including Lomagundi road, Mutare road, and Seke road. The greenery in the urban area interspersed with white built-up pixels characterized the central urban zone, shows that in 2013, Harare still retained a relatively substantial green canopy (Figure 4.2).



In 2015 vegetation cover had plummeted to just 87.7 km² a reduction of 680.2 km² (88.6%) in just two years. The 2015 LULC map shows that green patches have virtually disappeared across the entire study extent and has been replaced predominantly by bare area (brown) and built-up area. A near-total loss of visible vegetation across the landscape in 2015 is anomalous and is most likely attributable to seasonal dry-season image capture where deciduous vegetation loses its leaf cover and registers spectrally as bare soil, thereby inflating the bare area class and deflating the vegetation class. It is also plausible that this period coincided with actual clearing for development, land preparation, or drought-related vegetation stress (Figure 4.3)

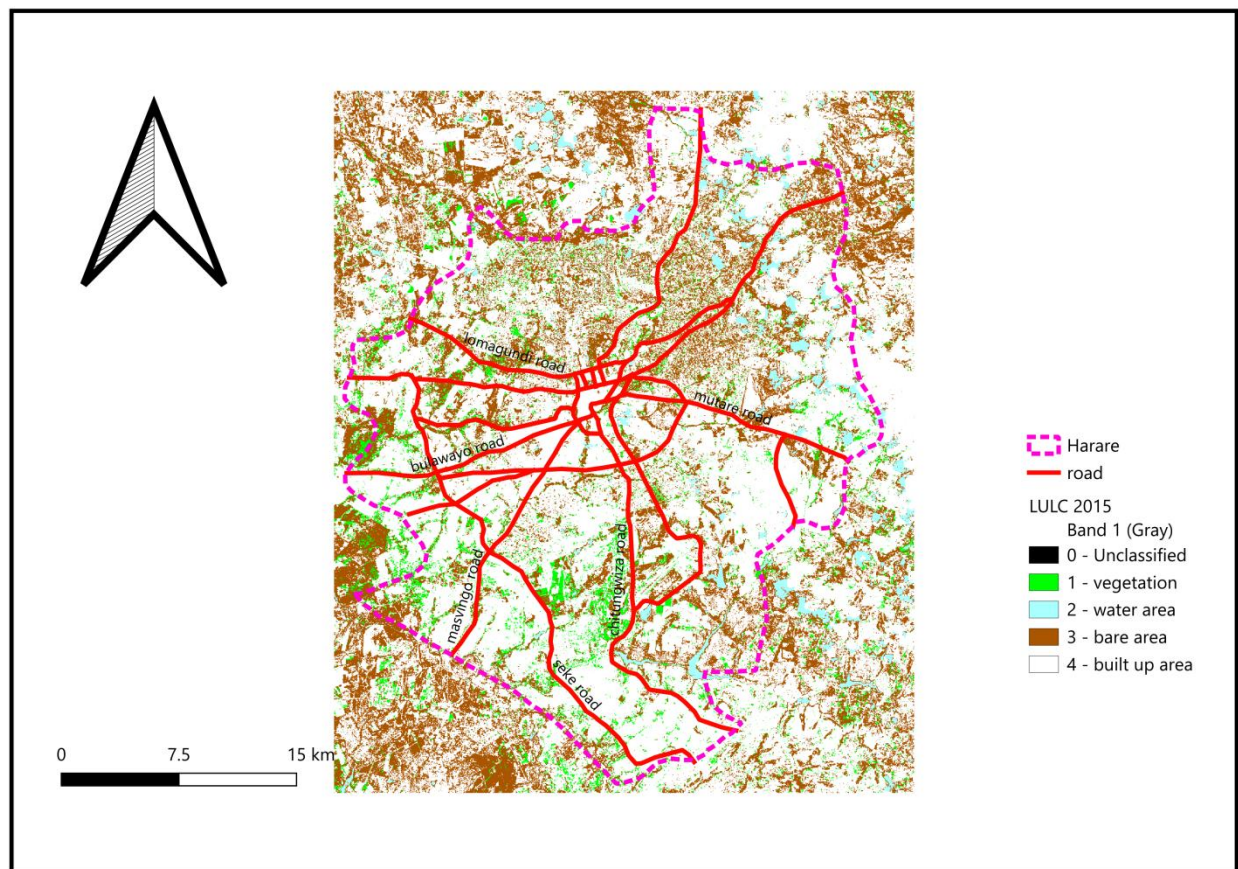


Figure 4.3 Harare LULC map 2015

The vegetation covers partially recovered to 541.5 km² in 2020. The 2020 LULC map shows that green has re-emerged strongly across the northern and eastern sections of Harare, especially the

Lomagundi road corridor and along the Mutare road belt. Central and southern portions of the city including areas around the Chitungwiza road and Seke road corridors remained dominated by built-up and bare pixels (Figure 4.4).

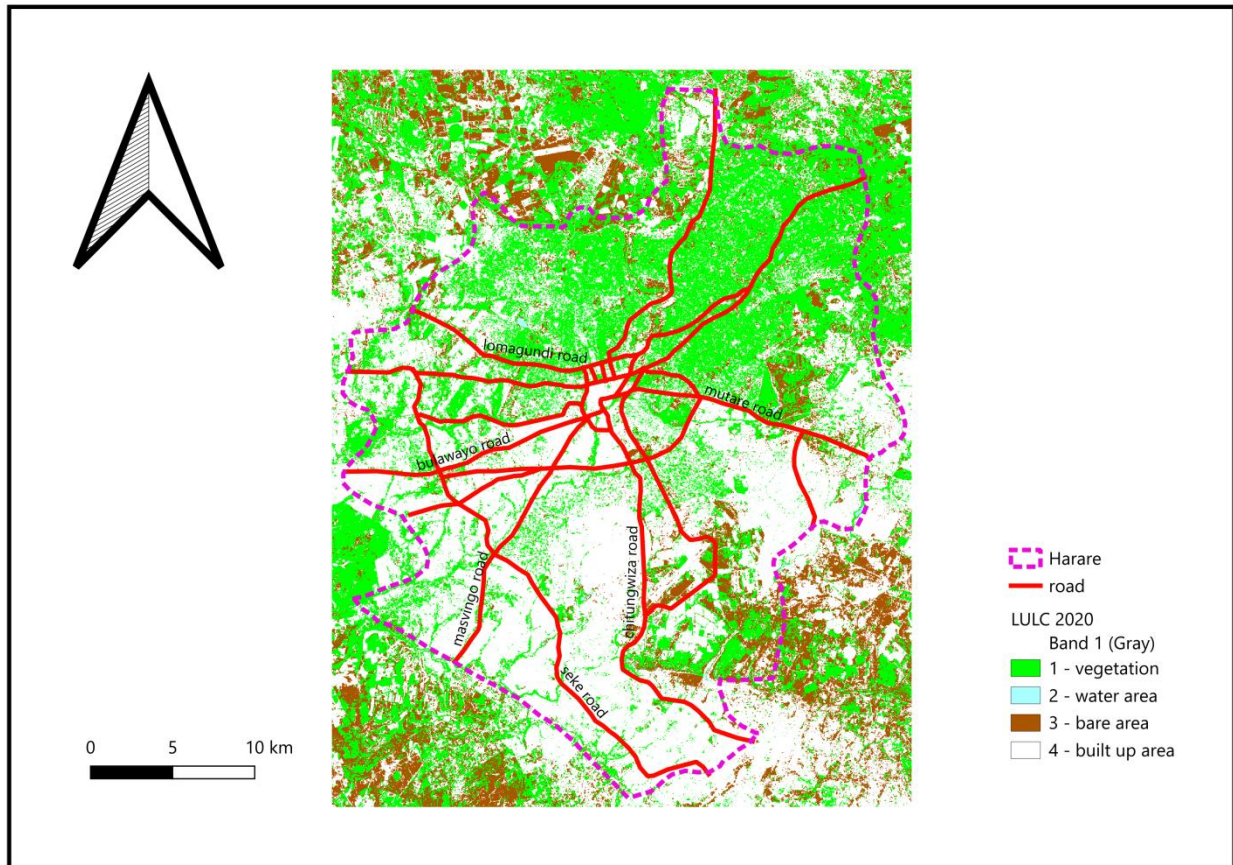


Figure 4.4 Harare LULC map 2020

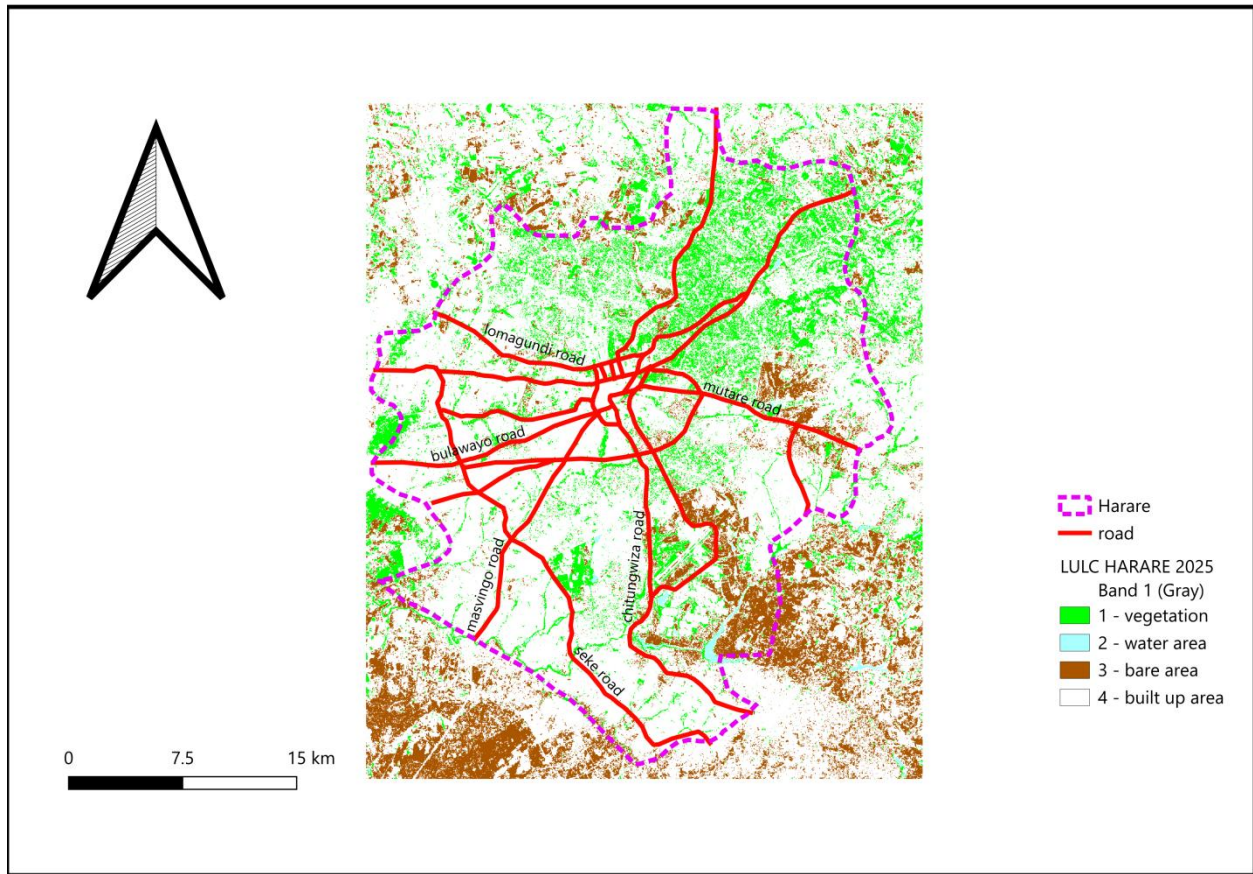


Figure 4.5 Harare LULC map 2025

From 2013 to 2025 vegetation declined by a 553.9 km² (72.1%). The trajectory is consistent with findings of 41% decline in natural vegetation cover in Harare.

4.3 ANALYSIS OF BUILT UP AREA CHANGE

Built-up area is the LULC class that most directly reflects urbanization it shows a clear overall upward trajectory throughout the study period from 758.6 km² in 2013 to 1 199.5 km² in 2025 (Figure 4.6).

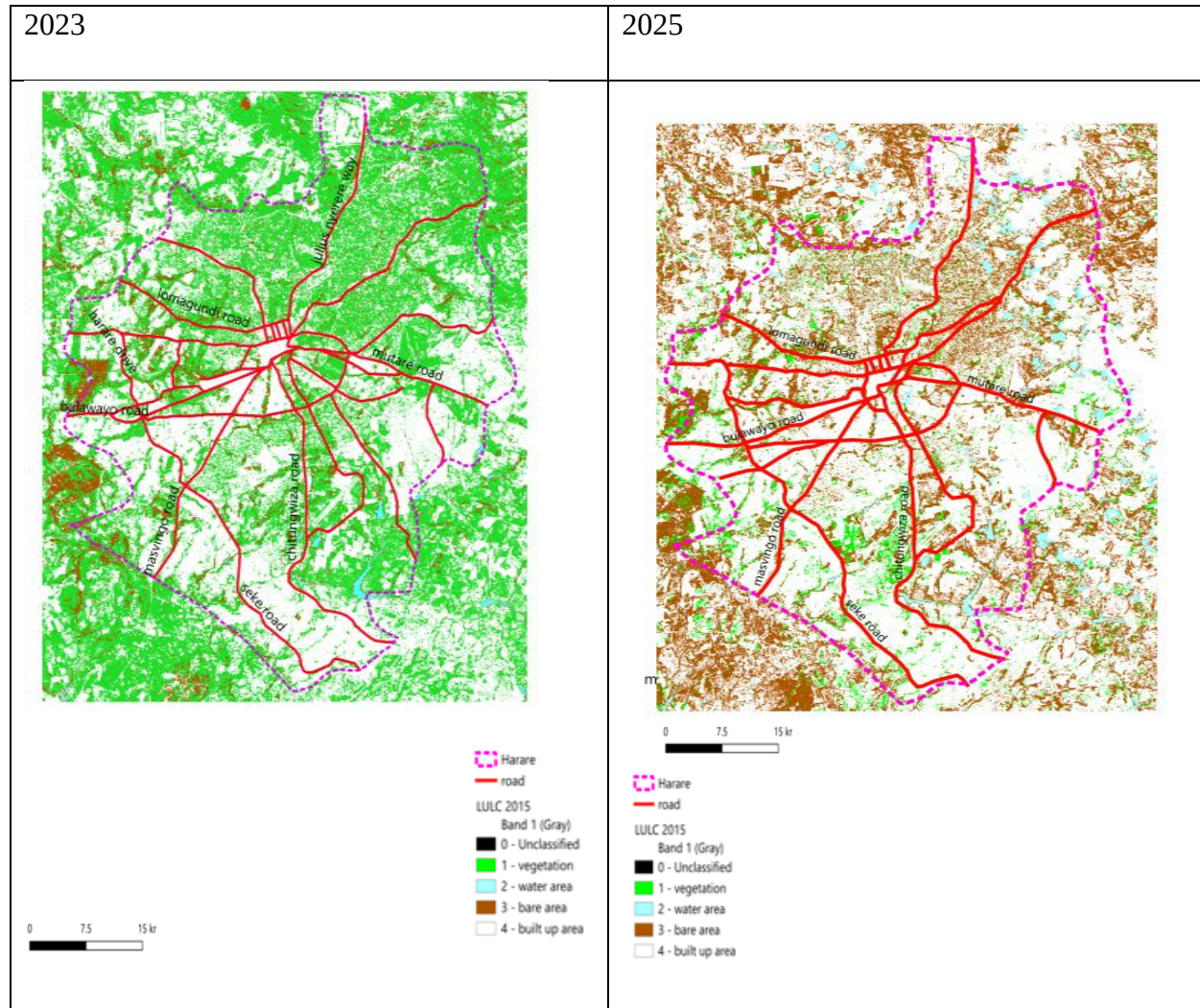


Figure 4.6 Harare LULC map 2013 and 2015

Built-up area increased by 350.4 km² between 2013 and 2015 the largest absolute gain in any two-year interval within the study period. This 46.2% increase over just two years reflects the rapid pace of informal and formal urban expansion that has characterized Harare's recent development. The 2015 LULC map shows that built-up area pixels dominate the central city and expanded into peril-urban areas along all major road corridors.

4.3.2: 2020 To 2025 - Sustained Expansion

The period between 2020 to 2025 built-up area increased sharply from 805.0 km² to 1199.5 km² a gain of 394.5 km² (49.0%). This 2025 LULC map illustrates this growth of built-up pixels dominate not just the historic city core but extend continuously outward along the Bulawayo Road, Lomagundi road, Mutare road and Chitungwiza road corridors. Southwestern and Southeastern peripheries previously characterized by a mixture of vegetation and bare patches are now substantially converted to built-up land.

The built-up area increased by a net 440.9 km² (58.1%) from 2013 to 2025 and this represents the clearest quantitative signal of Harare's ongoing urbanization, and its spatial expansion as shown by the progressive LULC maps which confirms that this growth is occurring at the urban-rural fringe at the expense of vegetated and bare land.

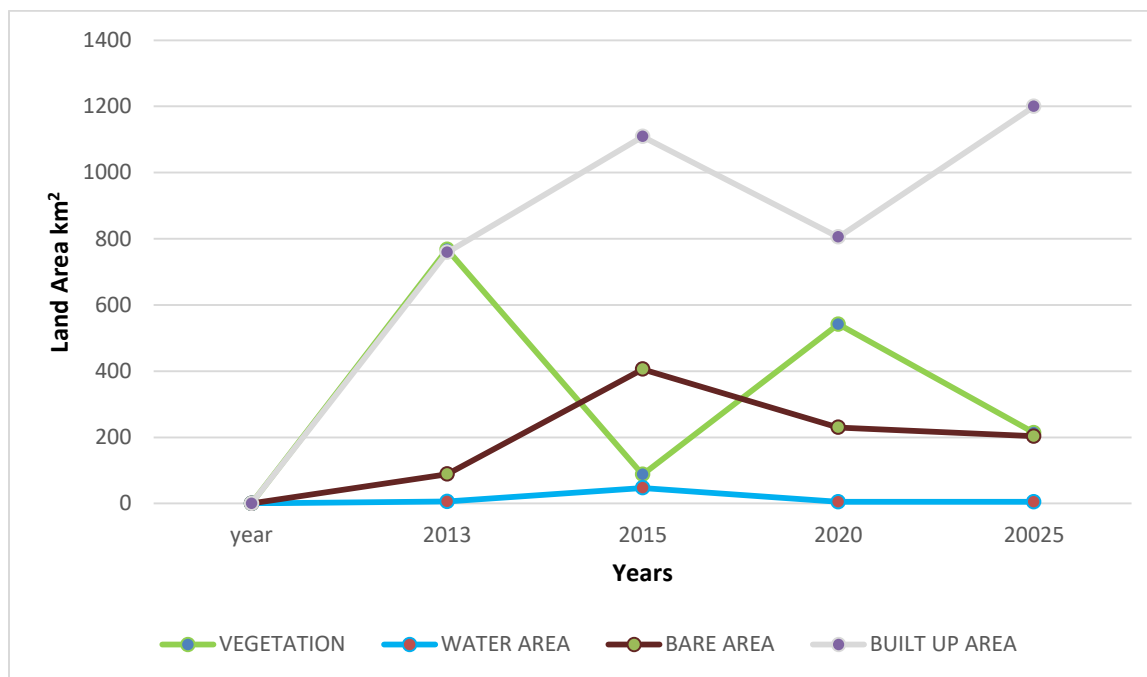


Figure 4.7 Vegetation Cover vs. Built Up Area Change in Harare (2013-2025)

The inverse relationship between vegetation and built-up area is visually prominent as built-up area rises, and vegetation generally declines (Figure 4.7). The sharp mid-period dip of vegetation in 2015 and the corresponding spike in bare area confirm the irregular character of the 2015 classification. Water area trend line is almost flat throughout, reflecting the relatively stable, small extent of open water bodies within the study boundary.

4.4 ANALYSIS OF BARE AREA CHANGE

The bare area encompasses exposed soils, cleared land, construction sites and degraded surfaces. This shows significant variability across the study period whereby 88.5 km² in 2013 peaking sharply at 405.9 km² in 2015 declining to 229.8 km² in 2020 and further reducing to 202.97 km² in 2025. (Figure 4.7)

The remarkable feature of the bare area data is the spike to 405.9 km² in 2015 and increase of 317.4 km² (358.7%) from the 2013 baseline origins. The spike is strongly associated with the probable use of dry-season imagery for the 2015 classification. Vegetation loses its green spectral signature in the dry season the satellite sensor records the exposed soil and litter layer beneath which is indistinguishable spectrally from genuine bare area this causes a significant overestimation of bare area and underestimation of vegetation in the 2015 data. Map of 2015 LULC map shows bare area dominating vast swathes of the landscape especially in areas that are known to be vegetated in normal seasons, further supporting this interpretation

Due to the 2015 peak bare area declined progressively to 229.8 km² in 2020 and 202.97 km² in 2025. This downward trend after 2015 likely reflects two concurrent processes, the normalization of classification as wetter-season imagery was used for later years; and the genuine conversion of previously bare or cleared land into built-up infrastructure as ongoing urban development activities progressed. Construction sites that appear as bare area in earlier years would have transitioned into built-up cover as buildings were completed. The map shows notable concentrations of bare area particularly in the Southern and Southeastern peripheries along the Chitungwiza road and Seke road belts suggesting active land preparation and transitional zones in these growth frontiers.

4.5 ANALYSIS OF WATER AREA CHANGE

The analysis highlights the significant changes in water areas with notable increase to 47.1 km² in 2015 from 5.75 km² in 2013 contrary to the overall trend (Figure 4.6 and 4.7).

The spike in water area to 47.1 km² in 2015 from just 5.75 km² in 2013 stands in notable contrast to the general trend. At first glance, this appears counterintuitive like if vegetation declined and bare area expanded, why would water area also increase?

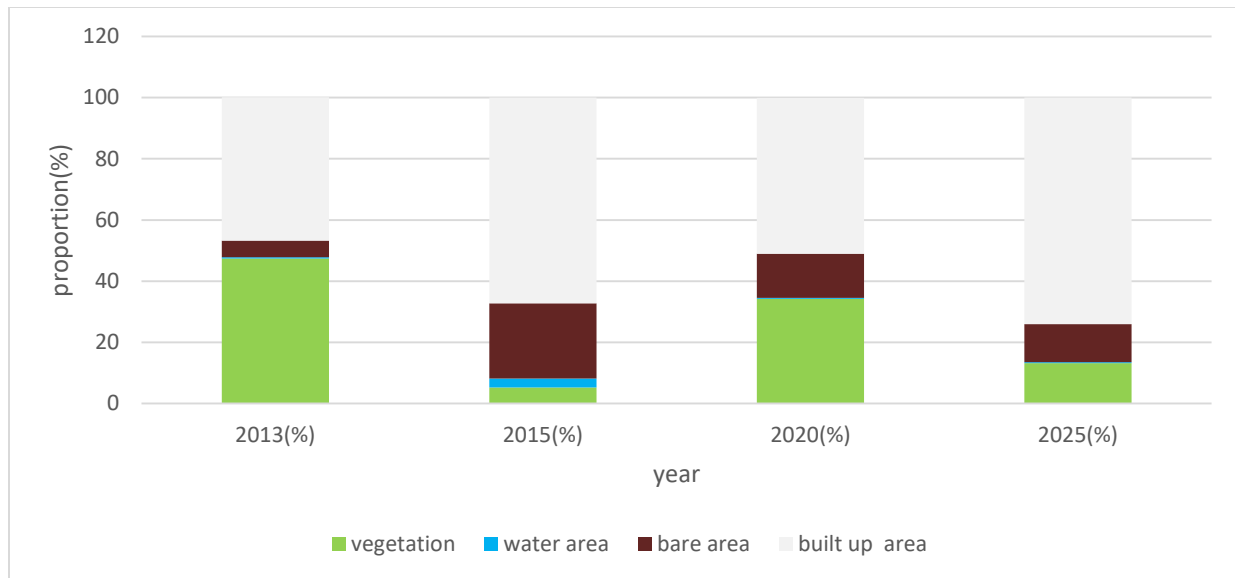


Figure 4.8 Proportional LULC Area Share by Classification (2013-2025)

In 2013, vegetation (47.4%) and built-up area (46.8%) were approximately equal in share. Built-up area IN 2025 dominates at 74.0% of total classified area while vegetation has fallen to just 13.2%. There is a dramatically different composition due to the classification anomaly where bare area (24.6%) was inflated and vegetation (5.3%) was extremely depressed. Water areas remain a marginal proportion throughout all four years, never exceeding 2.9% even in 2015 (Figure 4.8)

4.6 SPARTIAL PATTERNS OF LULC CHANGE FROM CLASSIFIED MAPS

The four LULC maps provide critical spatial insight into the location and direction of land cover change. Observations from the 2013, 2015, 2020, and 2025 classified maps characterize where and how Harare's landscape has been transformed.

4.6.1 City Core

The urban core of Harare shows that the area immediately surrounding the convergence of Lomagundi road, Mutare road, and Bulawayo Road is already predominantly built-up area in 2013 and has remained so throughout the study period. Maps from 2013-2025 show little change in land cover in this area across years confirming that the historic city center was already fully urbanized by 2013 and that subsequent expansion has occurred outward rather than inward.

4.6.2 Peril -Urban Fringe Expansion

The significant spatial change is visible at the urban fringe to the transitional zone between the established urban core and the outer rural periphery. Between 2013 and 2025 maps areas that are vegetated or mixed in 2013 are predominantly built-up in 2025. The corridor-based expansion is particularly visible in the western and southern sections of Harare where new settlements and peril-urban developments have extended built-up cover several kilometers beyond the 2013 urban boundary.

4.6.3 North-Eastern Zone

The 2020 map shows retention of vegetation cover in Harare's northern and northeastern areas lying beyond the main built-up core but within or near the city boundary. However, by 2025 the same areas show a pronounced reduction in vegetation with white and brown tones increasingly encroaching. This northern green belt likely includes remnant agricultural land and peril-urban vegetation which is under growing pressure from urban expansion. Persistence of green in the north-east of the 2020 map may be related to areas associated with the Lake Chivero watershed catchment and Mukuvisi green corridor, which have historically been afforded some protection though this does not appear to have halted vegetation loss by 2025.

4.6.4 Southern and Southeastern Periphery

There is a consistent pattern of bare area and built-up expansion across all four years, bare area concentrations are visible in this zone in both 2020 and 2025 suggest active land preparation, informal plot development and transitional land use characteristic of Harare's southern growth frontier. The zone encompasses peril-urban communities with high rates of informal settlement growth and limited planning oversight showing informal urban expansion in Harare's southern periphery (MSINDO, 2013)

4.7 NET CHANGE ANALYSIS (2013-2025)

Over the full twelve-year study period the built-up area gained the most land (+440.9 km²,

+58.1%) confirming urbanization as the dominant land transformation process in Harare (Table 4.2). Bare area also recorded a net increase of 114.47 km² (+129.3%) reflecting persistent land disturbance and clearing. Vegetation (-553.9 km², -72.1%) and water areas (-0.59 km², -10.3%) recorded net losses, with vegetation showing the most severe absolute and relative decline (Table 4.2). Near-complete replacement of vegetated land by built-up and bare surfaces within twelve years signal a profound ecological transformation of Harare landscape.

Table 4.2: Net Change in LULC Area (km²), Harare (2013-2025)

LULC CLASS	2013	2025	NET CHANGE	% CHANGE
VEGETATION	767.9	214	-553.9	-72.1%
WATER AREA	5.75	5.16	-0.59	-10.3%
BARE AREA	88.5	202.97	+114.47	+129.3%
BUILT UP AREA	758.6	1199.5	+440.0	+58.1%

The two dominant LULC classes were vegetation and built-up area. Shaded areas under each line emphasize the divergence between the two trajectories over time. Both classes were nearly equal in extent (767.9 km² vs. 758.6 km²) (Figure 4.9). By 2025 the gap had widened enormously with built-up area at 1199.5 km² and vegetation at just 214 km², this graphically captures the core land cover transformation story of Harare over the four study years, the progressive conversion of green, open, and vegetated land into impervious built-up surfaces.

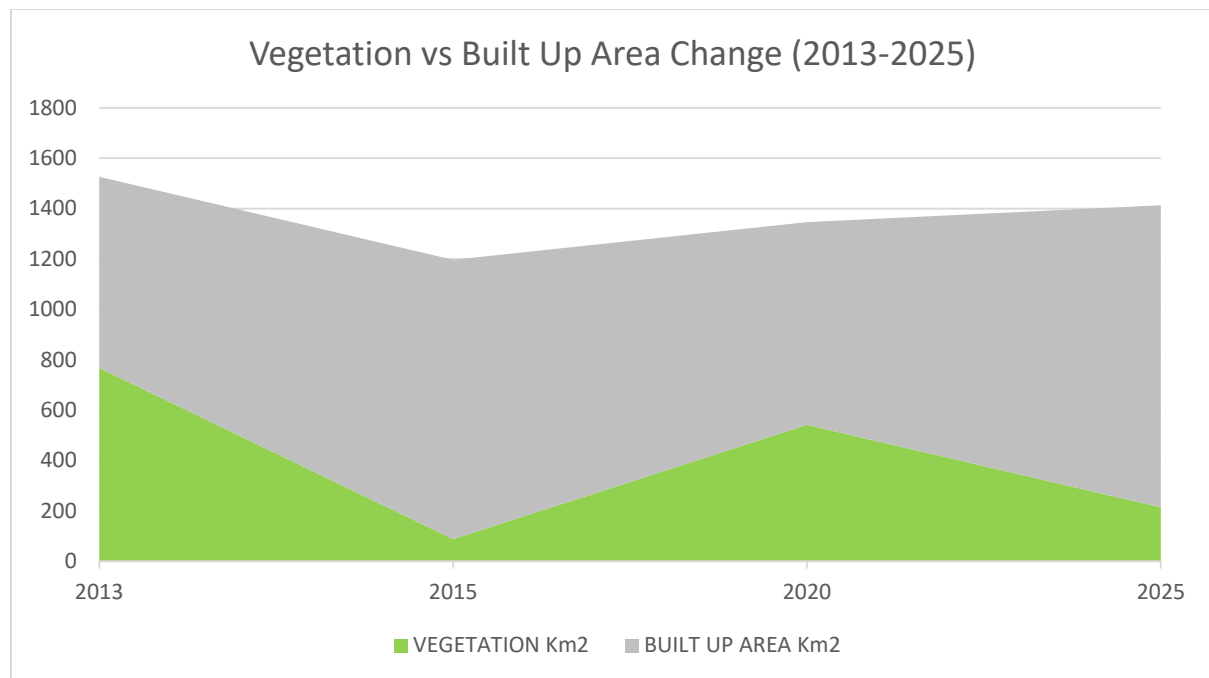


Figure 4.9 Vegetation vs. Built up area change

CHAPTER 5: DISCUSSIONS

5.1 INTRODUCTION

This chapter presents a discussion and interpretation of land use land cover changes findings from chapter 4. It assesses the environmental importance of LULC changes in Harare from 2013 to 2025, forming logical links between the measured landscape changes and their impacts on biodiversity and ecosystem functioning. The chapters' structure matches each of the study's objectives like spatio temporal patterns of urban land use change, the correlation between land use change and biodiversity decline and the impacts of urbanization on major ecosystem services. The study was also able to connect empirical results from Harare with regional and global evidences to position the local scenario within larger urbanization and ecology arguments

The results presented in this chapter show a consistent picture of rapid, urbanization-driven land cover transformation in Harare between 2013 and 2025, the overarching trend is clear, built-up area has expanded dramatically, primarily at the expense of vegetation cover while bare area has also grown as a transitional land state between natural and built surfaces.

5.1.2 Alignment with Documented Urbanization Trends

The findings closely align with previous studies on urban expansion in Harare indicating a substantial 58.1% increase in built up areas over twelve years (2013-2025) underscoring persistent (Forget et al., 2021b)

5.1.3 Implications of Vegetation Loss

The loss of 553.9 km² of vegetation cover in Harare has profound implications for urban ecology and ecosystem services affecting functions such as storm water absorption, temperature regulation, air quality and biodiversity. The spatial analysis revealed concentrated vegetation loss at the urban fringe particularly impacting ecological connectivity, riparian vegetation and wetland buffers crucial for hydrological functions. The decline in vegetation along watercourse corridors like Mukuvisi River poses challenges for flood regulation and water quality maintenance (Alikhani & Mummy, 2021)

5.1.4 The Role of Bare Area as a Transitional Class

Furthermore, bare areas play a significant role as a transitional land cover classes in the analysis. In Harare's peril-urban context bare area represents land that has been cleared for construction, agricultural preparation or informal settlement development. The persistence of significant bare area in the southern periphery in both 2020 and 2025 maps suggests that land conversion from natural cover to built-up use is an ongoing, phased process rather than an instantaneous transformation. This has implications for how LULC change statistics should be interpreted, a city that appears to have only moderate built-up expansion in a single time interval may actually be undergoing much more extensive land disturbance when bare area is factored in as a precursor to built-up cover (Matamanda, 2020c)

5.2 SPATIO TEMPORAL LULC CHANGE PATTERNS AND THEIR SIGNIFICANCE

Harare experienced accelerated informal settlement proliferation in peril-urban zones during this 2013-2015 period and it was partly driven by economic collapse and weakened planning enforcement (Matamanda et al., 2020). Research showed that Harare has experienced rapid urban growth during 2013-2025 as shown by 58.1 % increase of built-up area with a 72.1 decrease of vegetation. The evidence supports and also surpasses the rates of urban expansion reported by previous studies by Marondedze using Landsat data for the period of 1984 - 2018 as he found a 156% growth of built-up areas in thirty years which confirms the trend this paper has extended to the 2020s (Marondedze & Schütt, 2019c)

The speed of built-up area growth detected aligns with the overall growth pattern of sub-Saharan African cities whereby the average percentage of built-up area increased annually by 3-5% (Forget et al., 2021b). The result off this work which is 58.1% net growth over twelve years corresponds to about 4% per year expansion rate. Harare was then placed within this regional scenario. The difference when it comes to Harare is that the fast development is happening in a situation of insufficient formal planning capacity, limited infrastructure investment and poor enforcement of environmental regulations which led to ecologically harmful urban sprawl.

Analysis of LULC maps show that the increase happened mainly along corridors extending from the city center through major roads like Bulawayo Road and Mutare Road. This way of road stimulated peri urban growth is common for low-income African cities where road facilities are a

trigger for the emergence of informal settlements and formal subdivision developments (Matamanda et al., 2020). Harare's southern and south eastern outskirts especially areas along Seke and Chitungwiza roads were characterized by recurrent clusters of bare land as seen in the 2020 and 2025 LULC maps. Land conversion processes still take place and previous disturbed land is being changed into built up. Spatial distribution of LULC images shows that the expansion mainly occurs along corridors as new development is spreading from the inner city along major arterial roads like Bulawayo and Lomagundi corridors. This situation is commonly seen in African cities with low income populations where the presence of well-developed road networks play a crucial role in the growth of informal housing areas and the establishment of planned residential neighborhoods (Matamanda et al., 2020). The outskirts of area especially the southern outskirts corridors are continuously characterized by concentrations of bare areas in both the 2020 and 2025 LULC maps that can be interpreted as evidence of land conversion activities resulting in transformation of previously disturbed surroundings to build up areas. Bare area is still a high transitional class points to the multistage nature of urban expansion in Harare and cautions the current figures for built up area may not fully capture the extent of land disturbance in progress.

5.3 IMPLICATIONS OF VEGETATION LOSS FOR URBAN BIODIVERSITY

Total land area with vegetation cover has disappeared by 553.9 km² during the period under investigation impacts biodiversity in the city. Loss of vegetation is the main process through which the changing land use results in the extermination of different species by eliminating their habitats the food and breeding resources they depend on and the ecological connectivity of the landscape that sustains them. Specialist species and wetland dependent animals are even the species that suffer greater harm (Kundu et al., 2024). When it comes to sub-Saharan Africa, bird and plant diversity sharply decline with increasing urbanization intensity (Kumdet et al., 2025). The level of vegetation loss occurring in Harare not only affects the richness of species to a measurable extent, but also their functional diversity across multiple taxa.

On the 2025 LULC map, vegetation is now mostly limited to remnants at peri urban areas and isolated green corridors with the city center being almost without substantial green cover. This kind of pattern of habitat fragmentation where the remaining patches of vegetation keeps getting smaller and more spaced out, further disconnects the green areas through ecological connections

and lowers the ability of the small patches left to support the wildlife populations that are necessary for keeping the ecosystem functional in a hopeful way (Wu & Liu, 2014). Effects of fragmentation is also enhanced by edge effects considering that smaller isolated patches tend to have a higher proportion of edge habitat which typically comes with greater disturbance, invasion by exotic species and reduced quality for interior specialist species, because of this the gradual disappearance of peri urban vegetation reported in this study also acts as a sign (Sirimewan & Dharmasena, 2022)

The findings are consistent with a worldwide projection that urban land expansion might directly threaten more than 855 species by 2050 and that with biodiversity loss, sub-Saharan Africa would be one of the most severely affected areas by urbanization (Simkin et al., 2022). Loss of natural vegetation in Harare i.e. the wetlands and riverbanks is of great concern since these habitats are home to the highest number of endemic and wetland species (Marchesan & Kolasa, 2024).

5.4 LAND USE CHANGE AND ECOSYSTEM SERVICE DEGRADATION

5.4.1 Flood regulation

A major ecosystem service at risk is from urbanization in Harare is flood regulation. When vegetation and wetlands are replaced by built up areas the natural water cycle is broken i.e. soil infiltration decreases, surface runoff increases and more stormwater in a shorter amount of time leads to higher flood peaks (Mumuni et al., 2025a). Research data from this study shows that the city's area covered by impervious surfaces has risen by 440.9 km² between 2013 and 2025, this change has been directly linked to a decrease on the natural flood control capacity of the city

Harare's built-up areas are mainly built in peri urban fringes, and from a flooding point of view these areas where wetland buffers and riverside vegetation are the most important in absorbing and slowing down stormwater. Urban development in wetlands, which has been the focus of many studies in Harare (Kudumba, 2022c), is removing the natural storage and filtering functions provided by these ecosystems. Reports at the community level in areas like Chitungwiza shows that they have been using the land at or next to degraded wetlands as building sites has led to more frequent and intense flooding

5.5 METHODOLOGICAL REFLECTIONS

The important point of departure with methods is the uncontrollable factor that is 2015 LULC classification which seems to be an outlier. The increase in bare are and the abrupt reduction in vegetation cover in 2015 dataset is due to consequence of using a dry season satellite image in which deciduous trees have lost their green leaves appear like spectrally like bare soil. The seasonal spectral confusion between bare soil and vegetation is one of the major problems in supervised image classification of Landsat data (Talukdar et al., 2020).

From 2013 – 2025 the LULC data points offer a coherent and ecologically significant scenario of the vegetation decline and the increase of the built-up areas in Harare. Later studies should give preference to the usage of images taken during the wet season or multi date compositing techniques to minimize the problem of seasonal classification artifacts. Built-up area decreased from 1109.0 km² in 2015 to 805 km² in 2020 a reduction of 304 km². The reduction reflects classification more than actual demolition of structures the 2015 dry-season imagery caused spectral confusion between bare soil, dry vegetation and built-up impervious surfaces thereby inflating the 2015 built-up area figure. The 2020 classification captures a wetter season composite more reliably separated built-up from other land covers.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

- Built up area grew from 758.6 km² to 1199.5 km² which is a net increase of 440.9 km² (+58.1%) making it the dominant land cover class at 74% of the classified area by 2025
- Vegetation fell from 767.9 km² in 2013 to just 214 km² by 2025 which is a loss of 553.9 km² (-72.1%) from near equal dominance with built up land to a marginal 13.2% of total area.
- Bare area increased by 114.47 km² (+129.3%), functioning as a transitional class between natural and built cover as land is cleared ahead of construction
- Water areas held a stable ~5km² throughout, though their ecological conditioning has deteriorated independently of their spatial extent
- Urban expansion follows major road corridors outward from the city core in a ribbon pattern that fragments the surrounding landscape far more than compact infill development would
- The southern and eastern peri urban zones have seen the most intensive and ongoing land conversion with bare area concentrations in both the 2020 and 2025 maps indicating active land preparation
- These results are consistent with documented urbanization rates in sub-Saharan African cities but Harare's rate of vegetation loss appears to exceed regional averages

6.1.1 Biodiversity

- Scale of vegetation clearance in wetlands, riparian zones and peri urban areas provides strong spatial support for progressive elimination and fragmentation of biodiversity habitat in Harare
- Landscape fragmentation metrics show patch density rising and mean patch size falling, remaining vegetation is not just smaller in total but broken into more isolated ecologically fewer effective fragments
- Wetland dependent taxa, riparian specialist and habitat sensitive bird and plant communities face the greatest losses from the documented land cover changes

6.1.2 Ecosystem services

- Converting 440.9 km² of permeable land to impervious built-up surfaces has reduced Harare's natural capacity to absorb and attenuate storm water which raises flood risk for informal settlements who have no formal drainage infrastructure
- Removal of peri urban wetlands and riparian buffer zones has eliminated the cheapest and most effective flood protection for the settlements now occupying those areas
- Water bodies appear stable in size but their ecological condition has worsened causing loss of vegetated riparian buffers which means urban runoff enters rivers and dams with less filtration thereby degrading water quality for the whole city

6.2 RECOMMENDATIONS

6.2.1 Wetland and Riparian Buffer Protection

- Update Zimbabwe's national urban policy and Harare's spatial development plans to include legally binding green infrastructure standards built into development approvals
- Draw on documented experiences from other sub-Saharan African cities where green infrastructure improved both biodiversity outcomes and flood resilience

6.2.2 Systematic LULC Monitoring

- Standardize future image acquisition to the wet season to ensure vegetation is spectrally distinguishable from bare soil in all classification years
- EMA and Harare council should jointly establish an annual LULC monitoring programme with classified data published as an open geographic data and fed into planning decisions.

6.2.3 Governance and Policy reform

- EMA should have adequate resources and operational independence so that they can enforce existing environmental laws which are the basis for protecting wetlands and riparian areas that already exists
- Environmental impact assessment should be made mandatory to all urban developments that affect wetlands and riparian zones

- There should also be transparent, ecologically informed land allocation processes that formally record and account for ecological values before approving development

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