USE OF GEO-INFORMATION TECHNOLOGIES IN PREDICTING URBAN GROWTH TRENDS; AN INTEGRATED SIMULATION APPROACH: THE CASE STUDY OF LIMURU CENTRAL WARD

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Use of Geo-Information Technologies in Predicting Urban Growth Trends; an Integrated Simulation Approach:

The Case Study of Limuru Central Ward

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DECLARATION

This research project is my original work and has not been presented for a degree in any other University.

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

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This research project has been submitted for examination with my approval as the University Supervisor

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DEDICATION

I would like to dedicate this project to my parents, Mr. James Gichuki Gathura & Mrs. Mercy Muthoni Gichuki and my siblings, Lynn, Jidraff, Elsie and Candy and to anyone else who played a role in ensuring the successful completion of this project, thank you all. May God bless the work of your hands.

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ABBREVIATIONS AND ACRONYMS

ANN	Artificial Neural Network
BRT	Bus Rapid Transport
CBD	Central Business District
CGA	County Government Act
CIDP	County Integrated Development Plan
CSP	County Spatial Plan
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute, Inc
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
GIS	Geospatial Information Systems
GPS	Global Positioning System
IEBC	Independent Electoral and Boundaries Commission
IIBRC	Interim Independent Boundaries Review Commission
ISUDP	Integrated Strategic Development Plan
KRB	Kenya Roads Board
KeNHA	Kenya National Highways Authority
KCIDP	Kiambu County Integrated Development Plans

KII	Key Informant Interview
KMC	Kolkata Municipal Corporation
KNBS	Kenya National Bureau of Statistics
KNN	K-Nearest Neighbour
LCM	Land Change Modeler
LCW	Limuru Central Ward
LULC	Land Use Land Cover
MLP	Multi-layer Perceptron
NaMSIP	Nairobi Metropolitan Service Improvement Project
NDBI	Normalized Difference Built-up Index
NIUPLAN	Nairobi Integrated Urban Development Master Plan
NMGS	Nairobi Metropolitan Growth Strategy
NMR	Nairobi Metropolitan Region
NMS	Nairobi Metropolitan System
NSP	National Spatial Plan
OLI	Operational Land Imager
QGIS	Quantum Geographic Information System
REDD	Reducing Emissions from Deforestation and forest Degradation
RS	Remote Sensing

SDI	Spatial Data Infrastructure
STRM	Shuttle Radar Topography Mission
SUSTRAIN	Sustainable Urban Transport Solutions for Addis Ababa
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TOD	Transport Oriented Development
UN	United Nations
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VTUP	Variable Transformation Utility Panel
WHO	World Health Organization

ABSTRACT

Many urban areas exhibit different growth patterns spanning from linear development, transit-oriented development, concentric zonal development to multi-nuclei development patterns. In today's world, main urban areas present themselves as Central Business Districts (CBDs), that double up as mixed use commercial and residential areas, which serve majority of the population who live in and around them. Ideally, the CBD sites – for most cities around the world, were identified before any development took place, making it easier for the local authorities, urban planners and surveyors to demarcate and plan for sustainable development. Most, if not all jobs, are located in these urban areas, making these employment areas, urban growth hotspots. Decentralization of the traditional city was not only paramount for the survival of the CBD, but also necessary for creating new urban areas, which were relatively smaller than the CBD and played a significant role in shaping the urban spatial structure. The presence of multiple urban areas in a region contributes to, strengthening national competitiveness, social cohesion, service delivery, socio-economic integration and balanced regional development. When there is a shift from functional specialization of the CBD to economic specialization of the surrounding urban areas, this brings about changes in the economic processes and evolution of transport networks which are the foundation of urban growth and expansion, as in the case of Rhine Main Region in Germany. In Kenya, most of the known urban areas, like Limuru Town, emerged as traditional markets in the 1900's and grew to modern urban areas and municipalities that we see today. However, urban growth has been accompanied by rapid land use changes and sporicidal growth of informal settlements. As a result, urban areas growing in Limuru Central Ward, are deprived of basic infrastructure, land use harmonization and spatial synergies. This study therefore attempts to explore the use of GIS and Remote sensing technologies in observing past and present urban growth trends, which should be done prior to predicting sustainable urban planning. The findings from this study are expected to contribute to the knowledge of simulating how urban centres can be planned in the present to cater for the future spatial and infrastructural needs of the growing urban population. Predicting urban growth trends introduces more practical ways of spatial planning and policy development in developing countries, through spatial analysis and modelling using GIS and Remote Sensing technologies. As a result, the study has uncovered that some of the factors that have affected the rate of urbanization in Limuru Central Ward include, slope and elevation, existing clustered urban development in specific areas especially near Limuru Town or along the existing transport network, and availability of infrastructure especially the road network which plays a key role in determining how accessible urban areas are in the study area. The impact of urbanization in Limuru Central Ward between 1999 and 2019 has been identified as; significant decrease in land occupied by bare soil and vegetation, rapid land use changes to accommodate more built-up spaces, sporadically growth of clustered development or dense built-up areas, and the need to expand infrastructure in newly developed areas to promote accessibility. Prediction of urban development in the study area between 2020 and 2050, shows that in the future, the urban footprint is likely to increase near existing urban areas, especially along the transport networks and near existing built-up areas such as

schools. The urban footprint may likely adopt a mix of urban growth models – such us the multi nuclei and sector models, however, majority of the urban areas may most likely be located within proximity to the transport network – transport-oriented development.

CHAPTER ONE

INTRODUCTION

1.1. Background to the Study

Urban growth is the continuous spatial expansion of urban areas with respect to changing times, resulting to evolved urban spatial structures. The three major urban growth types are infilling growth, edge expansion and spontaneous growth. Some of the urban growth accelerating factors are immigration, commercialization, industrialization and availability of public purpose facilities and security. The more prevalent urban growth accelerating factors are in a specific urban area, the more urban growth is observed (Nong et al., 2018).

Globally, Europe has been the central focus of multiple urban development studies especially due to the existence of economic vibrant cities and increasing globalization. In Europe, major population concentrations and vibrant businesses are located in core cities, where else their linkage to second tier cities or sub centres gives them a continuous supply of human capital. This helps them boost their competitiveness with other regions on a global scale.

Germany, which is at the heart of Europe, has exhibited major changes in its urban system since the 20th century. Today, Germany has three metropolitan regions – Berlin, Munich and Rhine Main, which have core cities and primary hubs of economic development, making urban agglomerations more attractive to investors than the suburban areas and some core centres. The hinterlands with time have grown to become residential and employment areas, since firms and industries relocate to exclusive planned zones within their vicinity, to avoid the high land rents they are subjected to in the core urban areas. The shift of these firms and industries to the hinterlands, spurred growth of secondary employment centres, that later evolved to fully functional employment sub centres. Hence, these sub centres with time gained their independence from the main city.

Developing African countries have been growing steadily since the beginning of the 20th century, only to realize their exponential growth in the 21st century. For a country like Ethiopia, Addis Ababa is its largest city or in other terms, its primate city, surrounded by smaller urban centres. The size of the capital is attributed to the rising rural - urban migrations. Addis Ababa is riddled with concentration of human activities in the core region, as it gives its residents the hope of employment and better standards of living, where else the urban periphery lacks a stable employment environment, proper infrastructure and social amenities. Being the primate city or capital, it is home to most of the administrative functions and therefore lacks the ability to serve the whole threshold population equally and efficiently (Badiane et al., 2014). Projects like the Design of Sustainable Urban Transport Solutions for Addis Ababa (SUSTRAIN): Implementation of Bus Rapid Transit (BRT), have contributed to the city's evolving urban spatial structure, as it has progressively linked the capital and its surrounding towns, hence uplifting the regions overall urban status (UN HABITAT, 2017).

In Kenya, we have the Nairobi Metropolitan Region (NMR), which comprises of Nairobi City, Kiambu, Kajiado, Machakos and Murang'a Counties. Growth in Nairobi City County has resulted in urban sprawl within the adjacent counties, prompting planning of the Nairobi Metropolitan Region. The growth trajectory shows that most of the people are moving from Nairobi towards Kiambu County, especially in dormitory towns like Kiambu, Juja and Limuru. However, Kiambu County, unlike Nairobi City County, has fertile hinterland that surround the majority of its urban areas, thus prompting the need to protect these food reserves from the effects of urbanization. Urbanization of this magnitude has restructured the urban development of Kiambu and it's for that reason, this study focuses its investigation on predicting urban growth trends, especially in Limuru Central Ward within Kiambu County (Hawkins et al., 2018).

Studies have been conducted to show the impact of urbanization on their intermediate environment. One such study was conducted in Iran by (Saeidi et al., 2017). An integrated urban growth prediction model was used to come up with three scenarios for predicting future urbanization trends in Gorgan, Iran. This study employed

SLEUTH to come up with three urban growth scenarios - historical, managed and aesthetically sound scenarios; and GIS and machine learning to test the viability of these scenarios on simulating future urban growth of the study area. As a result, the study came up with an objective approach of modelling ways to preserve the aesthetic values of the landscapes, while encouraging compact urban growth and better urban management.

This study focused on one of the most urbanized sections of Limuru Sub - County, in particular, Limuru Central Ward which has; the Limuru Central Business District, upcoming multi story commercial buildings, major transport corridors; and boarders Kiambethu Tea Farm, Misri Informal settlement, Ngubi Forest, Manguo Swamp and other water bodies. In 1969, the CBD site was demarcated in advance making it easier for the local authorities to locate and plan for its use, as seen in **Appendix I** and yet, we observe commercial activities growing away from the planned CBD and withing residential areas. It was therefore important for this study to use GIS and Remote Sensing techniques to project urban growth patterns, as opposed to conventional theoretical analysis which project urban development in non-statistical methods.

1.2. Statement of the Problem

Limuru Central Ward has increasingly attracted urban development, prompting subdivision of arable land at an alarming rate. Growing urban areas like; Limuru Town, Kamirithu, Rironi, Mutarakwa and Gatimu, were able to shed their settlement or residential status and gain more economic diverse functions. These economic activities have attracted employment and investments in the area. With the changing urban structures, the Limuru Municipality has become overly congested with economic activities, overpopulated and has thus paved way for Misri informal settlement to emerge around the Limuru municipal boundary. This phenomenon is similar to growing urban areas globally, as a result of rapid urbanization, which is predicted to increase the urban population by 60.4% and in turn increase low-income settlements within the urban context (UN, 2018).

From a spatial analysis perspective, most of the non-built areas within and around the market centres in the greater Limuru Central Ward have been converted into built up areas, which ultimately contribute to the overall urbanization in the Nairobi Metropolitan region (NMR). As Limuru Central Ward evolves and increases its urban footprint, it continues to exhibit the same challenges as Kiambu County that are brought about by urbanization. Some of the major challenges associated with rapid urban growth in Limuru, similar to any upcoming urban area include insufficient road linkages between old and upcoming newly developed areas, increased informality, uncontrolled subdivision of land, deforestation and reduction of the arable land footprint. Without following proper urban planning procedures, urbanization may take a toll on sustainable urban development in Limuru Central Ward (Güneralp et al., 2018).

For many years, integration of GIS and Remote Sensing in urban planning, has assisted in simulating modern ways of predicting future urban growth pattern, monitoring or assessing and mapping out potential urban growth areas and hotspots. This in turn helps in measuring the magnitude of urban growth and identifying how urban growth affects its intermediate environment. Simulating potential urban growth patterns using identifies the transition potential of land use classes and predicts the spatial changes expected to occur in the study area. Urban prediction and simulation help facilitate ways in which negative trends in rapidly growing areas - such as Limuru Central Ward, can be mitigated through spatial modelling or scenario building.

1.3. Justification of the Study

Urban planning and urban prediction have not been explored to its full measure in Limuru Central Ward. The chaos of urban complexities is escalated by rural urban migration and as these urban areas evolve, there is uncontrolled urbanization and urban sprawl. As a result of that, urban growth has magnified land use conflicts, uncontrolled subdivision and charging informality in and around major developed areas, which hinders sustainable urban development. These problems arise when urban planning is merely taken as master planning and not as a tool of enabling spatial equalities in counties.

The absence of tailored approaches to mitigate the effects of urbanization in policies, counties are in turn missing viable approaches to urban prediction in their physical planning and exclusive urban planning policies. If adopted, the findings of this study may be applied by county governments in top-down planning approaches, to mitigate the effects of urbanization on physical space. With that in mind, this study has focused on distinguishing urban development over a given period time to prepare and monitor urban growth in the future.

1.4. Objectives of the Study

The main objective of this study is to explore the potential use of GIS and Remote Sensing technologies, in simulating urban growth trends of rapidly growing urban areas.

The specific objectives of the study are as follows:

1. To investigate the factors that drive urban development in small and medium urban centres in Limuru Central Ward.
2. To study urban development trends in small and medium urban centres such as Limuru Central Ward
3. To investigate the use of Geo-Information Technologies in simulating, predicting and monitoring urban growth patterns in rapidly urbanizing areas in Limuru Central Ward

1.5. Research Questions

The following research questions guided this study:

1. What factors drive urban development in small and medium urban centres in Limuru Central Ward?
2. What are the emerging urban development trends in small and medium urban centres in Limuru Central Ward?

3. How can Geo-Information Technologies be used in simulating, predicting and monitoring urban growth patterns in rapidly urbanizing areas in Limuru Central Ward?

1.6. Limitations of the Study

The study was faced with a few challenges, one of them being, availability of clear Landsat 5 remote sensing images for the year 2004. The study utilized United States Geological Survey (USGS) 30 m resolution Landsat images and was geared towards acquiring images between 1999 to 2019, at an equal interval of 5-years. However, the 2004 image of Limuru Central Ward – like the rest of the world for the preferred period of time, had several issues, which required several corrections, which would interfere with the analysis of the study area. It is for that reason; that the study utilized the 2003 Landsat 7 image instead.

It is important to bring to light that this study required multiple Landsat images obtained by different Landsat Satellites. All Landsat Collection 1 data and science products were removed from USGS data access platforms by December 30, 2022. Hence, the study employed the use of Landsat Collection 2 images and only used Landsat Collection 1 images, where the prior had several anomalies.

Some of the commonly known Landsat Sensor anomalies that the processed images had included, data loss (especially the Landsat 8 images– along the edges of clouds), detector stripping (mostly observed in Level 1 images of all Landsat Sensors) and detector failure (Landsat 5 and 7) (Landsat Missions (USGS), n.d.) .

Some of the other major limitations of this study include the presence of the Covid-19 Pandemic, which led to the closure of many offices, and limited my movement to and from resourceful places like the university campus and the study area. In the beginning it was difficult to proceed with the project because the closure of the campus meant that the normal school and project activities could not take place. The only way for progress was to wait for the ongoing curfew restrictions to be lifted so that there was easy movement to and from the resourceful places. This happened at around July and

August of 2020, about 2 months before normal university activities were restored. Once online school activities resumed, normal project activities did as well.

With the introduction of lengthier working hours, there was little to no time dedicated to the progress of the project. This, however, has been remedied by proper scheduling and planning of school and work activities, to have a more fulfilled work life-balance.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The greatest challenge brought about by urbanization in Kenya is, deteriorating urban structures. This simply means that, urban areas that grew because of trickled down economic effects from the core city- such as Nairobi CBD, are now incapable of handling the effects of urbanization. The establishment of dormitory towns for residents in the Nairobi Metropolitan Region within Kiambu county, has over the years led to the rise in Kiambu's urban population. Limuru Central Ward hosts Limuru CBD, Kamirithu Mutarakwa, Rironi and Gatimu as the most urbanized areas, settled by majority of its growing population and thus represents increasing urban activity. Urbanization in this area has been propelled by the growing transport systems interconnecting urban areas within the ward to those outside the ward, encouraging people to settle within its vicinity and work in further areas like Nairobi CBD and Kiambu CBD.

2.2 The Theoretical Review

Developed countries have been the central focus of multiple urban development studies especially due to the existence of vibrant cities and increasing globalization. Germany has exhibited changes in its urban system over the years. It has three metropolitan regions – Berlin, Munich and Rhine Main, which have core cities and primary hubs of economic activities, making them more attractive to investors compared to the sub-urban areas and some core centres. Cities in Germany have evolved to include Central Business Districts (CBDs) and higher order and lower order urban centres which all networked or interlinked as a result of improved transport network linkage between urban centres within regions (Growe, 2012).

In the case of Germany, urban areas and their respective hinterlands have grown codependently over the years. The core urban areas have been the hubs of high order goods and services including industries and tertiary institutions while the hinterlands grew especially as agricultural areas and sub-urban residential areas, with little economic and employment vibrance. They grew with time to become residential areas with a few commercial buildings, since firms and industries relocated to planned zones within their vicinity, so as to maximize on the reduced land rents. The shift of these firms and industries to the hinterlands, spurred growth of secondary employment centres, that later evolved to fully functional employment urban centres. These urban centres gained their independence from the main city and attained different functions, needed to serve their residing population. The type of urban structure shown below in **Figure 2.1** below, is similar to urban centres located within a Labour-divided polycentric region, as in the case of Berlin (Growe, 2012).

From the illustration below, we see that major core areas propelled the transformation of small settlements to grow into functional urban centres (1). This transition was complete once the small settlements were able to shed their settlement or residential status and gain more economic diverse functions, which attracted employment and investments (2). Today, changes in the economy are the foundation of urbanization, in that there is shift from functional specialization of the core city to economic specialization of the surrounding urban centres, similar to Rhine Main in Germany (3).

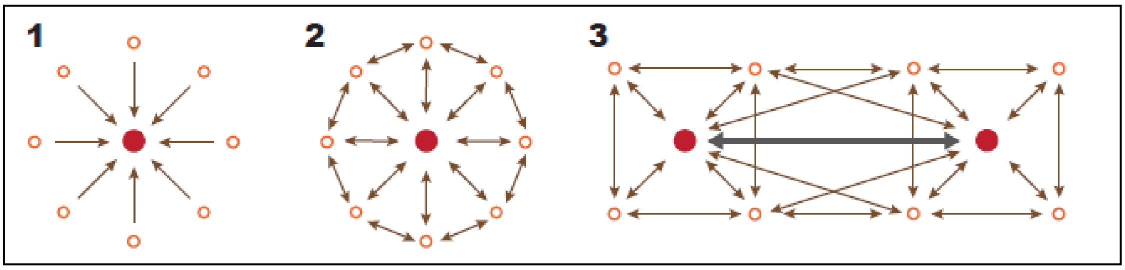


Figure 2.1 Evolution of Small Sporadic Market Centres to Functional Urban Centres

Source: (Growe, 2012)

Some of the challenges brought about by urbanization in the hinterland include, uncontrolled subdivision of arable land, unplanned growth of commercial areas, informality, stress on existing infrastructure and environmental degradation. In developed countries, some of these problems have been solved locally through enforcement of development control guidelines, urban and regional planning policies and setting up of modern infrastructure. However, the same solutions have been expounded in theory with little to no implementation in developing countries.

In conclusion, according to the study done in Germany by (Growe, 2012), development of core cities comes first then inter-city development across regions, with crisscrossed - heavily interconnected transport patterns, comes last. As a result, employment sub centres of similar sizes grow within the same region and have a fair distribution of economic activities within their newly developed employment sub centres. With such datasets available to work with, Germany is able to plan and predict future growth patterns and analyse growth models of urban areas in any given region, at any given time.

2.3 The Critiques of the Existing Literature Relevant to the Study

GIS and Remote Sensing technologies have been used globally to address urbanization challenges and come up with strategies to mitigate those challenges. In India a similar study was done to assess urban growth patterns and loss in urban green spaces, in Kolkata. This study was conducted because the quality of green spaces fell below the minimum standard required by the World Health Organization (WHO) and also, India lacked an accurate assessment of Urban green spaces. The study assessed urban growth dynamics, spatio-temporal changes and predicted the future state of Land Use Land Cover (LULC) patterns in the Kolkata Municipal Corporation (KMC). It was found that potential surfaces for urban growth included vegetation and grassland areas, and that the per-capita urban green spaces were sharply decreasing despite the decrease in urban population. Recommendations of implementing proper land use zoning system, a conservation policy and a comprehensive plan, were proposed as strategies for sustainable urban development and green space management (Dinda et al., 2021).

In China, Nanjing. Nanjing is the capital of Jiangsu Province with an urbanization history that dates back to 1978, as a result of the Chinese Economic reform. According to this study, rapid urbanization had affected; the agricultural and natural environment and the forestry sectors, and the air quality beyond the built-up airspace. Assessing land surface temperature has proven that Urban Heat Islands have intensified in urban areas, hence concluding that urbanization has a great effect on land surface temperature. Urbanization in the study area was measured by; the increase of paved surfaces, environmental degradation, increased man-made developments and increased heat emissions due to human activities and transportation. It was found out that the built-up area increased its footprint by 10.89% and that urban greenery was instrumental in cooling the city. The study recommended that there should be a reliance on urban greenery and suitable landscape compositions that'll contribute to cooling the city. The methodology developed would be best use to assess areas with high land surface temperature risks and the findings used as a framework for predicting the risks of future Urban Heat Islands on their intermediate environments (Wang et al., 2020).

2.4 Understanding GIS and Remote Sensing Technologies

GIS is a computer-based technology that is widely used to perform spatial analysis, statistical queries on location features. GIS integrates, manages and manipulates information stored in databases and provides additional tools for displaying spatial information visually, in form of graphs, charts, attributes and most importantly maps. Remote sensing is the science of continuously acquiring information about spatial objects from space, using satellites. Integration of these two technologies has elevated analysis of the earth and has been used as a tool for decision making, especially in addressing global changes such as environmental degradation and urbanization (CREAF, 2016). The role of using GIS and Remote Sensing to predict urban development in this study include to.

1. Monitor urban encroachment across various land use types, along streets and public transport networks and fragile ecosystems. This may advise future developers on the impact of their development to the surrounding environment.
2. Establish the effects of multiple urban and regional indicators that contribute to urbanization in Limuru Central Ward.

3. Investigate the causes of increased urbanization, which will be used in the future to make balanced decisions on physical planning and environmental planning concerns, especially on the fragile forested, riverine and agricultural areas.
4. Improve research on more effective ways of planning, designing mixed use residential neighbourhoods, which mitigate negative effects of urbanization.
5. Contribute to improved decision making and provide decision support to urban planners especially during development control and zoning of developable areas.
6. Characterize state of development and determine potential planning sites. This help’s in setting goals and developing strategic plans for tackling the resultant challenges brought about by urbanization.
7. Continuously update spatial information of the study area and use the same information to develop land use management tools and policies.
8. Develop urban growth scenarios aimed to improve the understanding of urbanization and to predict urban land use land cover changes in the study area.
9. Create a platform for analysing geographical data and displaying knowledge in new and more objective ways in urban planning, to show the present and simulate the future.

2.5 The Summary

Limuru Municipality has grown from a small market center since 1901, to a vibrant CBD today, due its proximity to Nairobi and to modern transport linkages such as, Kiambu Road (C63), Eldoret - Malaba Road (A104), Ngenia Road and the Kenya-Uganda Railway. Kamirithu and Mutarakwa have developed greatly due to their proximity to Dagoretti-Karen Road and Kamandura-Maai Mahiu-Narok Road. Rironi’s growth is influenced by Limuru Road (B3), Eldoret - Malaba Road (A104), while Gatimu has grown around the Ngecha-Chungu-Mali-Road. Existence of Rironi Market and Limuru Market within the study area and Chiakamunu market right outside the North-Western boundary, have attracted residential developments, influencing their growth throughout the study area. Government facilities such as schools and health centres and other support private facilities such as private hospitals have also attracted urban development.

Situated within a developing county, especially within the greater metropolitan area, Limuru Central Ward has had more reason to evolve and change its spatial structure with time, as compared to other Wards within Limuru Sub Country such as Ndeiya. Urbanization has brought about positive increase in economic activity and negative deterioration of both the spatial structure and the environment in the area. Misri informal settlement has grown right outside the Limuru CBD boundary, hosting several low-income residents. This has led to deterioration of infrastructure, environment degradation and encroachment along transport routes. Increasing human activities along transport networks in the study area, has encouraged misuse of road reserves and ignorance of development control guidelines. Large parcels of land have been subdivided into smaller plot sizes and arable lands have been converted into residential spaces. Being very close to the Manguo Swamp, Ngubi Forest and large tea estates, urbanization poses a great threat to the existing food baskets and cash crops within the arable land and the fragile ecosystems of Limuru Central Ward.

2.6 The Research Gaps

One of the greatest inventions in urban planning is the use of Land information system to improve management of public and privately owned land throughout countries. This has proven very useful in developed countries for many years, however, there has been a failure to launch in developing countries. At present, there are several people who have land disputes and nowhere near resolve, as the local authorities do not have proper land records and have no say over how private landowners sell and use their land. Creation and adoption of a land information system should be prescribed to curb land ownership, transfer and management issues which also would contribute greatly to mitigating the negative effects of subdivision of land.

Kenya has adopted bottom-up planning which in simple terms means planning with the people for the people. Some of the plans developed using the Bottom-up Approach are good on paper and mostly impossible to implement, being that the planning interventions need a lot of financial support. Combining the planning strategies, and GIS and Remote Sensing, allows the urban/town/physical planners in Kenya to;

identify spaces which naturally transform to accommodate the needs of their intermediate land uses, prepare for economic use of space, strategize on the best use of future land parcels, and protect the natural environment from deteriorating. Integrating geoinformation technologies ensures that there is an advanced way of predicting the needs for posterity, encouraging sustainability and controlled urbanization. It is for this reason that there is need to use modern technology to simulate and predict the study area's urban growth transformation between the years 2020 and 2055, to allow for prior planning and mitigation of negative effects of urbanization.

CHAPTER THREE

METHODOLOGY

3.1 Overview of the Research Methodology

This chapter outlines the research design, approach, target population, data collection methods, analysis procedures and introduction of the study area. The goal of this study is to predict the growth of urban areas by examining key influencing variables and applying simulation and predictive modelling techniques. The methodology adopted in this study shows how geospatial processes in ArcGIS and IDRISI softwares can be used to create both raster and vector inputs required for simulation and prediction, by using various geoprocessing tools in each software. A combination of integrated processes in both softwares was used to improve data visualization, conduct urban simulation, predict future urban growth trends, and most importantly contribute to improving the future urban planning processes.

3.2 Research Design and Approach

The study has adopted a longitudinal correlational research design that basically looks into trend analysis and how variables within the study area interact over time. This supports the integration of quantitative approach which further plays a key role in predicting and simulating future growth of the study area.

This study has four broad stages. Stage one was the theoretical investigation stage, which entailed overview of related literature and exploration of how modern technology can be used to simulate, predict, monitor and assess urban growth trends. In stage two the empirical and field investigations stage, was rolled out, to incorporate case study analysis. This was done through, desktop review, field visits and key informant interviews. This stage involved collection of both qualitative or descriptive data and quantitative or numeric data.

The third stage was the data analysis stage. This focused on both qualitative and quantitative data analysis. IDRISI software analysed raster data, ArcGIS Pro analysed both raster and vector data and Microsoft Excel was used to analyse quantitative or numeric data. Stage four was the data presentation, results and findings stage. The analysed data was presented in tables, pie charts, bar graphs, maps and narratives. The study was able to draw important conclusions and recommendations from the findings. The flow chart below as shown in **Figure 3.1**, has summarized the four broad stages as discussed above.

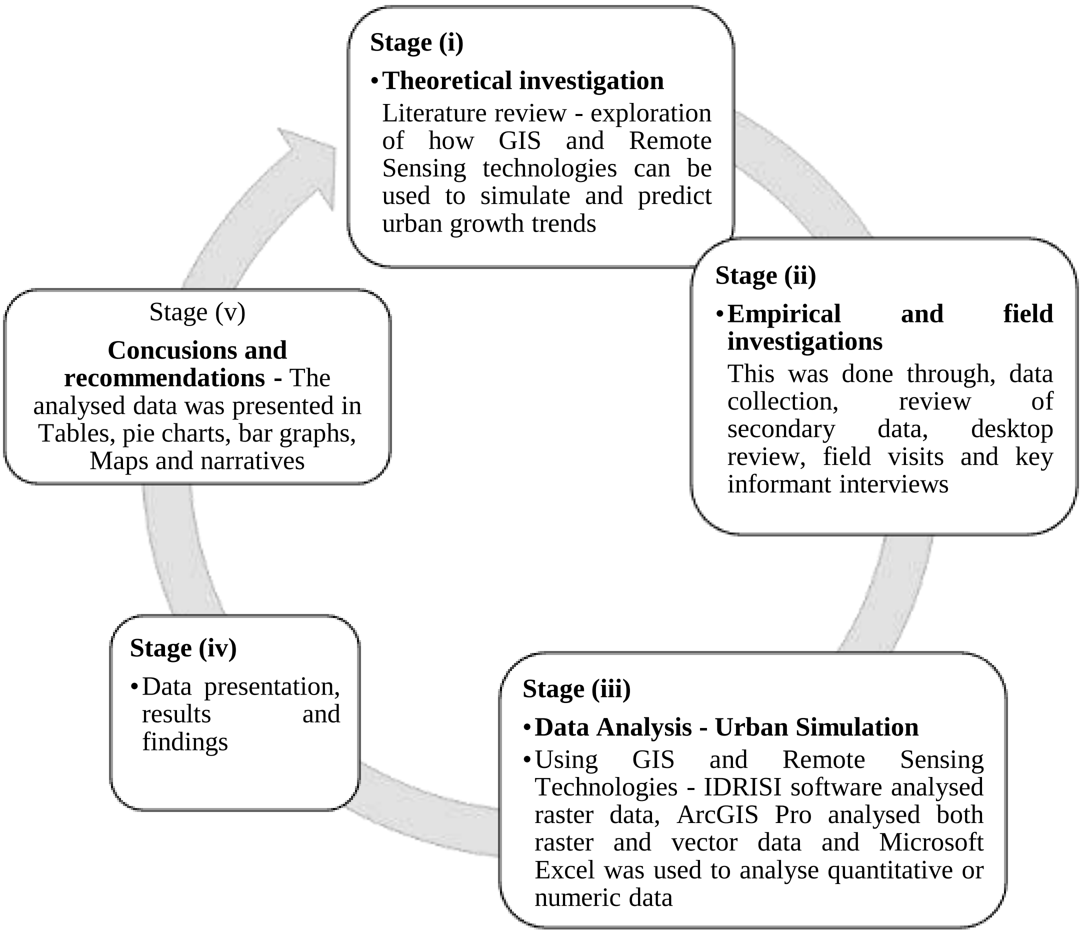


Figure 3.2 Research Outline and Research Process Flow Chart

Table 3.1 below gives a summary of the study processes, with respect to the study objectives, with reference to the four broad study stages discussed above. The study utilized different tools and softwares to analyse data and the results, both quantitative and qualitative, were presented using various presentation techniques, which are elaborated further in Chapter 4.

Table 3.1 Summary of the Study Process

Objectives	Theoretical and Empirical Investigations	Tools of Analysis (Data Analysis)	Results	Presentation Techniques
To investigate the factors that drive urban development in small and medium urban centres in Limuru Central ward.	Literature review	Reviewing Journals and articles	Derived factors that contribute to urban development	Narratives / Diagrams
	Classification of Landsat Images	Supervised classification using land cover signatures	Land Use Land Cover of Limuru Central Ward	Maps and Graphics
	Investigate the factors driving urban development and change in spatial structures.	Analysing classified satellite imagery of the study area for the years between 1999 and 2019	Changing magnitude of urban development in Limuru Central Ward	Maps and Graphics
To study urban development trends in small and medium urban centres such as Limuru Central Ward	Literature review	Reviewing Journals, articles, County Spatial Plans	Knowledge of urban development trends in Kenya	Narratives / Graphics
	Spatial analysis (Location of urban areas)	Google Earth and ArcGIS	Distribution of urban areas in Kenya and Limuru Central Ward	Maps and graphics
	Trend analysis – through observation and simulation	ArcGIS	Trend of urban development in Limuru Central Ward	Maps

Objectives	**Theoretical and Empirical Investigations**	**Tools of Analysis (Data Analysis)**	**Results**	**Presentation Techniques**
To invoke the use of Geo-Information Technologies in simulating, predicting and monitoring urban growth patterns in rapidly urbanizing areas in Limuru Central Ward	Identify locations of urban growth – spatial representations of urban growth trends	IDRISI and ArcGIS	Spatial location of urban growth sites	Maps
	Analyse measurable growth indicators (independent and dependent variables)	IDRISI/ArcGIS	Explore how the study variables affect the future urban growth patterns	Maps and Figures
	Urban growth prediction and simulation	Land Change Modeler in IDRISI	Compare the simulation of the urban growth trends from classified images, with the spatial and analytical results of the predicted images	Maps showing future growth areas and scenarios

3.3 Target Population and Sampling Techniques

The target population for this study was the people living within Limuru Central Ward (LCW). The study also targeted the infrastructure, primarily roads, which have developed within the study area. The sampling technique used to select urban areas that showed significant growth trends was the purposive sampling technique. For this study, it was better to deliberately select the urban areas that were more defined in the study area, which could provide better results during analysis.

3.4 Data Types, Sources and Collection Techniques

The raster and vector data was sourced using primary and secondary methods, as shown in **Table 3.2** to **Table 3.6** below of this report.

Table 3.2 Data Types and Sources

Data	Resol ution	Source	Purpose	Related Studies	Product
Satellite Images	High/ Mode rate	USGS	Classification of land uses	N/A	LULC Maps
Transport Network shapefiles	High	Open Street Map	Categorize road networks	NIUPLAN 2014	Assess growth patterns and establish growth nodes
Population data	N/A	Kenya Nati onal Bureau of Statistics (KNBS)	Correlate census data and projection results	Kiambu County Integrated Development Plans (KCIDP)	Narratives supporting simulation results
Topograph ical Map	High	Survey of Kenya	Investigate linkage of changing physical	Kiambu County Integrated	Prediction Maps

Data	Resolution	Source	Purpose	Related Studies	Product
			infrastructure / other land uses and urban growth	Development Plans (KCIDP)	
List of urban areas	N/A	KNBS	Extract names and locations of urban areas	Kiambu County Integrated Development Plans (KCIDP)	Map of urban areas in Limuru Central Ward

3.4.1 Primary Sources of Data

The primary data in this study, was mainly used to develop the base map of the study area. Vector data was digitized while raster data was processed using spatial analysis tools in ArcGIS. **Table 3.3** below, shows more details.

Table 3.3 Primary Sources of Data

Type of Data	Resolution	Data Extracted
Vector data	High	Urban area boundaries, transport and network data, Urban centres, schools, hospitals, forest and water bodies
Raster data	High and Medium	DEM and Slope

3.4.2 Secondary Sources of Data

The secondary data utilized in this study was downloaded from various sources, as shown in **Table 3.4** below. This data was used to develop LULC change and prediction maps, land surface temperature maps and compute-built index and derive spatial characteristics of the study area.

Table 3.4 Secondary Sources of Data

Secondary Data Sources	Type of Data	Data Extracted
Survey of Kenya Limuru Topo Sheet 148/1	Scanned Maps (primary data)	Physical infrastructure
United States Geological Survey (USGS): Landsat-7 Enhanced Thematic Mapper Plus (ETM+) – 1999, 2003. Landsat-5 Thematic Mapper (TM) product – 2009 Landsat-8 Operational Land Imager (OLI)- 2014, 2019, 2023	Raster data 30-m resolution Landsat satellite	Raster image of the study area (used for classification)
Google Earth Engine Landsat 7 (ETM+) – 2002 and Landsat 8 (OLI)- 2013		Land Surface Temperature
Literature review	Literature related to the study area	Population data
FAO, ESRI, IEBC Administrative boundaries (pre and post revision)	Vector data	Different study area boundaries

3.5 Data Collection Procedures

The data utilized in the study was collected using various techniques. These techniques are broadly categorized as primary and secondary data collection techniques, as shown in **Table 3.5** below.

Table 3.5 Data Types and Collection Techniques

Type of Data	Collection Technique
Primary data	• Field work (observation checklist), digitizing topographical Maps, interviewing residents and key informants and collection of data using GIS Mapper Mobile Application
Secondary data	• Downloading shapefiles from; FAO, ESRI and IEBC websites • Downloading raster imagery from USGS website • Literature review of related journals and articles

3.6 Data Processing, Analysis and Presentation Techniques

Data analysis consists of data cleaning, data interpretation and data visualization. The softwares used to analyse the data collected included, ArcGIS, IDRISI, Google Earth Engine and Google Earth. Before raster data was analysed, the satellite images were processed using image enhancement techniques such as Spatial Filtering (Gaussian low pass and smoothening filters), Image restoration (geometric and radiometric corrections) and image enhancements in IDRISI/ArcGIS. Once the data was processed and analysed using the above softwares, the data was presented in form of maps and narratives, detailed in this report, as shown in **Table 3.6** below.

Table 3.6 Data Analysis and Presentation Techniques

Data Analysis	Tools of Analysis	Presentation Techniques
Spatial analysis (location of urban areas)	Google Earth and ArcGIS	Maps and narratives
Classification of human activity sites on satellite images (image classification)	Supervised classification using land cover signatures (IDRISI/ArcGIS)	Maps and Narratives
Trend analysis of urban areas and prediction of urban expansion	Classifying satellite imagery of the study area for the years between 1999 and 2019 using IDRISI//ArcGIS	Maps, graphs and charts

3.7 Study Area Definition

Kiambu County was formally part of the Central province before devolution in 2010. Today, as seen in **Figure 3.2** below, it is one of the 47 counties in Kenya. It is situated within the Nairobi Metropolitan Region. Kiambu town is its main administrative center, hosting main government and administrative offices and one of the largest urban populations in the country. Kiambu County has 12 constituencies or sub-counties which in total cover an area of approximately 2,543.42 Km^2, as shown in **Figure 3.3** below. Limuru Sub County is one of the 12 Sub Counties in Kiambu. It covers an approximate area of 281.8 Km^2. It is strategically located in the South-West of Kiambu, next to Nakuru and Kajiado County. It has five wards namely, Bibirioni, Limuru East, Ndeiya, Limuru Central, and Ngecha which have a collective total of 16 sub-locations altogether.

The scope of study covers the growing urban areas within Limuru Central Ward, shown in detail in **Figure 3.4** below. The study area is approximately 22.23 km^2. Limuru Town, which is the most urbanized area in Limuru Central Ward, is about 35.1 Km from Nairobi CBD and is on an elevation of 2,257 m. It is situated at 237715.18 m East and 9877534.99 m South (UTM 37 S).

Figure 3.2 Map of Kenya Showing 47 Counties

Source: (Survey of Kenya, n.d.)

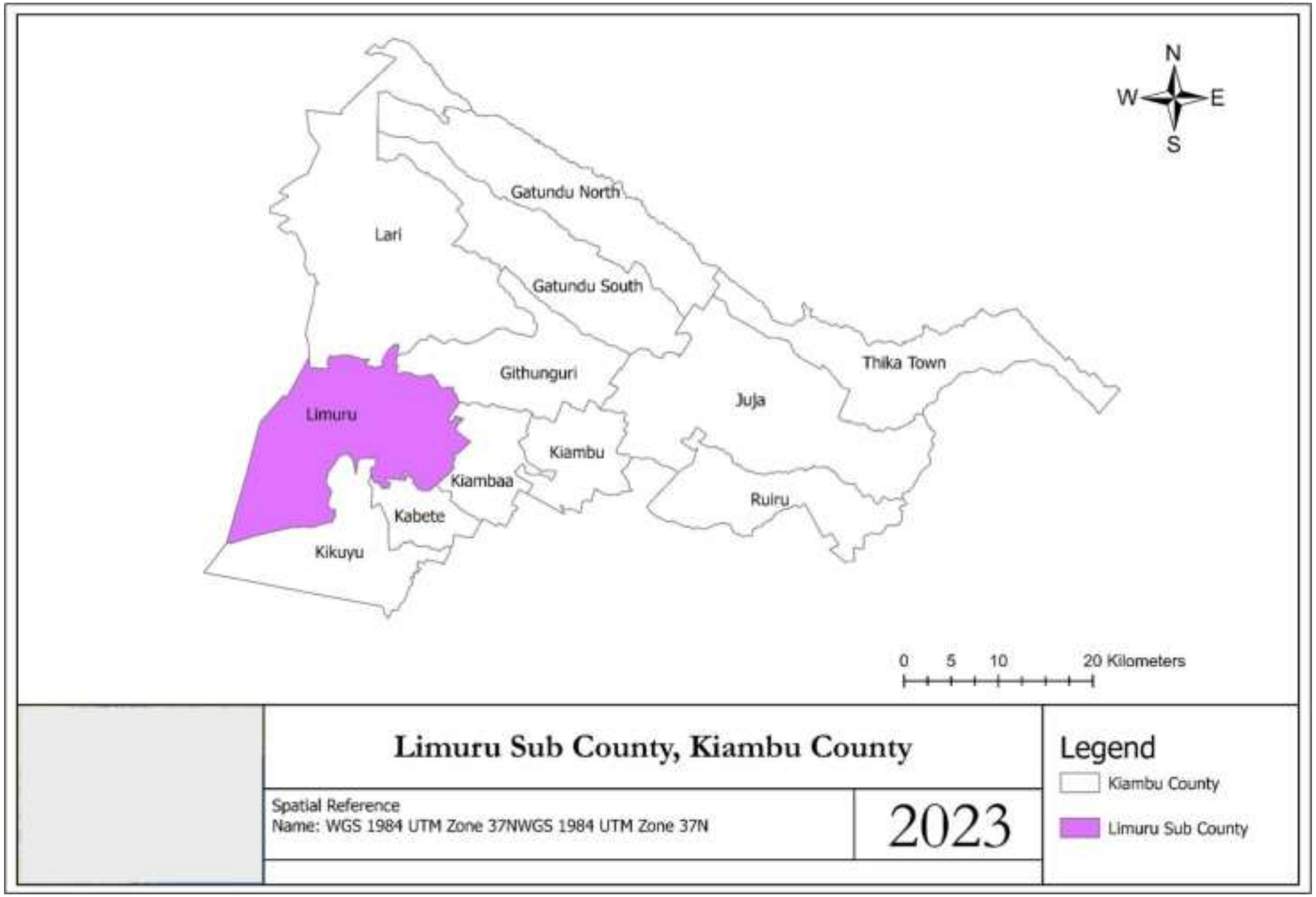


Figure 3.3 Map of Kiambu County Showing Location of Limuru Sub County

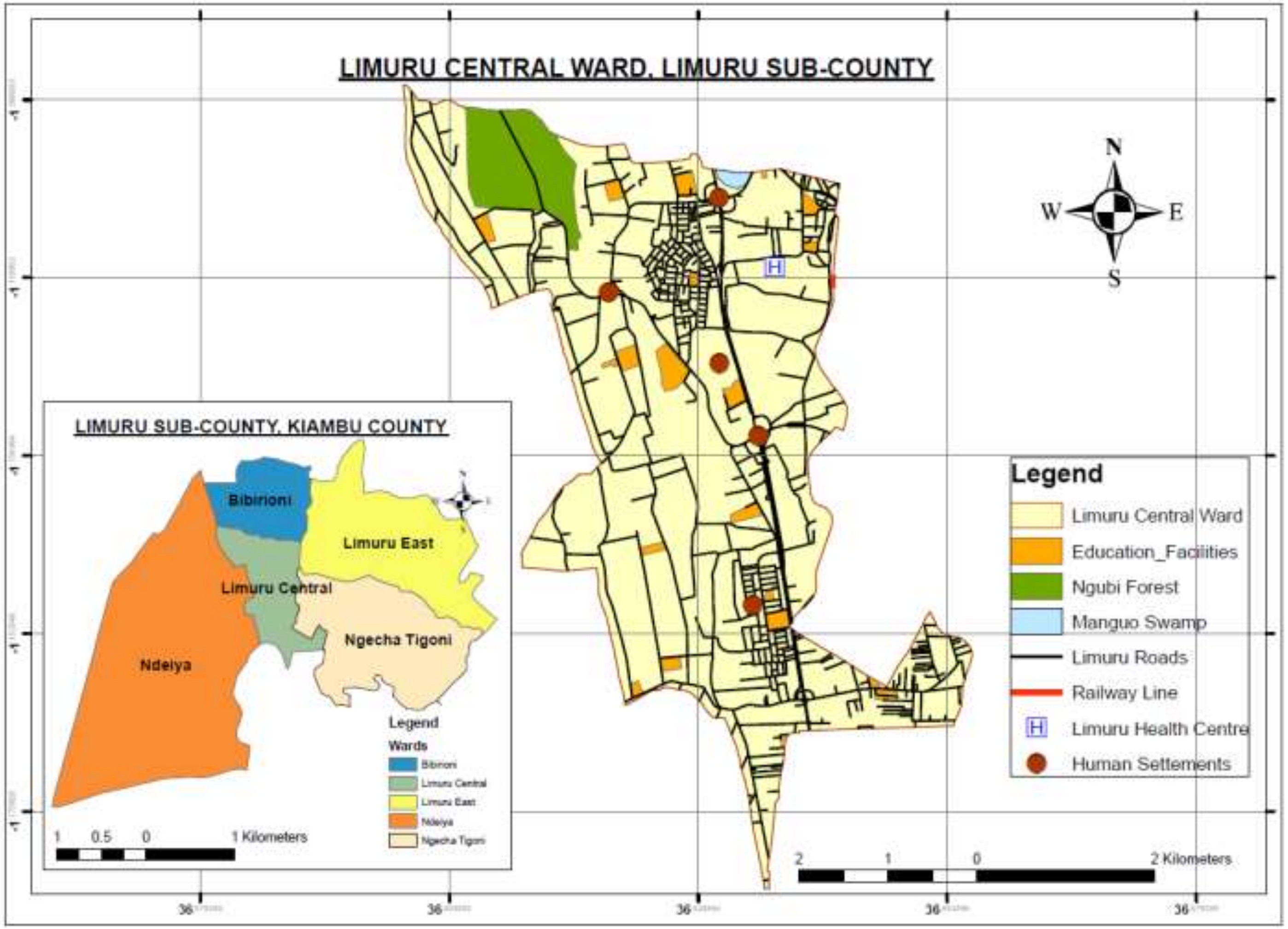


Figure 3.4 Map of Limuru Central Ward, Limuru Sub-County

3.8 Methodology for Simulating and Predicting Urban Growth Trends

3.8.1 Urban Planning and Urban Trend Analysis

Urban areas are constantly expanding horizontally and vertically, to accommodate the growing population. In as much as vertical growth of urban areas is taking place, it is the horizontal expansion of cities that is observed more, as it occupies more geographical space. Some urban areas, like Westlands and Upper Hill in Kenya, grow and sprawl faster than others, as they are equipped with more infrastructure and are better managed, while others, such as Old Kijabe in Kenya, deteriorate as a result of being neglected and lacking adequate infrastructure to support the needs of the existing and growing population.

In as much as urban planning plans for future needs of urban areas and their immediate urban periphery, most of the plans – such as the Spatial Plans, Action Area Plans and Development Plans developed in Kenya, don't consider simulating the growth of areas prior to proposing future strategies and planning interventions. Bottom-up planning has always taken the lead as it is supported by the Constitution of Kenya. Public participation is encouraged especially when creating interventions for the people, however, without spatial projections, urban planners will not be able to see the magnitude of change that may potentially take place in the spatial space.

3.8.2 Predicting Spatial Changes

Simulation and prediction help urban planners create accurate scenarios of future urban trends which represent what can take place in real life. These scenarios normally look into bridging the gap between the needs of the people and how these needs can be presented spatially without creating stress on the existing and future urban spatial structures. This study has employed both qualitative and quantitative research, hence the need to incorporate a conceptual or theoretic model, for the reader to have a better understanding. The conceptual or theoretic model of this study has been used to set boundaries of the scope of research and the relationships between the constructs of the study, to help visualize what the study has achieved. Modelling urban growth has given a greater perspective to how urban areas have evolved and how governments can adapt different growth trends and make better policies and improve the planning process.

These policies and plans, help mitigate the negative effects of uncontrolled urbanization, therefore, developing a conceptual or theoretical model - that shows how modern technologies can be used in assessing, mitigating, and predicting urban growth trends, was necessary. The motivation behind this study, was propelled by the fact that urbanization is global, and a number of developed countries have used GIS and Remote Sensing to analyse the impact of urbanization, in both the past and present scenarios to predict how urbanization affects the future. **Figure 3.5** below represents the broad steps taken in simulation and prediction using geoinformation technologies.

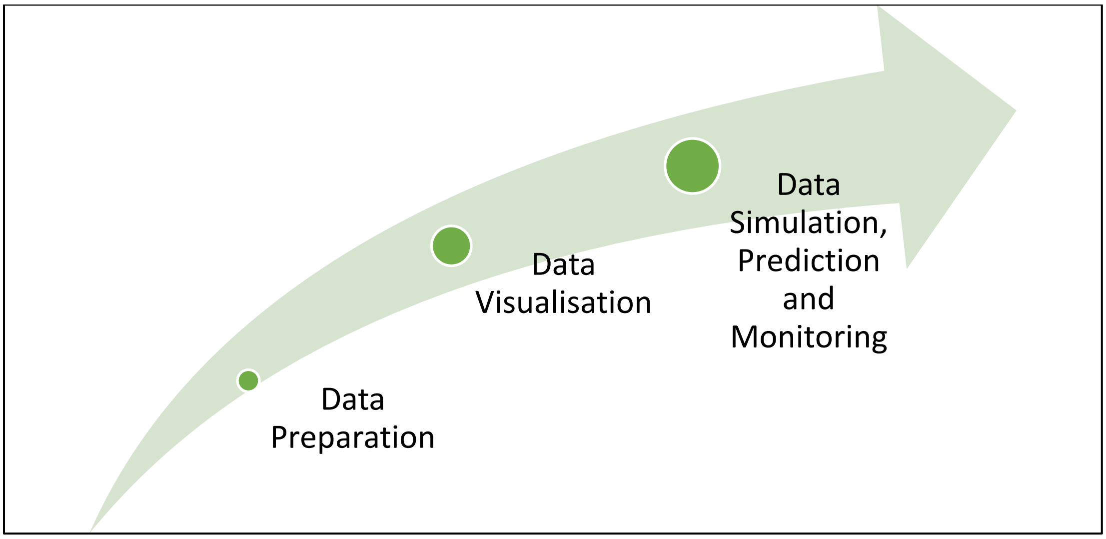


Figure 3.5 Broad Steps in Simulation and Prediction

Some of the urban models that explain how urbanization takes place spatially include the concentric zone model, Transport Oriented Development model and Multi-Nuclei Growth model. Modelling urban growth helps us; indicate where urban growth is most likely to take place, simulate how urban growth may likely be in the future, understand why urban growth occurs, know the dependent and independent variables that contribute to such growth and how urban growth can be controlled to avoid uncontrolled growth or rapid urbanization from taking place. Modelling also helps us know if predicting urban growth hotspots, enforcement of specialized policies and formulation of a better planning process, helps mitigate challenges brought about by uncontrolled urbanization.

Land cover changes are one of the largest imprints of humans on the Earth. The methodology, in **Figure 3.7** below shows how GIS and Remote Sensing processes have been integrated and used throughout the study. The tool utilized during simulation and prediction was the Land Change Modeler which is imbedded in the IDRISI Selva Remote Sensing Software. Understanding and projecting transitions into the future is critical for smart development, biodiversity conservation and managing climate mitigation strategies such as REDD (Reducing Emissions from Deforestation and forest Degradation). Urban prediction and simulation require several GIS and Remote Sensing inputs which are cleaned, edited, manipulated, pre-processed, and processed in ArcGIS Pro, to create the variables meant to facilitate the simulation and prediction process in IDRISI, as seen in **Figure 3.6** below. The simulation technique of choice was the Land Change Modeler, which is an example of a Predictive Change Modelling module in IDRISI.

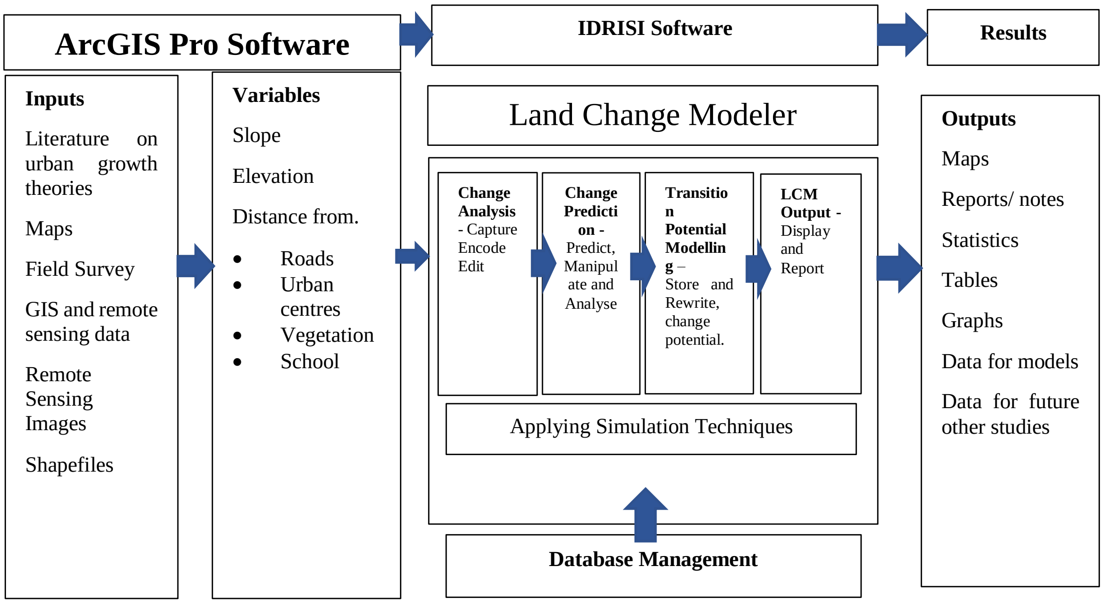


Figure 3.6 Steps in Predicting and Simulating Urban Growth Trends

Source: Adopted from (FAO, n.d.)

Unlike the GEOMOD module which simulate one land transition to the other one land use at a time in IDRISI, LCM acts upon several transitions at once to give a comprehensive projected scenario of the area of the interest. The 3 steps utilized in LCM were Change Analysis, Transition Potential Modelling and Change prediction, to generate predicted LULC maps of the study area. All the outputs are generated and stored automatically in one folder, for easy access and database management (Clark Labs, 2018).

3.8.3 Modelling Technique for Simulating and Predicting Urban Growth

The methodology shown in **Figure 3.7** below, was divided into three stages, The raster process, the vector process, and the integrated simulation process. The raster process involved downloading Landsat images for the years; 1999, 2003, 2009, 2014, 2019 and 2023. All these images were classified using the supervised classification method, after they had undergone some atmospheric corrections processes - geometric and radiometric corrections. The study also computed accuracy assessment, Kappa, and LULC Change analysis on the classified images, which helped in producing statistical information of the study area - after the study area was extracted.

The vector processes included, updating, digitizing, sorting and cleaning the shapefiles, and clipping to the shapefiles to the study areas' extent. Thereafter a GIS database was created to store all the vector inputs. The vector datasets were analysed and later used to generate the inputs, in Chapter 4 of this report, required by the LCM for prediction, simulation and monitoring. In other studies, urban prediction has been done using SLEUTH in QGIS while others have utilized CA_MARKOV in Terraset or IDRISI software. Some of these previous studies include, Predicting the future urban growth and it's impacts on the surrounding environment using urban simulation models: Case study of Ibb city – Yemen by (Al-Darwish et al., 2018) and Modelling and Predicting Urban Growth of Nairobi City Using Cellular Automata with Geographical Information Systems by (Mundia & Aniya, 2007).

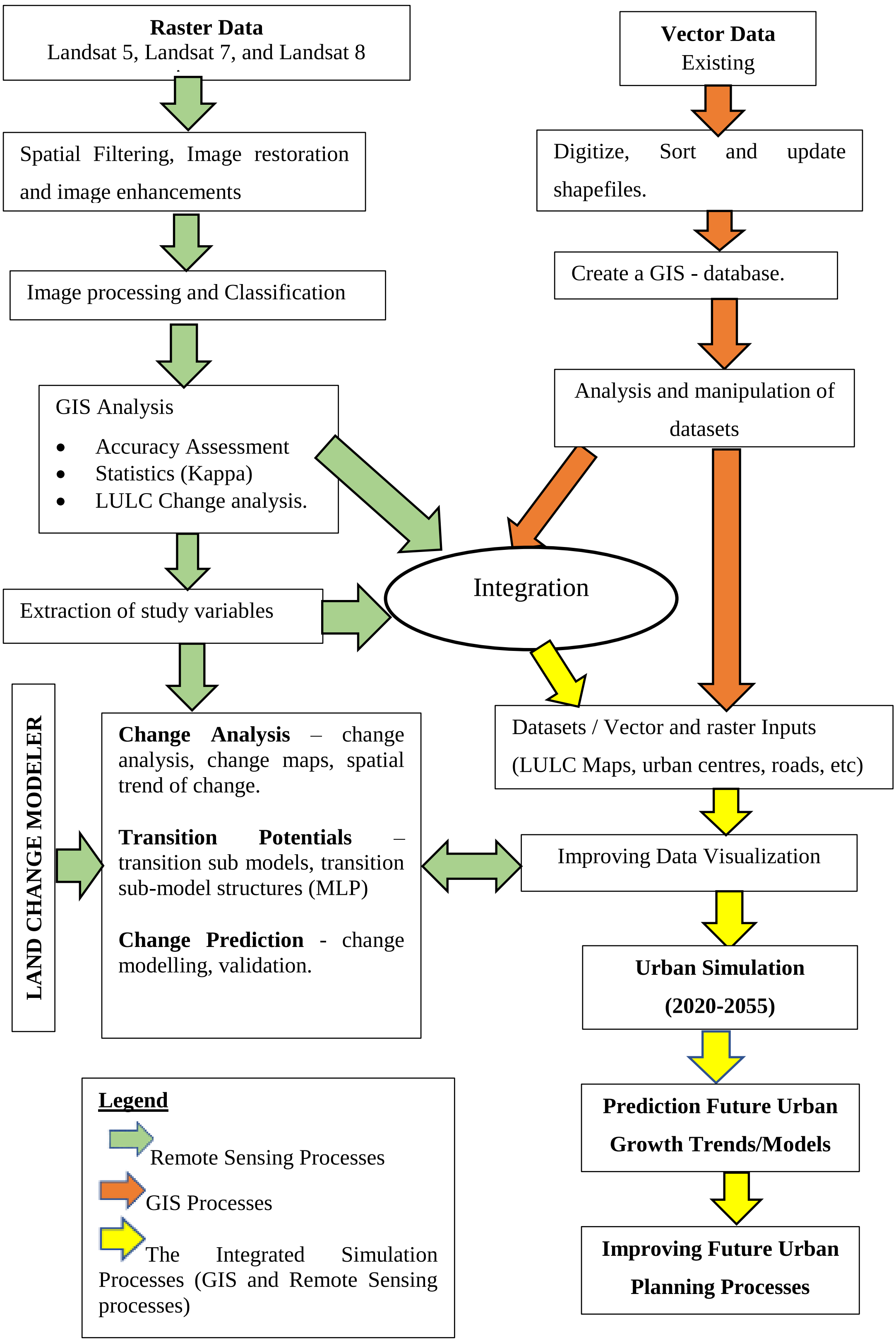


Figure 3.7 Modelling Technique for Simulating and Predicting Urban Growth

For this study, the Land Change Modeler in IDRISI was used because of the added advantages it brings on board to the study. The Land Change Modeler (LCM) analysed historical land cover data to assess, model and predict land cover change, using powerful machine learning procedures. Major components of LCM include:

Land Change Analysis

Given two historical land cover layers, LCM quickly generates graphs and maps to show land changes in terms of, gains and losses, net change, persistence, and a breakdown of contributors to each transition. LCM includes the ability to generalize complex transitions using trend surface analysis.

Transition Potential Modelling

Modelling the potential of land to experience specific transitions (such as clearing of vegetation) lies at the very heart of LCM. Using historical land cover layers along with a set of potential explanatory variables (such as proximity to roads, soil type and slopes), LCM uses empirical modelling tools to establish the relationship between them. LCM currently supports logistic regression, a modified KNN (K-nearest neighbour) and an exceptionally powerful Multi-layer Perceptron (MLP) neural network for model development. In the latter case, a very detailed accounting is provided of model skill and the degree of contribution of each explanatory variable.

Change Prediction

Using transition potential models as a foundation, LCM uses machine learning processes to project the expected quantity of change and a competitive land allocation model to determine scenarios for a specified future date. Options exist to incorporate planning interventions such as incentives and constraints, proposed reserve areas and infrastructural changes (Clark Labs, 2018). Chapter three has given a glimpse of the literature on evolution of urban centres in developing countries, an understanding of challenges facing urbanization in Kenya and how modern simulation techniques can address urbanization challenges. This chapter has also elaborated on a methodology for simulating and predicting urban growth trends using the Land Change Modeler. Chapter four below gives more details on the research findings.

CHAPTER FOUR

RESEARCH FINDINGS, ANALYSIS AND RESULTS PRESENTATION

4.1 General Findings

This chapter has expounded on the background of the study, justified the study and mentioned the study limitations. Literature review has covered, the evolution of urban centres in developing and developed countries and further looked into urbanization in Kenya. The study has further looked into predicting urban growth while using Geoinformation Technologies. The objectives of the study have directed the choice of research methods and contributed to the theoretical analysis used to compare future simulation 1 and 2 of the study area, as detailed in section 4.7.2. Finally, the chapter has discussed the research findings, analysed and presented the results obtained to predict future urban trends.

4.2 Study Area Analysis

It is important to note that the study area has evolved in shape and size over the years, due to population growth and delimitation of administrative boundaries by the IEBC. According to history, Kenya had 117 constituencies in 1963. After the constitutional reviews in 1966 and 1986, the number of constituencies grew to 158 and 188 respectively. The number of constituencies further grew to 210 in 1996 and 290 by 2010 (Interim Independent Boundaries Review Commission (IIBRC), 2010) and (Independent Electoral and Boundaries Commission (IEBC), 2012).

Figure 4.1 below shows the Landsat Images for Limuru Sub County in 1999 (a) and 2019 (b), representing landcover extent. At the scale presented in the figure, it is generally observed that there is very little change in landcover, as the images have not been classified. The greyish, brownish area represents bare land, while the green areas represent vegetation and forest. **Figure 4.2** below shows the administrative boundary of Limuru Sub-County in 1999 (a) and in 2019 (b). The major difference is that in (a), sub – locations were the smallest administrative units while after devolution in (b), Wards are the smallest administrative units.

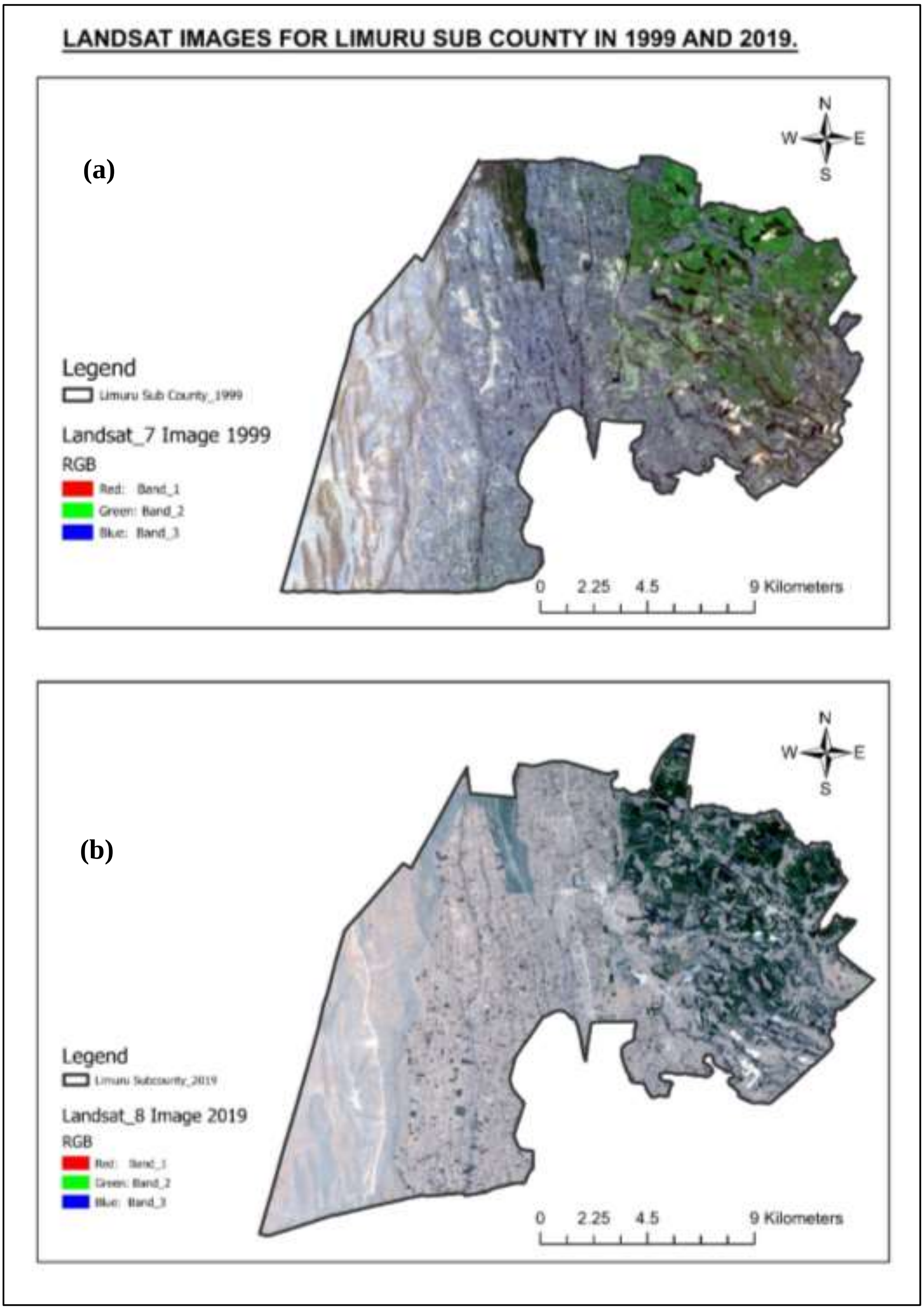


Figure 4.1 Landsat Images for Limuru Sub County in 1999 (a) and 2019 (b)

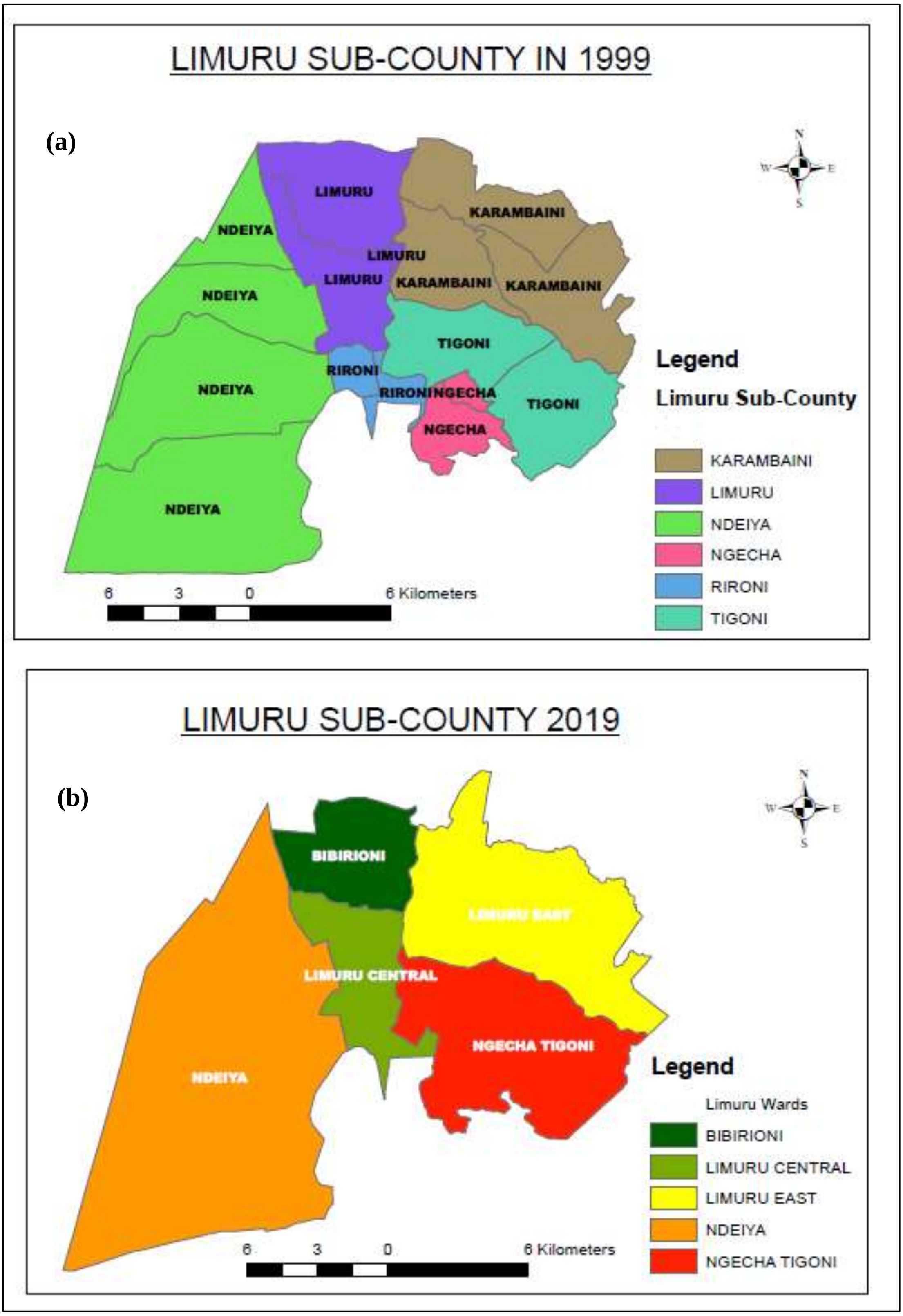


Figure 4.2 Boundary of Limuru Sub-County in 1999 (a) and in 2019 (b)

Figure 4.3 below, shows Limuru Location in 1999 (a) and Limuru Central Ward in 2019 (b). In 1999, the then extent of the study area boundary encompassed two locations – Rironi and part of Limuru. Rironi location had, Rironi and Gatimu sub-locations; while Limuru location had Limuru Town, Kamirithu and Bibirioni sub-locations. Years after devolution, the administration units were revised in 2017, ahead of the 2019 population and housing census by the IEBC. Previously referred to as locations are what we refer to as wards today in Kenya. The study area extent today is known as the Limuru Central Ward, which has an approximate area of 22.3 km^2, as seen in **Figure 4.3 (b).**

In order to capture today's study area extent, the current Limuru Central Ward shapefile was superimposed with the 1999 administrative shapefile, to identify which sub-locations were within the study area needed to create the 1999 extent of the study area as seen below. This resulted in the inclusion of Limuru town, Kamirithu (in Limuru Location), Rironi, and Gatimu (in Rironi Location) Sub Locations), in **Figure 4.3** and **Figure 4.4**.

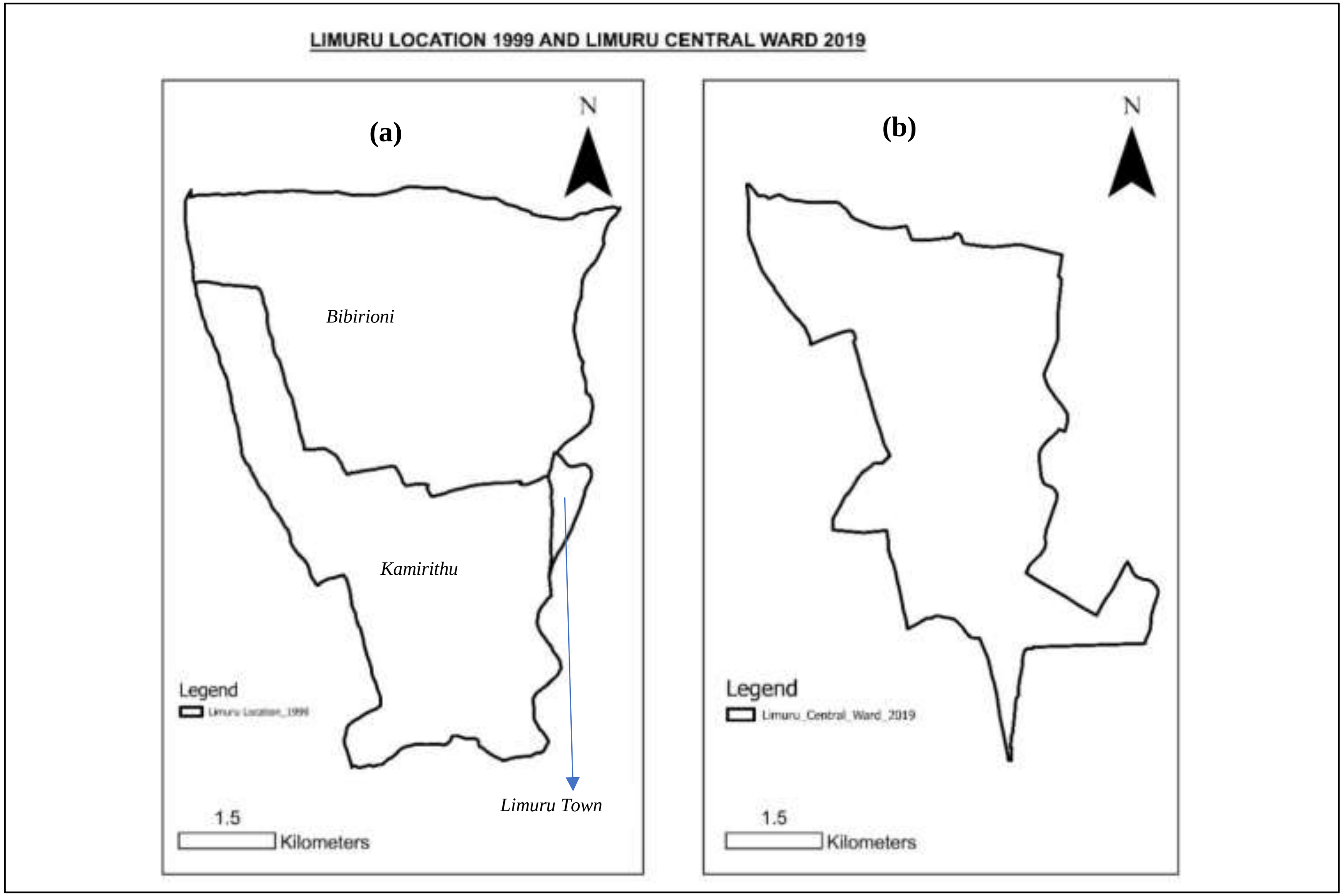


Figure 4.3 Limuru Location in 1999 (a) and Limuru Central Ward in 2019 (b)

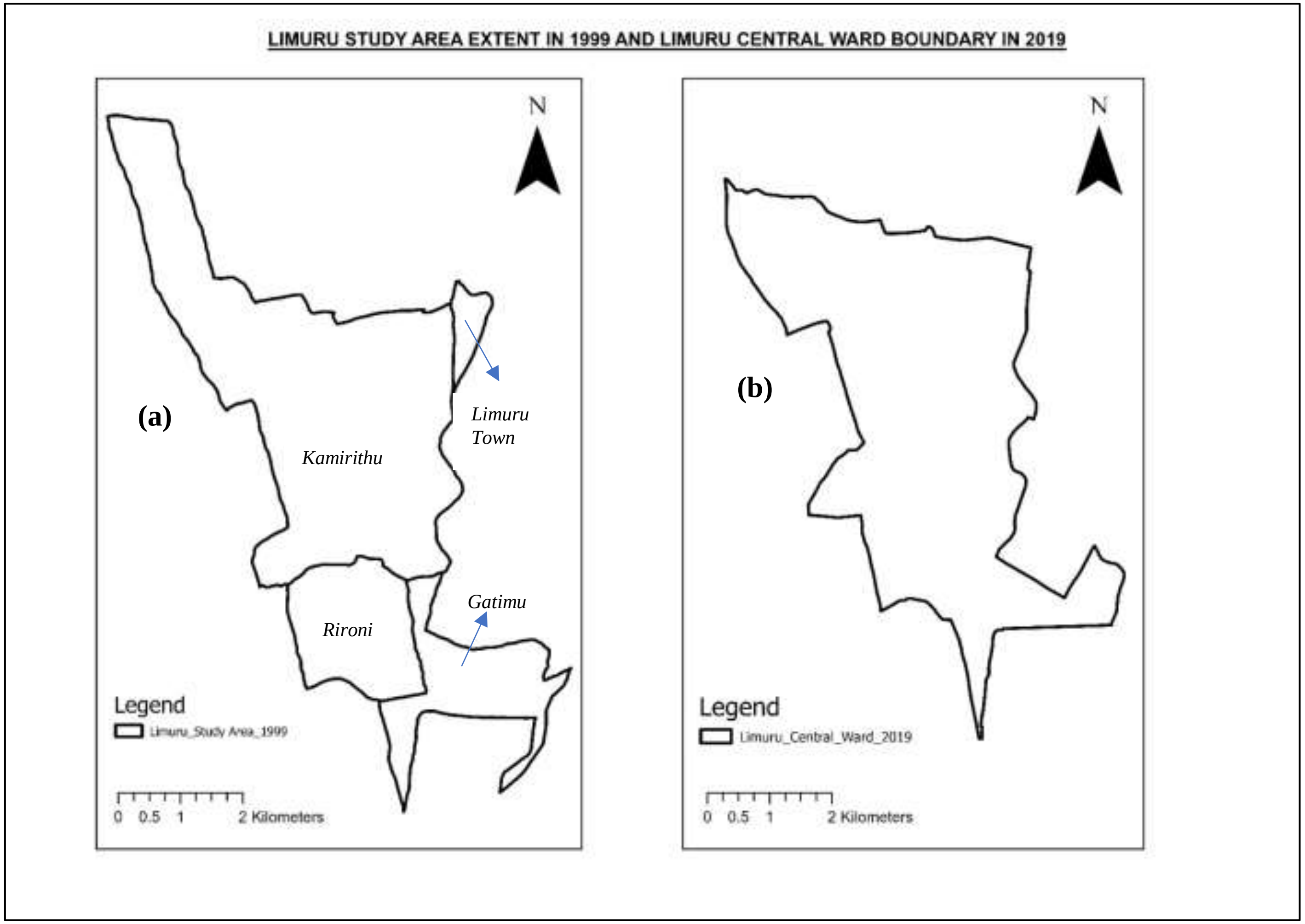


Figure 4.4 The Study Area Extent in 1999 (a) and the LCW Study area in 2019 (b

4.2.1 General Topography of the Study Area

The study area is located between 2,126.64 m to 2,312.16 m above sea level. The area gently slopes from the North-East to the South-West. It is surrounded by Tea Farms and dense vegetation to its West and North- East and less dense vegetation in other areas. **Figure 4.5** below in a 2023 image that shows the general topography of Limuru Central ward and its neighbouring regions.

Figure 4.5 Satellite Image of Limuru Central Ward and Its Surrounding Region

Source: (Google Earth)

Figure 4.6 (a) below shows that the highest part is located along the Limuru Town boundary, which is adjacent to Limuru East Ward, along the Northwest boundary. The topographical profile along the A104 (red line) and the topographical profile between the highest and the lowest areas (black line) as seen on **Figure 4.6 (b)** below, shows that the gradient of the study area changes steadily. This allows for provision of proper man-made drainage channels through out Limuru Central Ward.

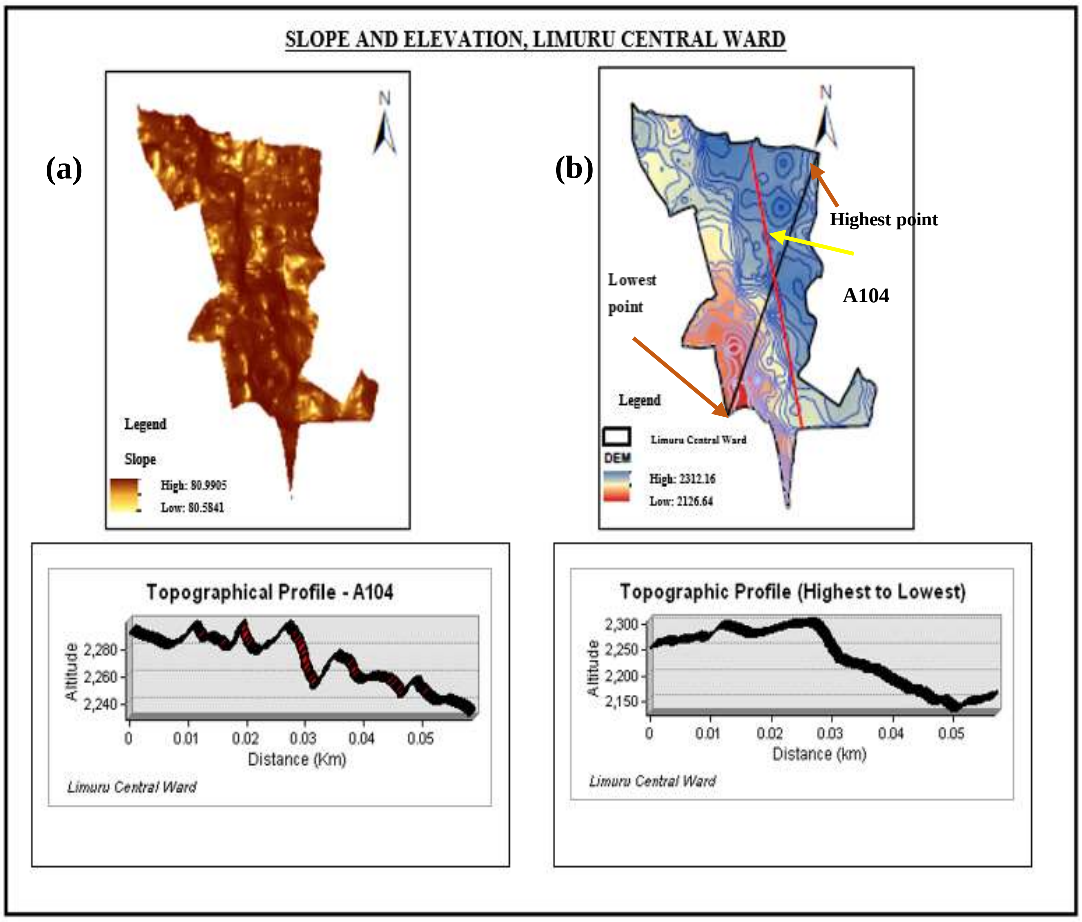


Figure 4.64 Slope (a) and Elevation (b) of Limuru Central Ward

4.2.2 Geology of the Study Area

Limuru Central Ward has both Limuru Trachyte and Tigoni Trachyte, shown in **Figure 4.7** below. Limuru Trachyte (1.94 - 2.64 Ma) contains characteristically clustered groups of K-feldspar phenocrysts, which tends to form boulder outcrops, and grades upwards into Pantellerite. These erupted as a series of conformable flows with reverse polarity, which overtopped the escarpment in this area. A thickness of 400 m is exposed in the eastern rift escarpments near Ndeiya, away from the study area (BAKER et al., 1988).

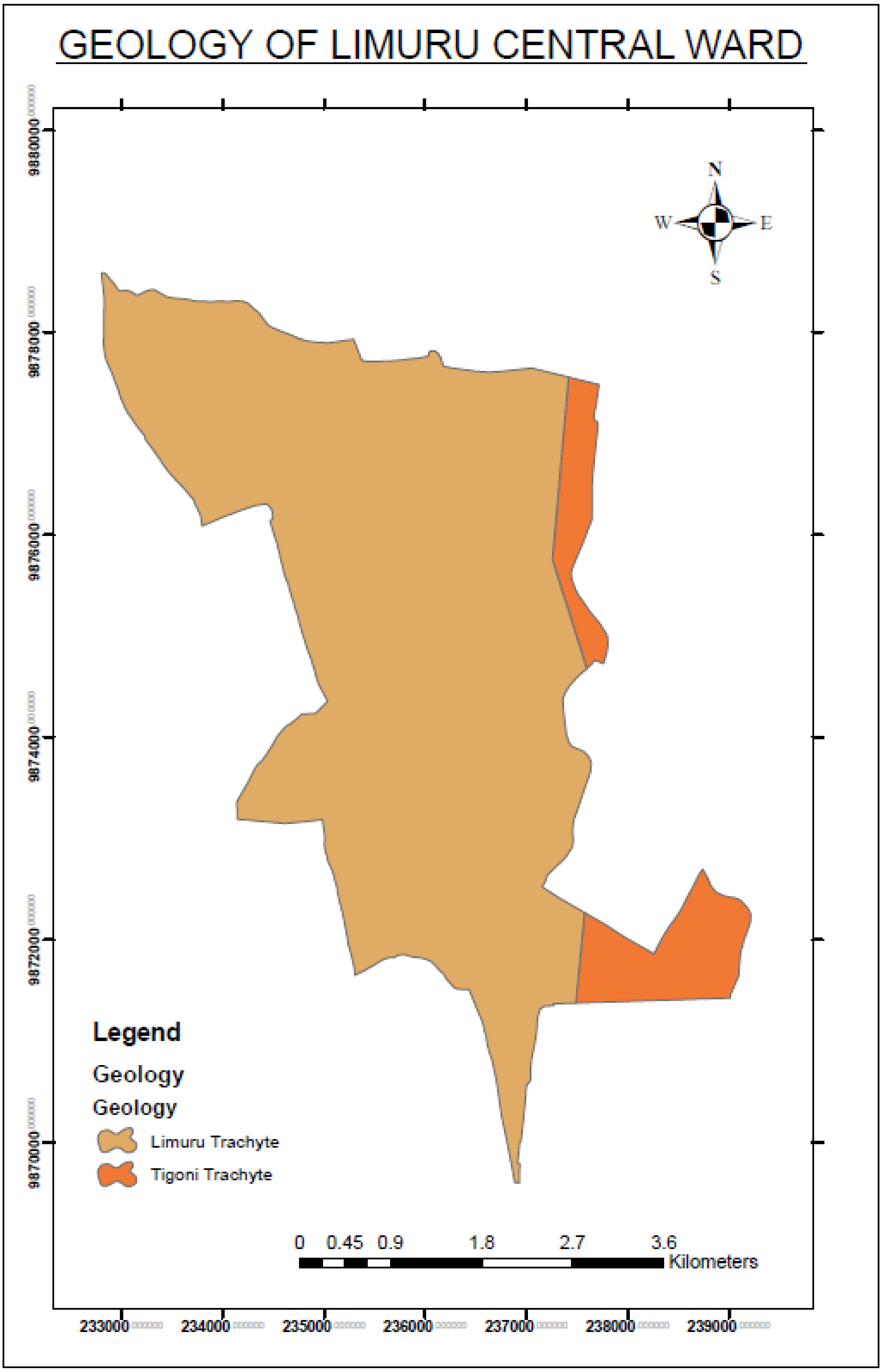


Figure 4.75 Geology of Limuru Central Ward

4.2.3 Soils

Limuru Central Ward has very thick fertile soils that emerged from weathering of the Limuru Trachyte. The soils have high mineral content and are suitable for small-scale and large-scale farming activities (Saggerson, 1991). The soils in the study area are generally used for small scale agricultural activities as seen on **Figure 4.8**, while large scale tea zones are located in Limuru East Ward which boarders the study area along its North-Eastern boundary.

4.2.4 Hydrology and Drainage

The study area has very shallow seasonal streams that drain from the Ngubi forest (located in the North-East) towards the South. These streams occur when the area receives heavy rains. The only permanent water body in the study area is the Manguo Swamp, located in the North, a short distance from the Limuru CBD as seen on **Figure 4.8** below.

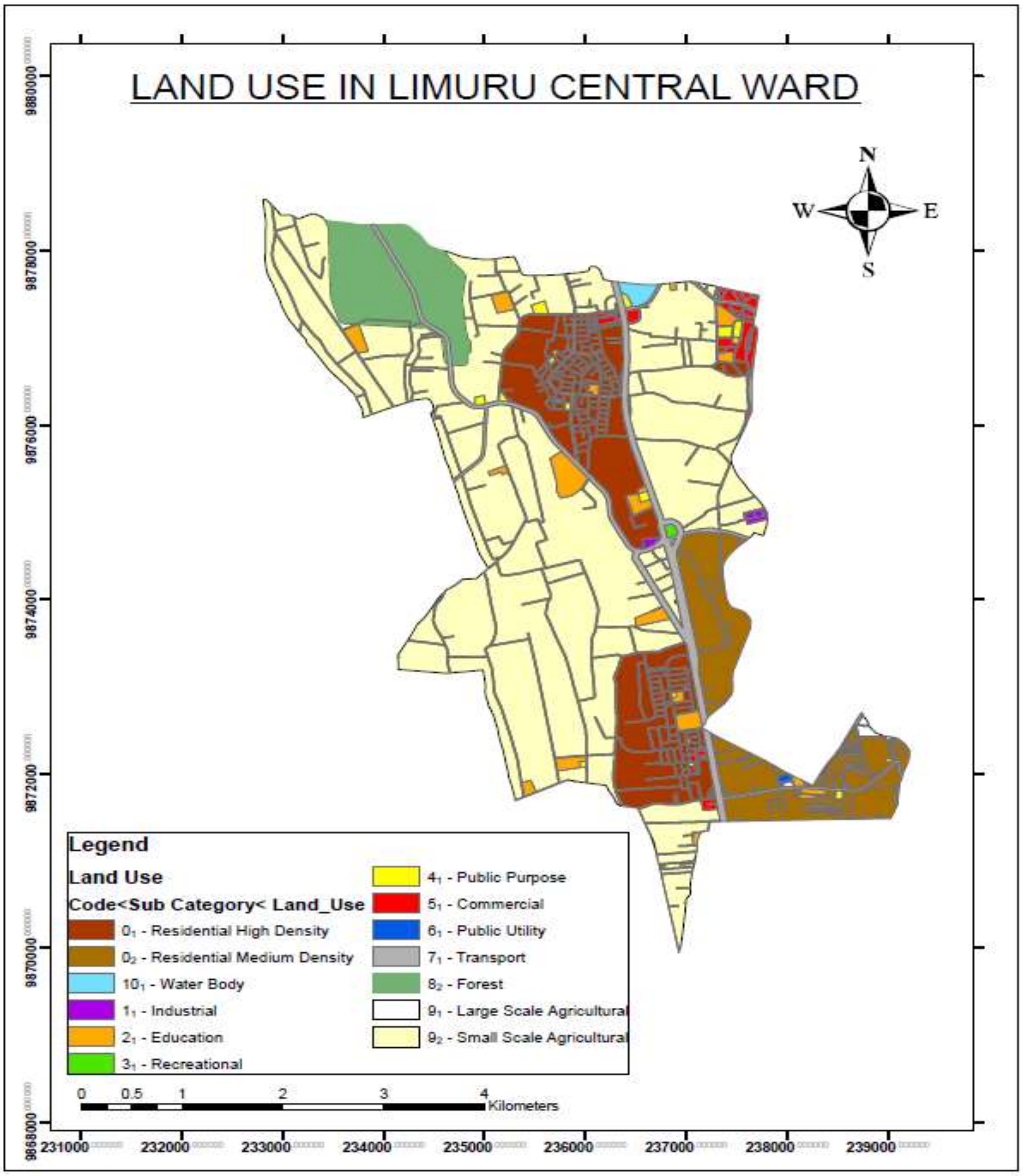


Figure 4.86 Major Land Uses Zones in Limuru Central Ward

Table 4.1 below, summarises the percentage area of the Limuru Central Ward land uses. The largest land use is small scale agriculture (62.186%), and the least is Transport (0.002%).

Table 4.1 Percentage Areas of the LCW Land Uses

Land Use Code	Land Use	Area (Percentage)
0^1	Residential High Density	12.771%
0^2	Residential Medium Density	11.621%
1^1	Industrial	5.663%
2^1	Education	3.329%
3^1	Recreational	0.056%
4^1	Public Purpose	1.464%
5^1	Commercial	1.193%
6^1	Public Utility	0.043%
7^1	Transport	0.002%
8^1	Forest	0.020%
9^1	Large Scale Agriculture	0.337%
9^2	Small Scale Agriculture	62.186%
10^1	Water Body	1.315%

4.2.5 Land Surface Temperature

Land surface temperature - measured in Kelvin, is an important geophysical parameter in global energy balance studies and hydrologic modelling. Surface temperature data are also useful for monitoring crop and vegetation health, and extreme heat events such as natural disasters (e.g., volcanic eruptions, wildfires), and urban heat island effects (Department of the Interior U.S. Geological Survey (USGS), 2018).

This study incorporated Land surface temperature data to validate the effects of urban heat islands on increasing urban footprint in Limuru Central Ward. The formula for computing LST is as follows (Wang et al., 2020):

$$\text{LST} = \frac{T}{1+(\lambda+\frac{T}{\rho})\text{In}\ \varepsilon}$$

- T is band 6 in Landsat ETM+, and Band 10 in Landsat OLI/TIRS,
- λ is for the thermal bands.
- $\rho = \text{h} \times \frac{c}{\sigma}(1.38 \times 10^{-1} JK^{-1})$ And.

- ε is the emissivity computed from NDVI,

As an example, LST was computed in Google Earth Engine as shown below. The range in years gave a more visible difference in spatial distribution of the effects of Land Surface Temperature on Urban development in the study area. **Figure 4.9** shows us that there was a significant rise in LST in the study area, between 2002 and 2013.

The cooler region borders the Limuru East Ward to the East and the warmer area borders Ndeiya Ward to the West. The increase in urban footprint within the study area, is progressively contributing to the adverse effects of climate change as a result of the urban heat trapped within the urban centres throughout the study area.

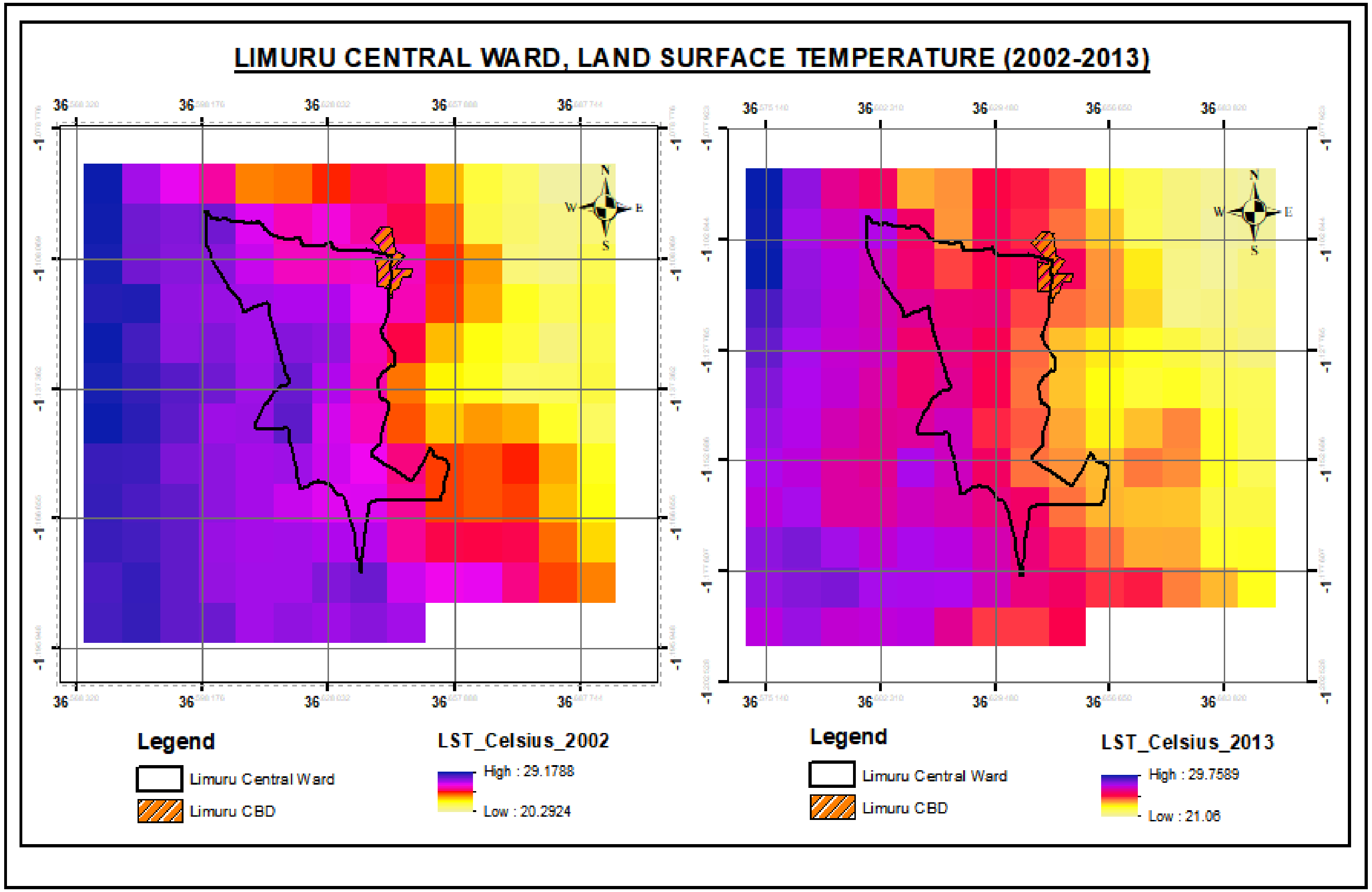


Figure 4.7 Land Surface Temperature Increase between 2002 and 2013.

4.3 Challenges of using GIS and Remote Sensing to Predict Urban Growth

Urban Planners or Physical Planners use Geoinformation technologies to prepare maps, from inception to completion. However, very few use geoinformation technologies to predict the future urban growth trends spatially.

The visionary aspect of urban planning in developing countries, is mostly driven by the strategies formulated many years ago. This is evident in some of the plans prepared as seen in **Appendix I** and the well-known Nairobi Metropolitan Growth Strategy which was developed in 1973 (Nairobi Urban Study Group, 1973) – one of the maps is shown in **Appendix VI**. Developed countries have been able to embrace the use of geoinformation technologies during the planning stage and the prediction stage, to better account for the emerging trends in urban growth while alleviating the consequences of conventional urban planning practices.

4.3.1 Insufficient Interaction with GIS

In the world we live in today, especially in the developing countries, the school curricular has not introduced the use of computers as a mandatory subject in schools. This has therefore contributed to the lack of computer skills being harnessed by the younger generation. Many GIS and Remote Sensing practitioners interact with geoinformation technologies when they are studying at the university level. Once they done, only few proceed to utilize the acquired skills in their day-to-day work tasks.

4.3.2 Lack of Timely Revision of Plans and Policy Enforcement

Enforcement plays a crucial role in ensuring that there is continuity in solving spatial problems both at present and problems which can occur in the future. As mentioned above, the 1973 Nairobi Metropolitan Growth Strategy (NMGS) was formulated in response to the sectoral issues that were being reported to the city council as from 1967. Some of the sectoral issues reported by the residents included transportation, water, and housing issues.

The NMGS was meant to address these issues till the year 2000, however, the plan in use till 2013 and later replaced by the Nairobi Integrated Urban Development Mater Plan (NIUPLAN). The NIUPLAN was not only developed to serve the Nairobi City County but also the rest of the Nairobi Metropolitan Region, between 2014 to 2030 (JICA, 2018). There are no clear laws which govern timely revision of plans and it's because of that very reason, that outdated plans and strategies are used to mitigate modern day urban problems. This has proven futile and hence the need to integrate geoinformation technologies, to plan and predict ways to better plan for future urban areas.

4.4 Growth Patterns and Trends of Limuru Central Ward (1999 – 2019)

In general, Limuru Central Ward has experienced an increase in the built up / urban areas and a decrease in vegetation cover from 1999 to 2019. Infrastructure has influenced the growth pattern of the new built-up areas, as it has opened up inaccessible areas to accommodate new buildings in the study area. This growth has resulted to Transport Oriented Development along main transport corridors such as Kiambu Road (C63), Eldoret - Malaba Road (A104), Ngenia Road, Limuru Road (B3), as will be further explained in this sub section of Chapter Four.

4.4.1 Acquisition of Study Area Images

The study area is located within Path 168 and Row 061 of the Landsat scene. The raster images, seen as **Figure 4.10 (a - e),** used in this study were downloaded from the USGS Website. The 1999 and 2002 images are from the Landsat 7 Enhanced Thematic Mapper Plus (ETM+), the 2009 Landsat image is a Landsat-5 Thematic Mapper (TM) image, while the 2013, 2014 and 2019 images are from the Landsat 8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS). These images were processed during the day and hence had less cloud cover.

4.4.2 Land Use Land Cover Classification and Accuracy Assessment

It is important to note that the study area shown in **Figure 4.10** below, utilized the 2017 LCW boundary as seen in **Figure 4.4 (b)**, instead of using the old LCW boundary to carry out the analysis. The Landsat images were classified into three major land uses; Urban (Built Up Area), Bare Soil and Vegetation. This was done to ensure that the output generated in ArcGIS was processed smoothly from inception to prediction, since all the inputs were required to be within the same processing range. Images (**a-e)** in **Figure 4.10** below represent the study area in 1999, 2003, 2009, 2014, and 2019. They were later processed, pansharpened and further classified, as seen in **Figure 4.12** below, to show the mainland uses that would be discussed in this study.

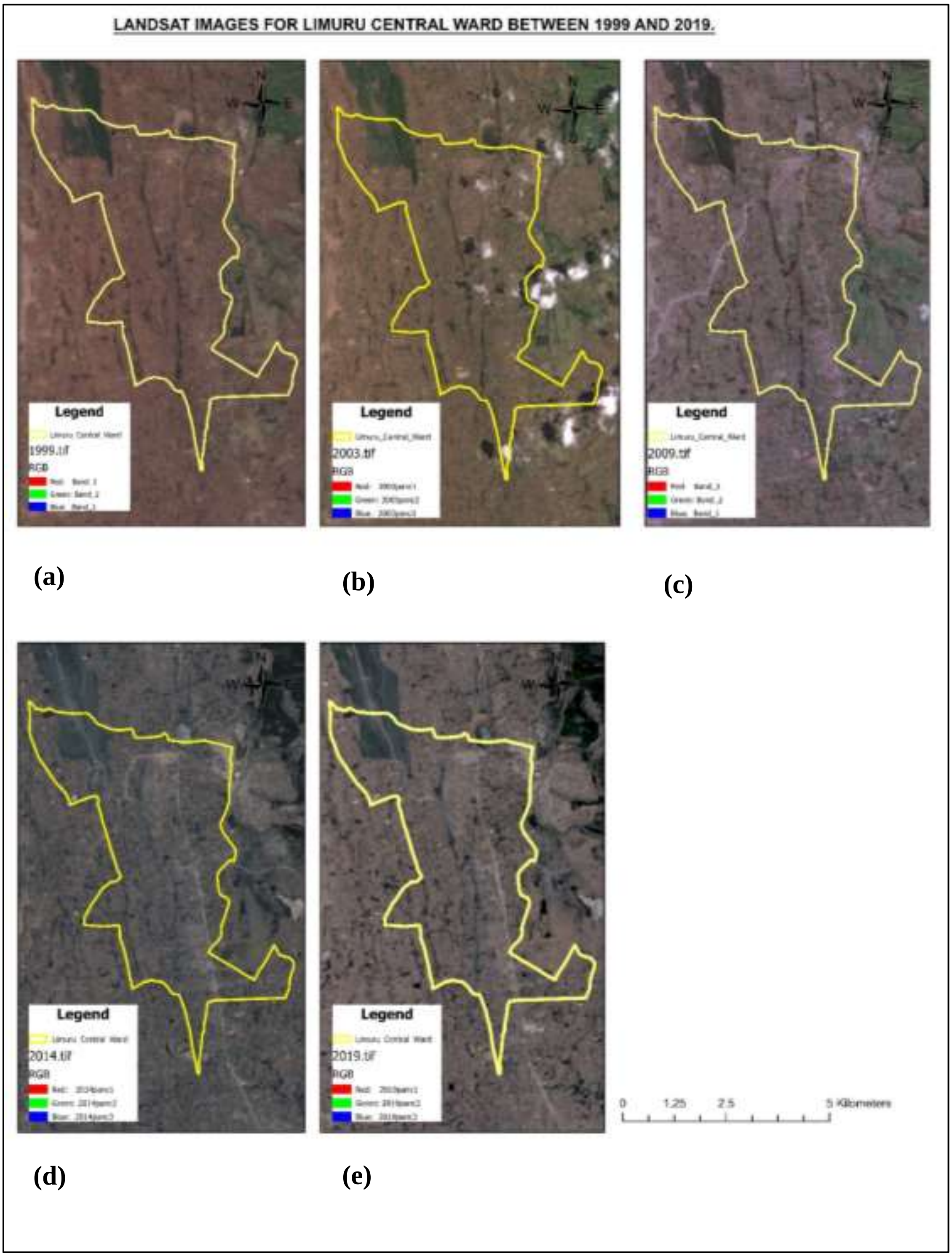


Figure 4.10 Landsat Images for Limuru Central Ward Between 1999 and 2019

The method of classification used was the Maximum Likelihood Supervised classification in ArcGIS Pro. The accuracy assessment during classification ranged from 75% to above 90% and the Kappa coefficient (in percentage) was above 40% for all images. This shows that the supervised classification the study employed was more accurate than unsupervised classification, that the study would have otherwise used.

In reference to **Figure 4.11** and **Figure 4.12,** the urban areas in LCW, within Kwa Mbira, Limuru CBD, Mutarakwa, Kamirithu, Kamandura and Rironi, have grown steadily since 1999 till date. The area covered by Bare Soil decreased from 1999 till 2009 and increased in 2014 before increasing once again in 2019. This information is summarised in **Table 4.2** and **Figure 4.11** below.

Table 4.2 LULC Values in Limuru Central Ward (1999 - 2019)

Land Use	Class Value	1999 (a)	2003 (b)	2009 (c)	2014 (d)	2019 (e)
Urban	**20**	2%	3%	5%	8%	9%
Bare Soil	**30**	91%	72%	68%	83%	75%
Vegetation	**40**	7%	26%	28%	10%	15%
		100%	**100%**	**100%**	**100%**	**100%**

The positive increase in Urban in 2014 was due to the sharp decrease in vegetative cover within the study area, between 2009 and 2014.

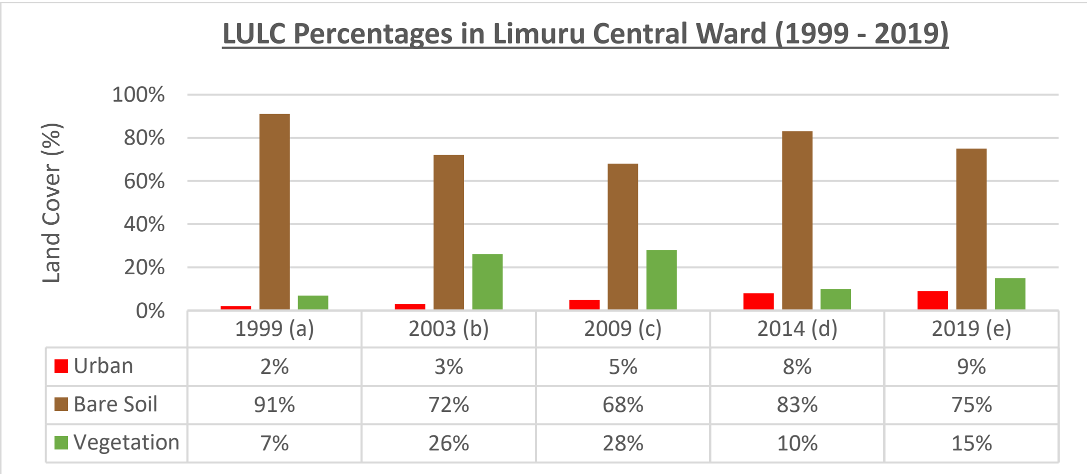


Figure 4.11 LULC Percentages in Limuru Central Ward (1999 - 2019

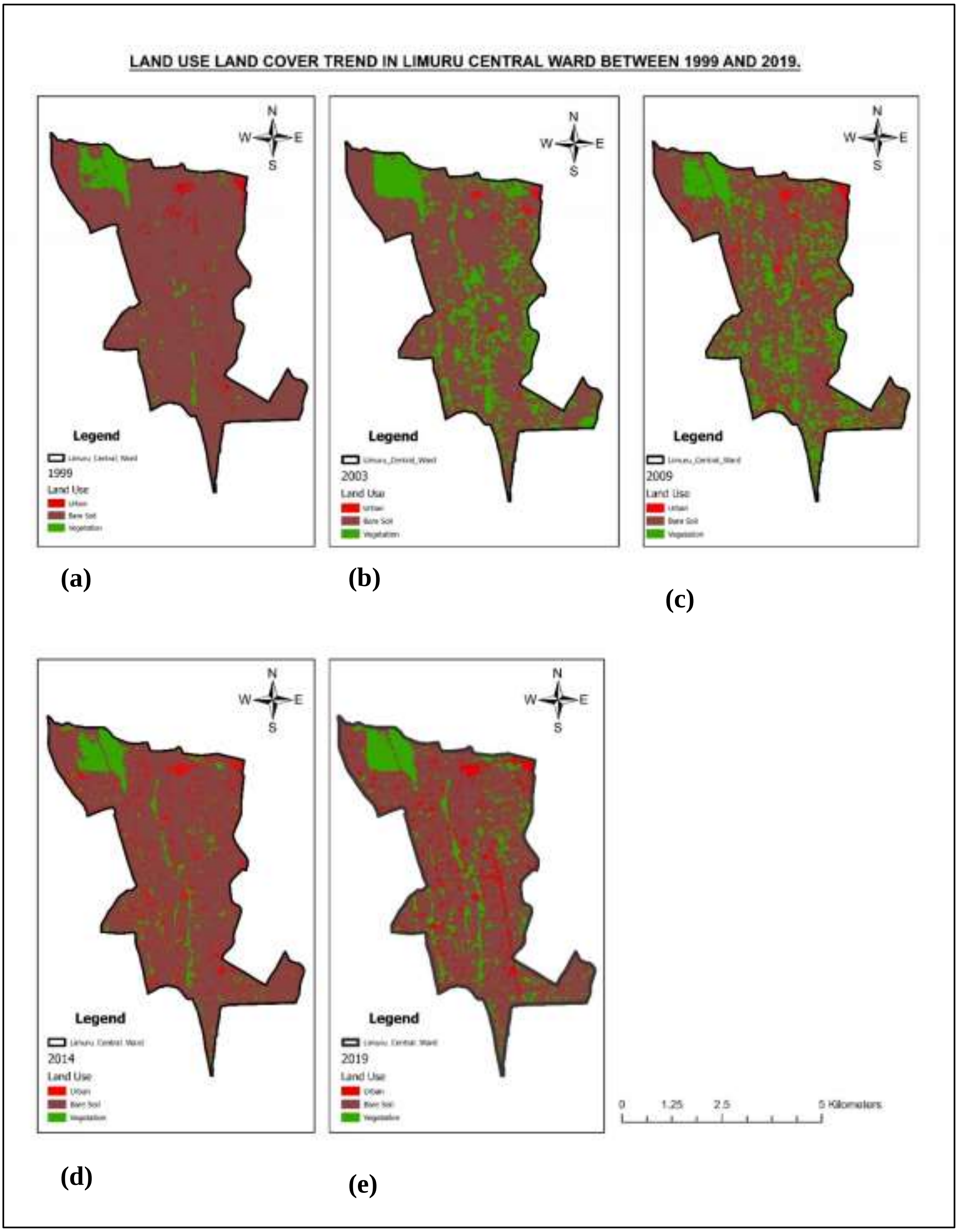


Figure 4.12 LULC Trends in Limuru Central Ward (1999 – 2019)

4.4.3 Urban Growth Hotspots (1999 and 2019)

Majority of the urban area in Limuru Central Ward are located within Limuru, Kwa Mbira, Mutarakwa, Kamirithu, Gatimu, Kamandura and Rironi. In the earlier years, Kwa Mbira and Limuru CBD were the larger urban areas as compared to the other urban areas within the study area. This was majorly attributed to proximity to major roads as seen in **Figure 4.12** and urban friendly land use zones as seen in **Figure 4.8**. The urban centres have grown outward from the core, concentrating the commercial activities at the center, hence exhibiting the concentric urban growth model as seen in most CBDs.

As mentioned previously in section 3.2 of this report, the major roads present in the study area include Kiambu Road (C63), Eldoret - Malaba Road (A104), Ngenia Road, Limuru Road (B3). Rironi's growth is influenced by Limuru Road (B3), Eldoret - Malaba Road (A104), while Gatimu has grown around the Ngecha-Chungu-Mali-Road. The main roads traversing the study area have allowed people to move with ease and have encouraged people to settle along the road, as in the case of Rironi, hence promoting Transport Oriented Development (TOD) pattern of growth. Kamirithu and Mutarakwa have developed greatly due to their proximity to two Tertiary Roads, Dagoretti-Karen Road and Kamandura-Maai Mahiu-Narok Road.

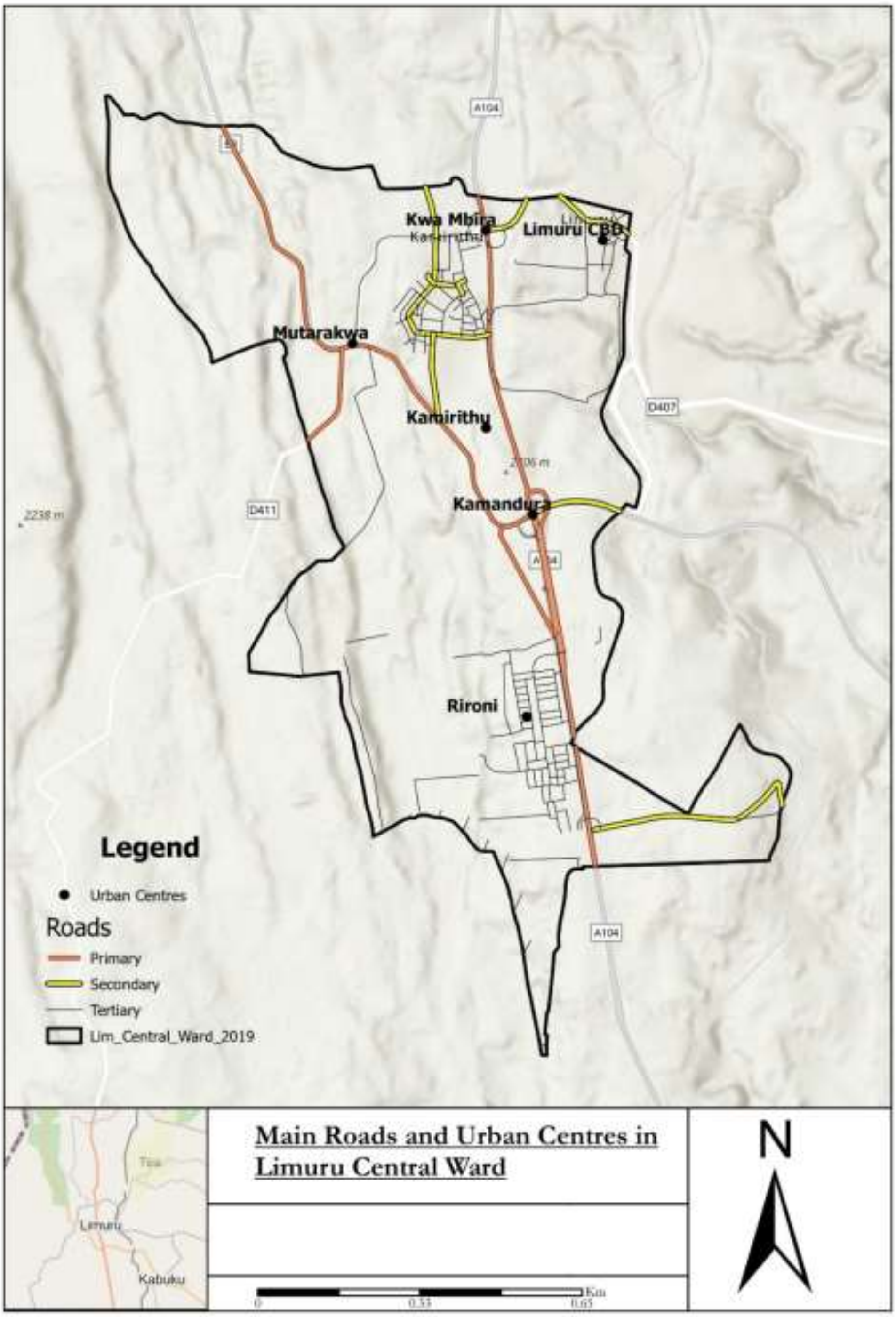


Figure 4.13 Main Roads and Urban Centres in Limuru Central Ward

Source: (Author)

4.5 Modelling Results of the Land Change Modeler (LCM)

The classified raster images in ArcGIS Pro, were imported in IDRISI, for further processing. The process required only two classified images, the 1999 and 2019 Maximum Likelihood Supervised Classified Raster Images.

4.5.1 Statistical Analysis

The LCM has been used to analyse the classified images of the study area to derive the past and present urban growth trends and to predict and simulate the future urban growth trends. Prior to modelling, GIS analysis was performed to extract spatial and statistical information.

Database query (Reclassification)

The tool was used to produces a new map image by reclassifying the values of an input image into specific number of classes. For this study we only utilized 3 classes, hence this assisted in identifying the spatial extent of the built-up areas and to analyse past trends of urban growth later visually. Some of the major built up areas identified before in ArcGIS Pro, were also seen in IDRISI. Some of the urban areas included Limuru Central Ward included Limuru Town, Kamirithu, Rironi, Mutarakwa and Gatimu. Reclassification extracted the built area footprint and analysed the major changes in the built area footprint.

Statistics (Crosstabulation)

Figure 4.14 shows that analysis is possible only when two (or three images), have identical number of classes. The study computed similarity statistics to check if there were any changes between the classes of the classified images, while the Kappa Index of Agreement (KIA) showed the degree of agreement between the two images (Clark Labs, 2018).

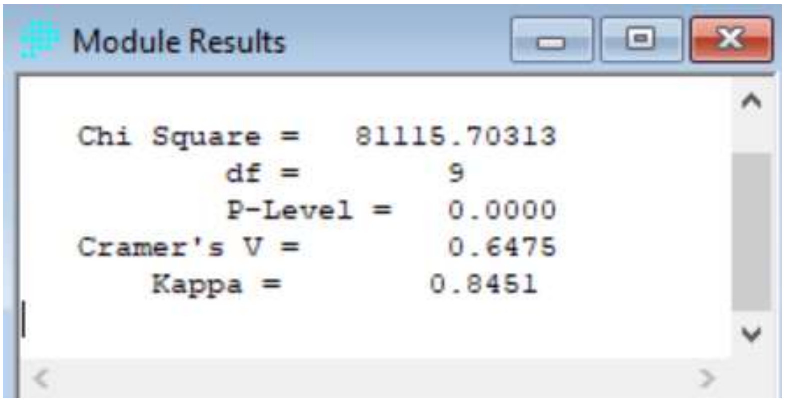


Figure 4.14 Crosstabulation Results in LCM Statistics (Regression)

The purpose of regression was to check if there was a perfect correlation between the different classes in the two classified images. Perfect correlation means that there is no change (r value=1). The 1999 image was the independent variable (X-axis) while the 2019 image was the dependent variable (Y-axis). As seen in **Figure 4.15** the r value was 0.961931, this means that there was an overall positive change between the two classified images.

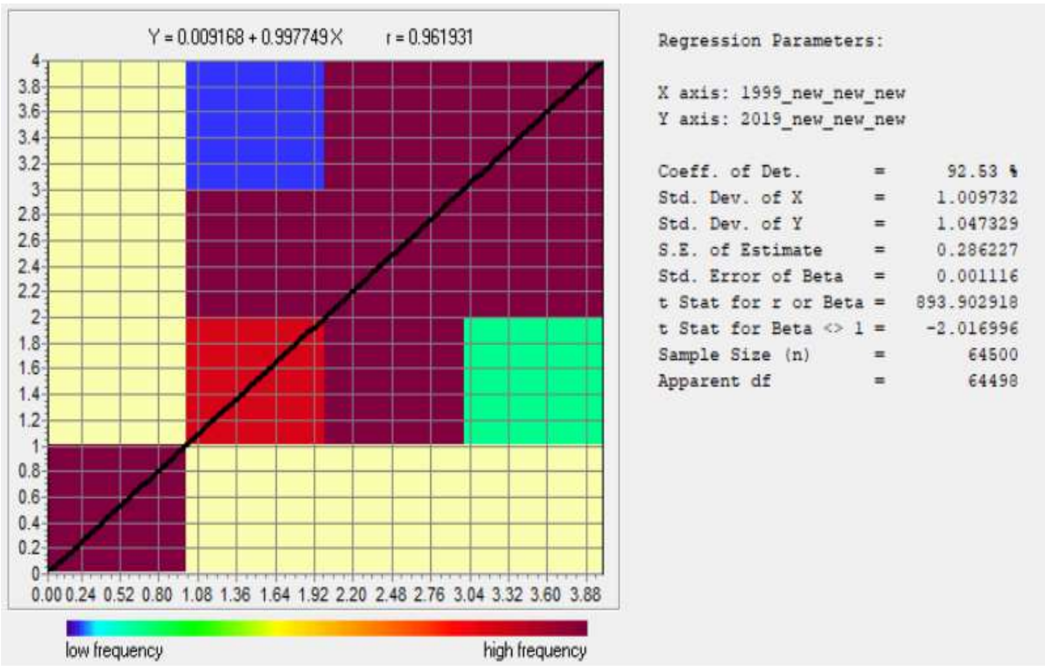


Figure 4.15 Regression Analysis Graph

4.5.2 Change Analysis

In this study, it is evident that; undeveloped areas near urban centres are susceptible to land changes and the magnitude of change that occurs on bare land is useful in determining whether people value farm production or urban growth. **Figure 4.16** shows that between 1999 and 2019, the Built up and vegetative areas significantly increased in Limuru Central Ward, while the space occupied by bare soil decreased.

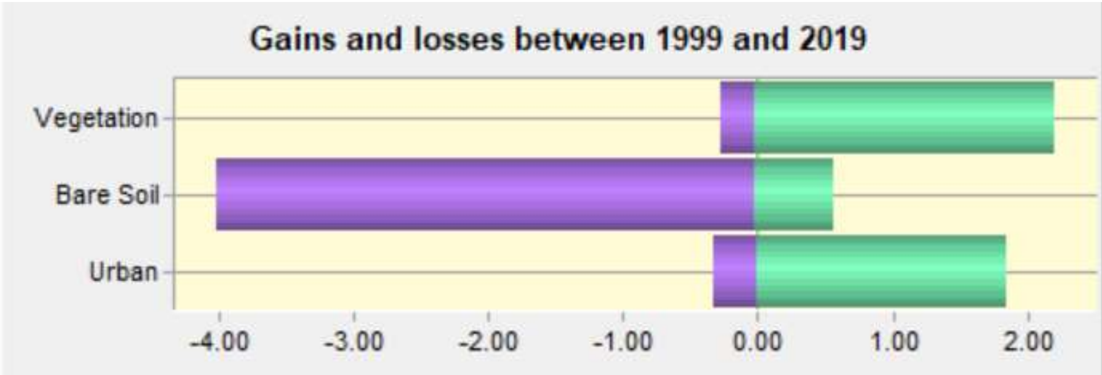


Figure 4.16 Gains and Losses between 1999 and 2019 (in km^2)

In **Figure 4.17**, the built-up area and the vegetation had a positive increase in Limuru Central Ward while Bare soil decreased overtime to accommodate the growth of the other two major land uses.

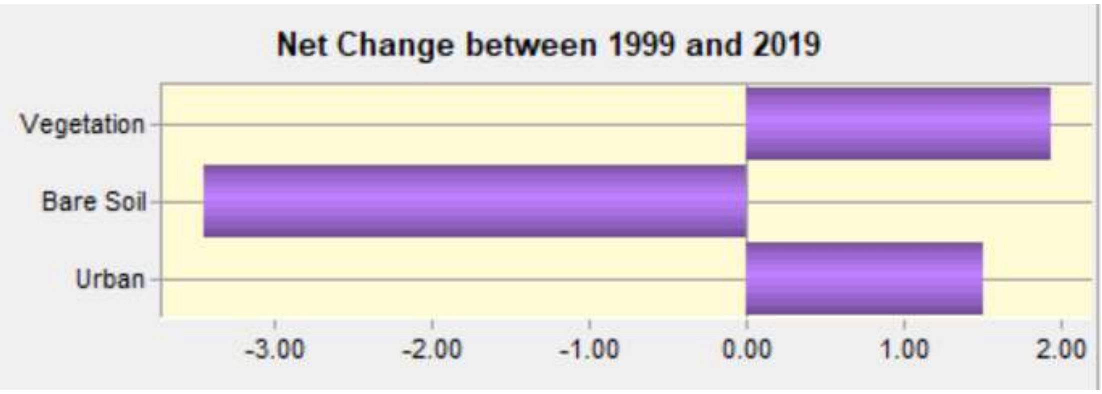


Figure 48.17 Net Change between 1999 and 2019 (in km^2)

In **Figure 4.18,** urban areas increased when Bare Land decreased, while there was little decrease in Vegetation cover as a response to the steady increase of the Built-up areas (Urban).

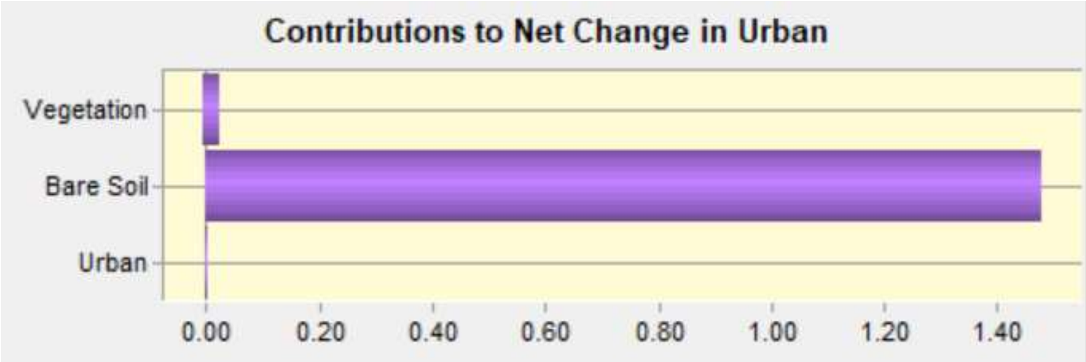


Figure 4.18 Contribution to Net Change in Urban (in km^2)

In **Figure 4.19**, there was an overall decrease in Bare soil with the steady increase of the Built-up areas and the Vegetation.

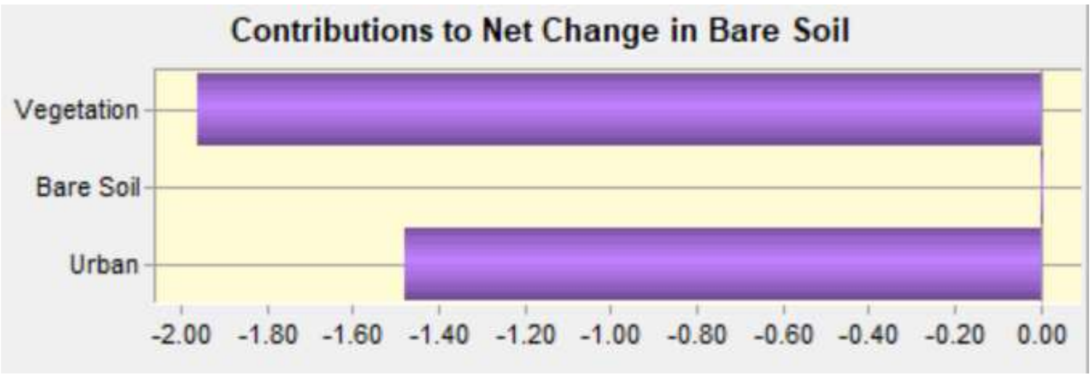


Figure 4.19 Contributions to Net Change in Bare Soil (in km^2)

In **Figure 4.20,** vegetation increased when Bare Land decreased, while there was no observable decrease in the Urban areas/Built areas when Vegetation increased.

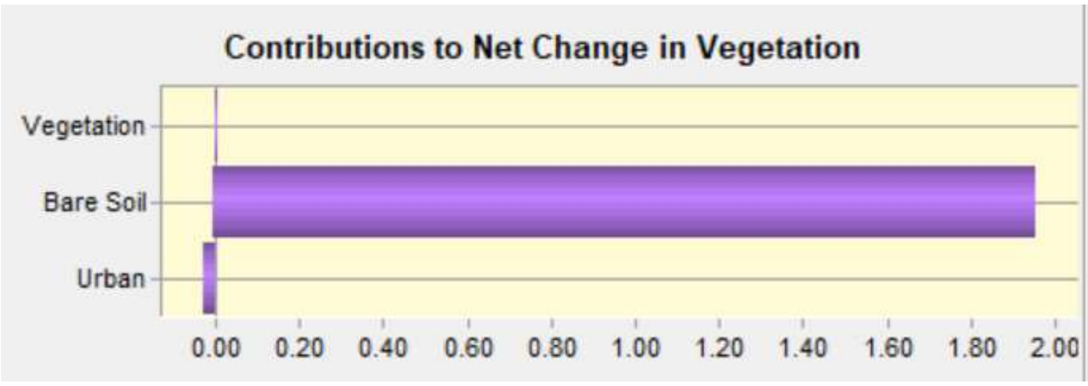


Figure 4.20 Contribution to Net Change in Vegetation (in km^2)

4.5.3 Production of Change Maps

Land Change Modelling easily depicts land change dynamics in any given area. The Land Change Modeler (LCM) uses pairwise comparison of qualitative data to produce land use change maps. The change maps allow one to map the changes described in the change analysis panel of the model. This research mapped spatial changes within a threshold of more than 1 km^2 and ignored transitions that were less than 0.3 km^2. This threshold was used to identify significant land use changes in Limuru Central Ward.

Figure 4.21 shows that the highest transition potential recorded in the study area between 1999 to 2019 represent land use land cover changes from bare soil to urban, from urban to bare soil in some areas and from bare soil to vegetation. Land use changes from bare soil to urban give way to development of clusters of urban developments, changes from urban to bare soil, paved way for future farming and areas for future urban development, while changes from bare soil to vegetation pave way to farming and preservation of forested areas.

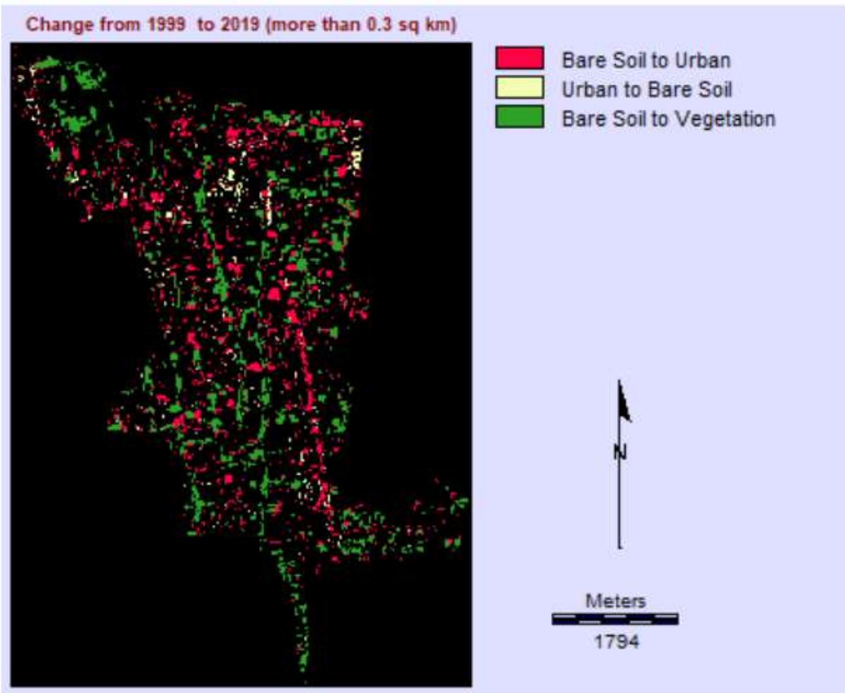


Figure 4.21 Land Use Changes between 1999 and 2019 (more than 0.3 km^2)

4.5.4 Transition Potential Maps

Transition potential maps describe the probability that a transition may occur in the modelled landscape and will be used in predicting future change in Limuru Central Ward. Transition potential modelling employed Multi-layer Perception (MLP) neural network which is a machine learning tool. Once calibrated it was used to predict future scenarios. By default, in LCM, each transition is a separate sub-model, but multiple transitions can be grouped into a single sub-model if it is considered that they all result from the same underlying driving forces. The transition sub-models were grouped into a single sub model, and the variable transformation utilities was used to create transitional variables.

Only MLP can be used to model multiple transitions in one sub-model. In general, as the number of transitions that are grouped into one sub-model increases, the task becomes more and more difficult for MLP to solve. This can easily be gauged from the validation accuracy report that the MLP provides. Hence producing more accurate results in this study.

4.5.5 The Transition Variables

MLP creates a multivariate function that is trained to predict transition based on the values of the driver variables. On the Variable Transformation Utility Panel (VTUP), the MLP option does not require the variables to be linearly related, but transformation can sometimes make the task easier for it to solve in cases of strong non-linearities, thus yielding a higher accuracy. For all model types, logistic regression, MLP and SimWeight, variables must either be converted into a set of Boolean (dummy) variables or transformed using the evidence likelihood transformation option (highly recommended).

The Change Analysis tab was used to create Boolean maps of areas that have gone through the transition being modelled. Static and dynamic variables were determined at each time step of the prediction stage of the model, dense vegetation within the study areas that’s not Ngubi forest, is dynamic because with the increase in the built there is encroachment and hence reduction of the vegetation cover due to encroachment.

The driver variables were slope, DEM, and distance from main urban centres, roads, schools, Ngubi forest, Manguo swamp. The MLP neural network has been extensively enhanced to offer an automatic mode that requires no user intervention. The transition variables in **Figure 4.22** below, were used as inputs for the transition model, to compute the simulation and prediction maps.

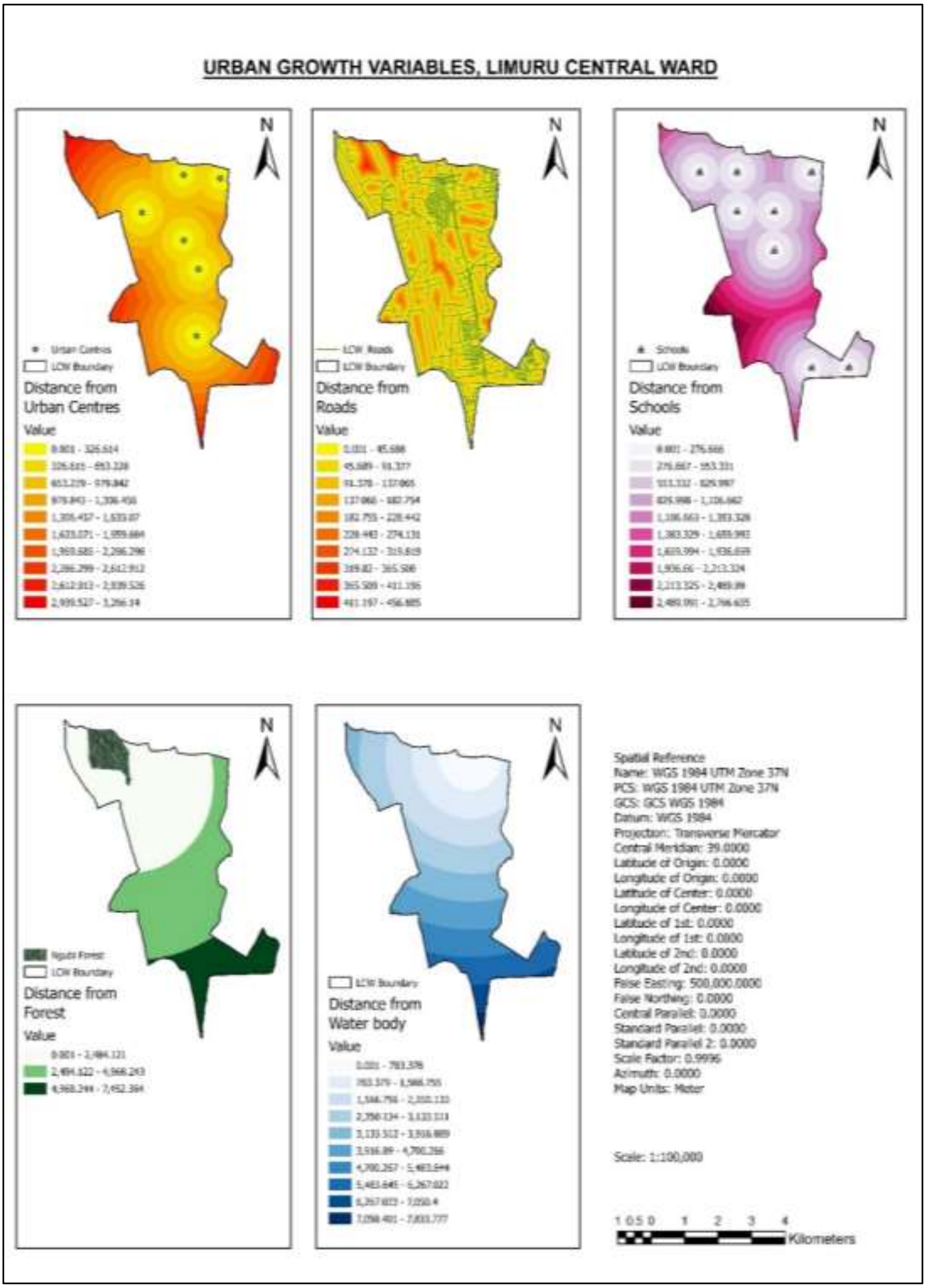


Figure 4.22 LCM Transition Variables, Urban Growth Variables

4.6 Prediction and Simulation

The transition variables in **Figure 4.22**, were used as inputs for the transition model, to compute the simulation and prediction maps.

4.6.1 Accuracy Rate of the Transition Sub Model

The MLP Neural Network simulated the growth of the study area at an accuracy rate of 77.93% as shown in **Figure 4.23**. The transition variables: slope, DEM, and distance from the main urban centres, roads, schools, Ngubi forest, and Manguo swamp, were interchangeably prioritized within the model, to give two alternate future scenarios of Limuru Central Ward, between 2020 and 2055 at intervals of three years. This epoch was applied to capture the validation Map, to validate the current growth scenario (supervised classification) in the study area as compared to the prediction results of the LCM.

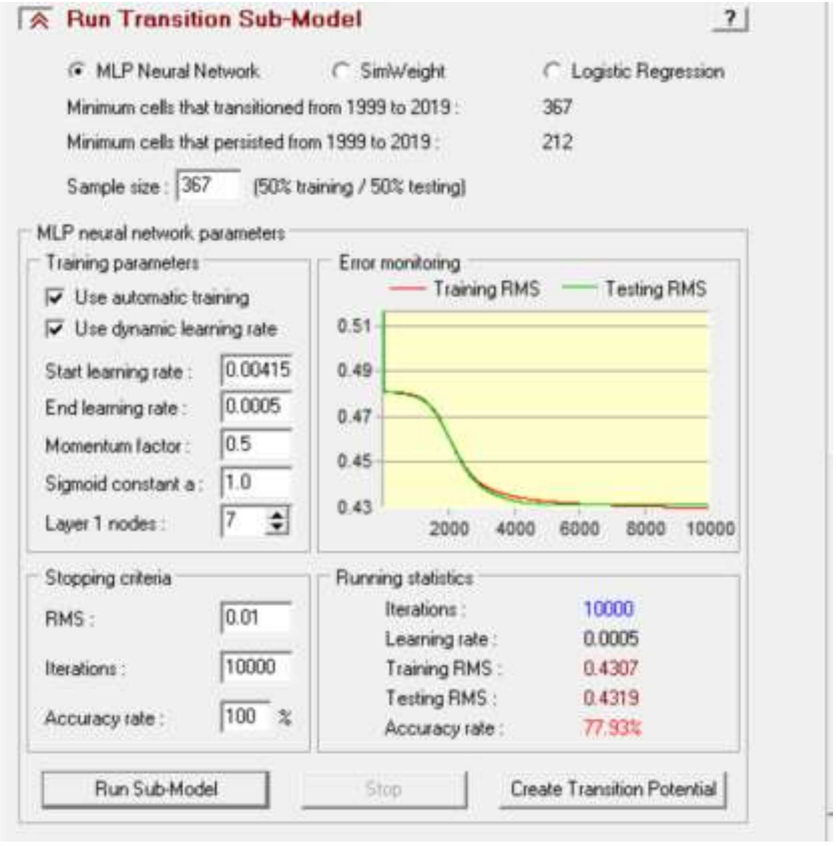
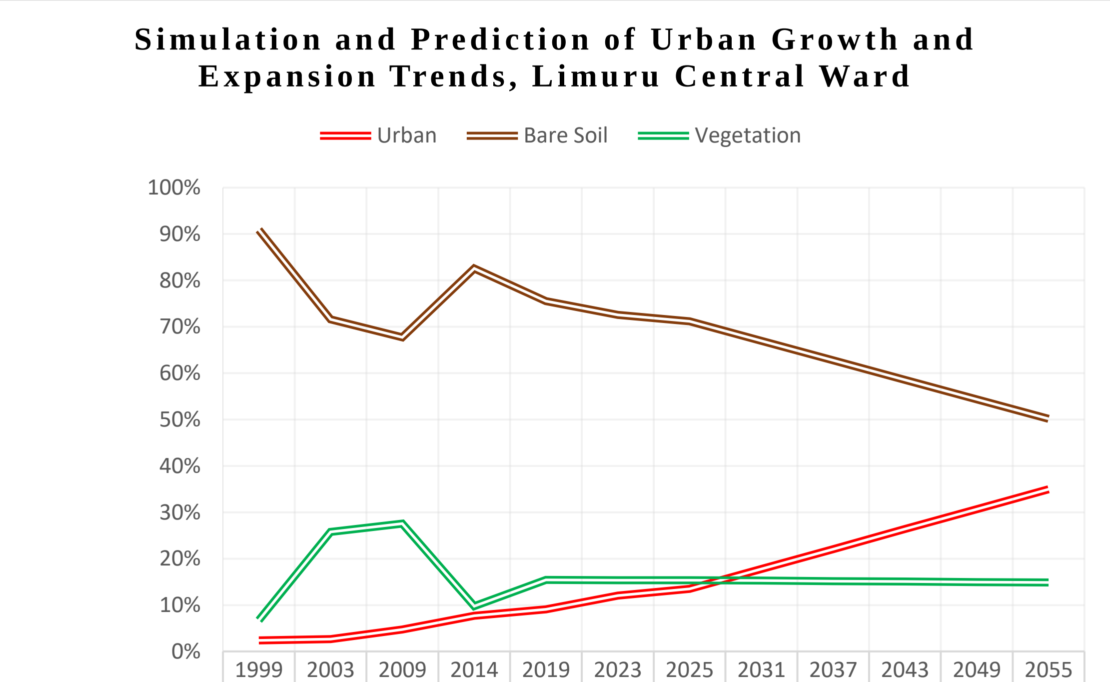


Figure 4.23 Transition Sub-Model (MLP Neural Network) _LCM

4.6.2 Gains and Losses by Category

Figure 4.24 shows the land use changes from 2020 to 2055. At a glance, the rapidly changing land uses are summarized as; Urban - (positive change), Vegetation (positive, negative and no change) and Bare Soil (negative, positive and negative changes). As seen in the graph below, the nature of growth between 2020 and 2055 is characterized with the following.

- Built up areas may have the greatest gains while the vegetation, the least losses per area.
- Built up areas has the greatest net change while bare soil has the least net changes.
- Bare soil contributes to the greatest net change in the Built-up areas while vegetation contributes to the least net changes in the built-up area.



	1999	2003	2009	2014	2019	2023	2025	2031	2037	2043	2049	2055
Urban	2%	3%	5%	8%	9%	12%	13%	18%	22%	26%	31%	35%
Bare Soil	91%	72%	68%	83%	75%	73%	71%	67%	63%	59%	54%	50%
Vegetation	7%	26%	28%	10%	15%	15%	15%	15%	15%	15%	15%	15%

Figure 4.24 Simulation and Prediction of Urban Growth and Expansion Trends

After re-visiting the site and surrounding environs, some of the contribution to net changes in the study area may be attributed to the following:

- The development of High-Income Settlements, such as the Tilisi Mixed Use Master Plan right outside the South-Eastern border, hence allowing the middle income and low income to settle within the study area, where land is more affordable.
- Presence of multi-storey developments in the Limuru CBD and along the Main roads, which promote multipurpose use of buildings (commercial on the ground floor and residential on the upper floors). This contributes to transport oriented development along the main transport routes.
- In reference to **Appendix V,** Zoning of land by the Kiambu county as development control mechanism, has allowed residential use in most land parcels within Limuru Central Ward
- Existence of protected areas such the tea zones adjacent to the study area, have promoted urban growth towards other bordering areas and also within the study area.

4.6.3 Model Validation

Model Validation was done to show how the result of the predicted map compares to the classified LULC 2023 map. **Figure 4.25** shows the processed Landsat 8 image of the study area in 2023 before the image was classified. **Figure 4.26 (a)** shows the classified Landsat 8 image for the study area in 2023, while **Figure 4.26 (b)** shows the predicted LULC map generated by the LCM model, for the Limuru Central Ward in 2023.

The study maintained three main classes, to give more accurate results in the study area. The urban area is more pronounced in the predicted map because the map has captured roads as part of the urban development. Hence one can see the area under urban development represented as vertical and horizontal lines in the predicted map. The model maintained its accuracy and has shown that the prediction technique used was a suitable choice for simulation and prediction of the LULC changes, not only for the study area, but other study areas in future as well.

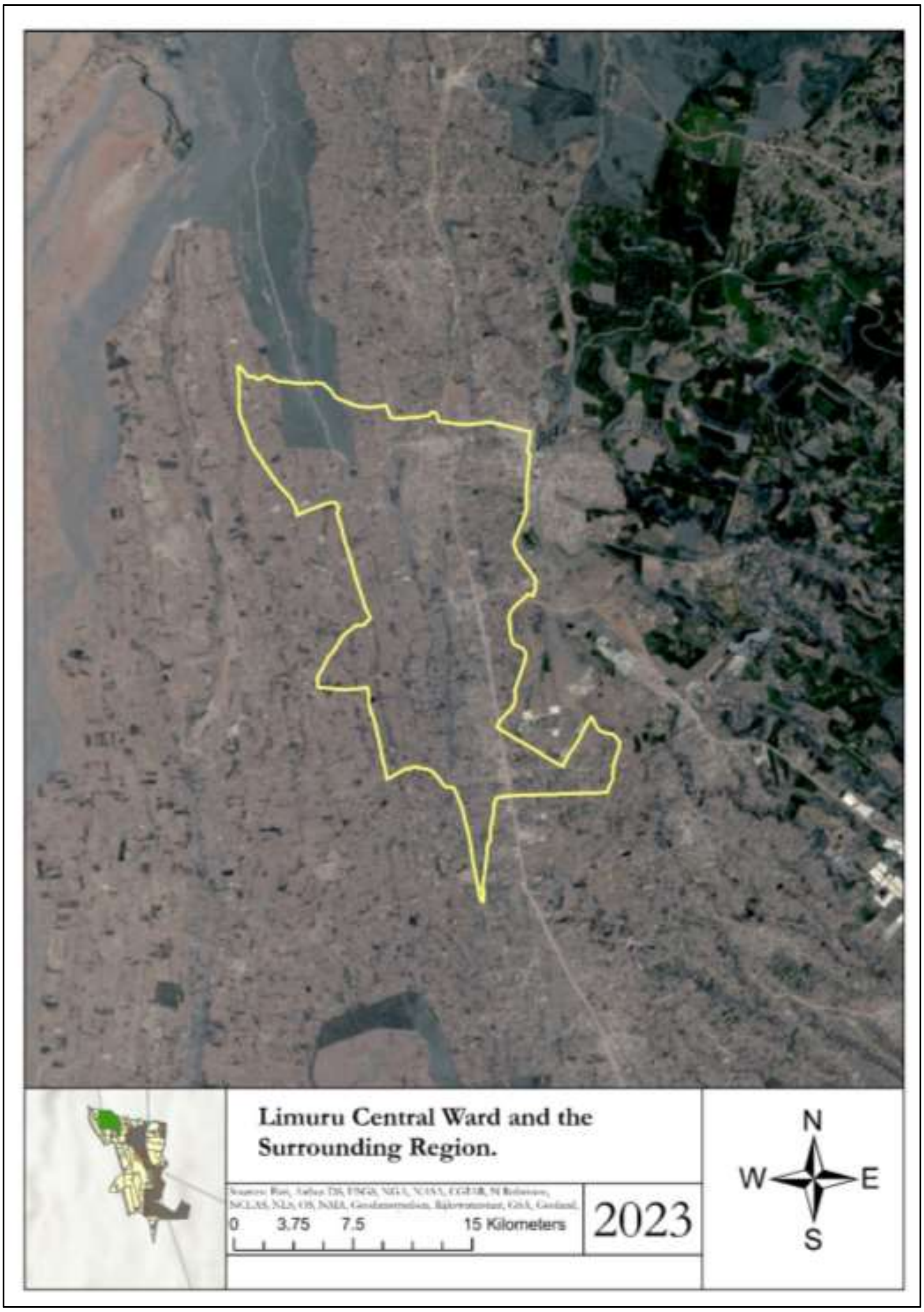


Figure 4.25 Landsat 8 Satellite Image of Limuru Central Ward in 2023

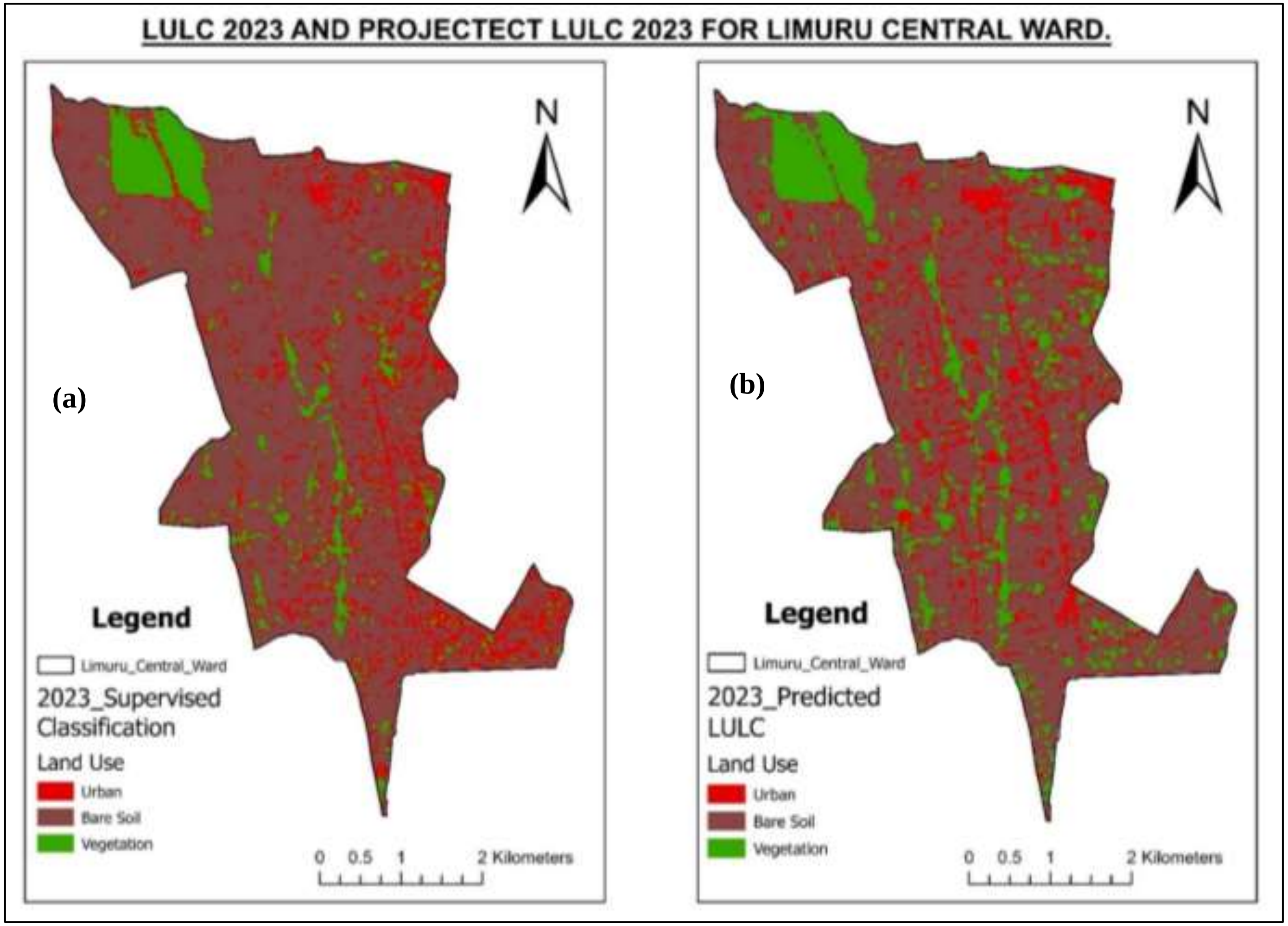


Figure 4.26 LULC 2023 and Projected LULC 2023 (Simulation 1)

4.7 Analysis of Suitable Land for Urban Development

This section has expounded the discussion on the two simulated scenarios of the study area between 2020 and 2055.

4.7.1 Future Urbanization Trends of Limuru Central Ward (2020 – 2055)

There is an increase of urban development throughout the world, as a response to increased rural urban migration and expansion of sub-urban areas. In the case of Kenya, the urbanization rate in Nairobi City County, unlike in the study area, differs from any other urban area in Kenya. The study done by (Mundia & Aniya, 2007), shows that majority of the land in Nairobi was expected to be urbanized in future, hence indicating more urban development in Nairobi, the capital city of Kenya.

In this study, it is important to note that both Simulation 1 and 2 have indicated similar percentages of Urban development throughout the prediction period, while showing different percentages of bare soil and vegetation. According to the maps generated in the LCM model, **Figure 4.27** and **Figure 4.28,** the causes and effects of urban growth and expansion in Limuru Central Ward, can be summarized as follows,

Factors affecting Urbanization.

- Slope and Elevation
- Existing Density of development (clustered urban development)
- Distance to roads and urban centres (existing growth hotspots), bare soil (availability for land to expand), forest and water bodies or swamp (restricted areas of development), schools (existing public and private facilities)

Impacts of Urbanization

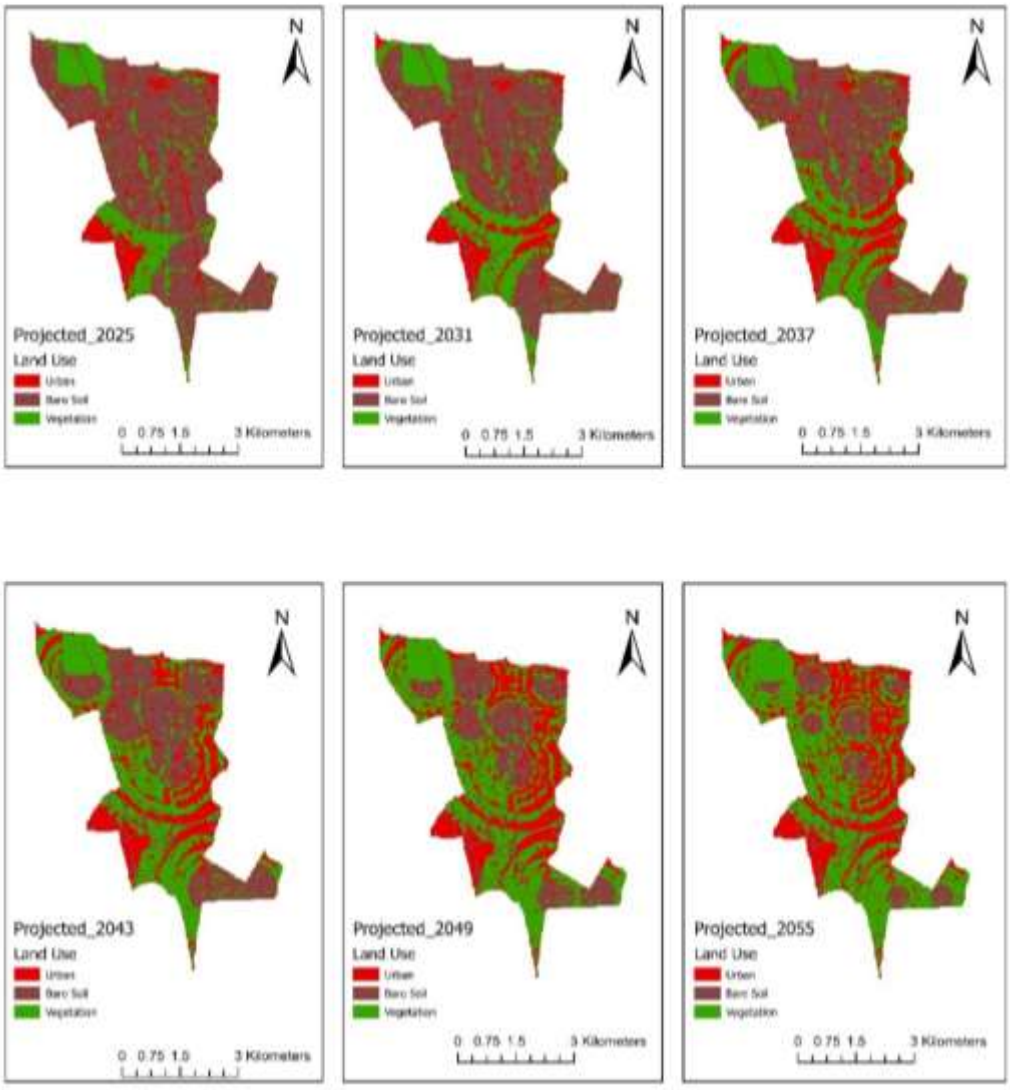
- Rapid land use changes to accommodate more built-up spaces.
- Sporadically growth of clustered development or dense built-up areas.
- Need to expand infrastructure in newly developed areas.
- Significant decrease in land occupied by bare soil and vegetation.

Scale: 1:100,000

	2025	2031	2037	2043	2049	2055
Urban	13%	18%	22%	26%	31%	35%
Bare Soil	71%	67%	63%	59%	54%	50%
Vegetation	15%	15%	15%	15%	15%	15%
	100%	100%	100%	100%	100%	100%

Figure 4.27 Limuru Central Ward LULC Prediction (2025 - 2055) Simulation 1

LIMURU CENTRAL WARD LULC PREDICTION (2025-2055) - SIMULATION 2



	2025	2031	2037	2043	2049	2055
Urban	13%	18%	22%	26%	31%	35%
Bare Soil	65%	55%	45%	35%	25%	15%
Vegetation	21%	27%	33%	39%	45%	50%
	100%	100%	100%	100%	100%	100%

Figure 4.28 Limuru Central Ward LULC Prediction (2025 - 2055) Simulation 2

4.7.2 Preferred Future Scenario

The more diverse a simulation is, the more flexible it is to change and grow to accommodate people's future needs. In reference to this study, the preferred future scenario of the Limuru Central Ward is one that will be sustainable and one that will allow for seamless urban planning while encouraging interconnectivity of different clusters of development.

Table 4.3 below, compares how spatial features in the study area's urban simulations, seen in **Figure 4.29** and **Figure 4.30**, spatially resemble to the above-mentioned ecological models. The ecological models of the major cities in the world are represented spatially as the outcome of how different land uses interchangeably grow over time. Some of the known urban growth theories, which are spatially represented as urban growth models, include the; Concentric Zone Theory (coined by Ernst Burges in 1925), Sector Theory (coined by Homer Hoyt in 1939), Multi Nuclei Theory (coined by Chauncy Harris and Edward Ulman in 1945), Green Urbanism (coined by Steffen Lehmann in 1990), (Majeed & Abaas, 2023) and Transport Oriented Development (TOD) (emerged in the late 1990's) (Yen et al., 2023).

Table 4.3 Comparing Future LCW Scenarios to selected Ecological Models

Model	Spatial Representation	Simulation 1	Simulation 2
Concentric Zone	There is only one CBD/ Built up area/ Main zone of activities (cluster of urban development), located at the center of the region.	Yes	
	The main transport network forms concentric rings radiating from the center of the region.		Yes
	Secondary transport network converges at the main cluster of development in the region.	Yes	
	Density of development decreases as one moves away from the main cluster of urban development.	Yes	Yes
Sector	Built up areas are observed along major transport networks.	Yes	Yes

Model	Spatial Representation	Simulation 1	Simulation 2
	One main cluster of urban development, is located at the center.	Yes	
	Wedge-like urban development occurs along the transport network and radiates away from the main built-up area.	Yes	
	Existence of primary and secondary roads spread out in the region.	Yes	Yes
	Density of development decreases as one moves away from the main cluster of urban development.	Yes	Yes
Multi Nuclei	Existence of one main built up area (cluster of urban development) and other smaller multiple built up areas in the region	Yes	Yes
	Density of development decreases as one moves away from the clusters of urban development, towards the periphery.	Yes	Yes
	Existence of primary and secondary roads spread out in the region.	Yes	Yes
	Suburbanization – development of other clusters of urban development away from the main cluster of urban development (CBD)	Yes	Yes
	Existence of public facilities (like schools)	Yes	Yes
TOD	Compact urban development	Yes	
	Decrease in development as one moves away from the clustered development and into the region	Yes	Yes
	Presence of Green/open spaces or vegetation	Yes	Yes
	Dense development, or clustered urban development near public transit stations (such as, bus stops and railway stations)		
	Increased transport network connectivity in and around clustered settlements.	Yes	Yes
Preferred Scenario:		**17**	**13**

Sources: (Tredinnick, 2014), (Majeed & Abaas, 2023), and (Yen et al., 2023)

Simulation 1 scores higher than Simulation 2. The conclusion is that Simulation 1, seen in **Figure 4.29**, shows more flexibility to accommodate several outcomes of urban development as compared to **Figure 4.30.**

Based on the foregoing discussions, especially the maps generated, and facts collated and discussed, the preferred future scenario, **Simulation 1**, allows the future urban development of Limuru Central Ward,

- To accommodate a multitude of people's spatial needs,
- To explore better urban planning and promote urban development along already established transport routes,
- To promote sustainable urban development near densely vegetated areas such as Ngubi Forest to the Northeastern side of the study area; and most importantly,
- To gradually expand urban infrastructure in future urban hotspots along the urban periphery, without putting pressure on arable or bare land in Limuru Central Ward.

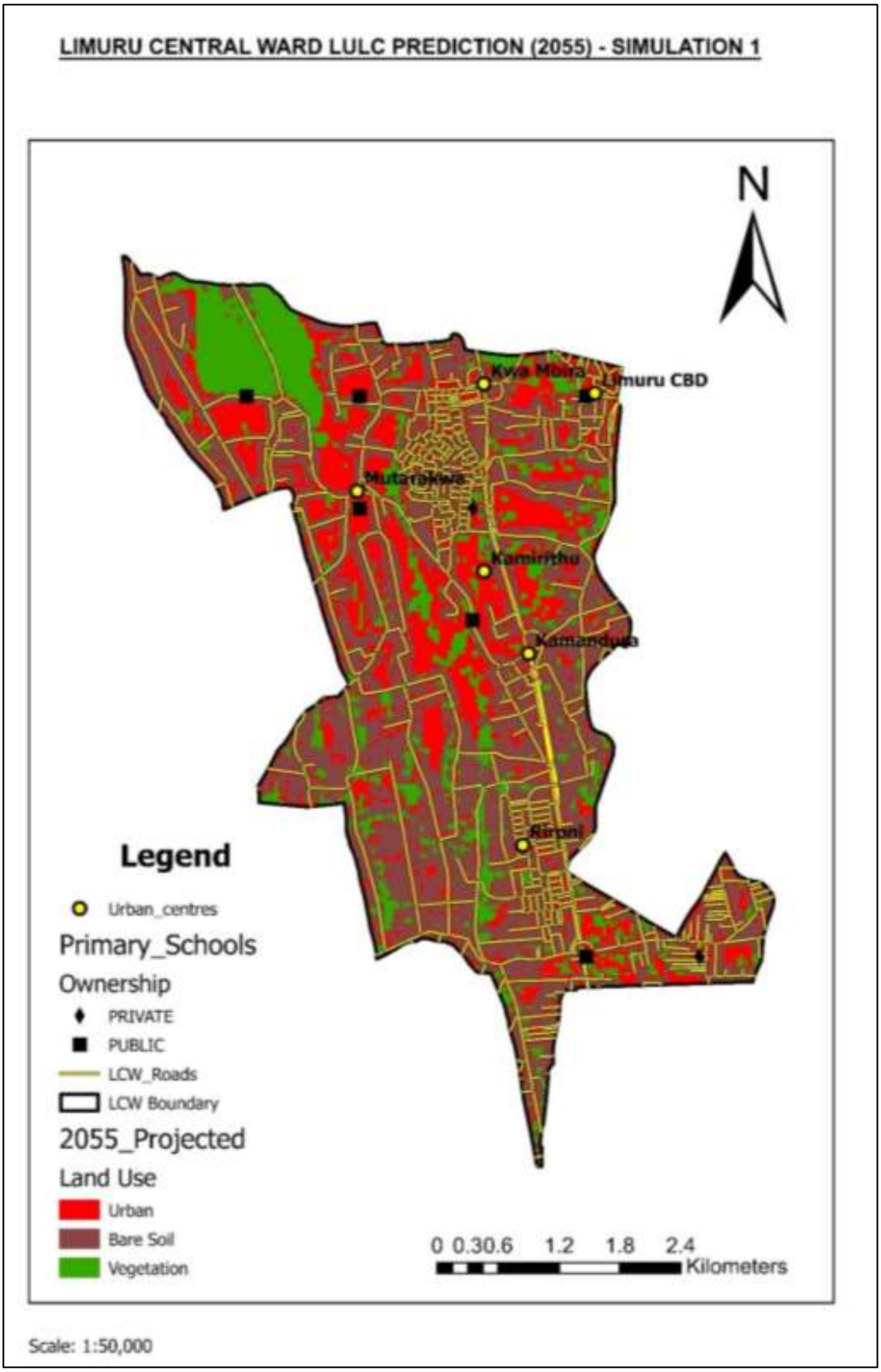


Figure 4.29 Limuru Central Ward LULC Prediction (2055) - Simulation 1

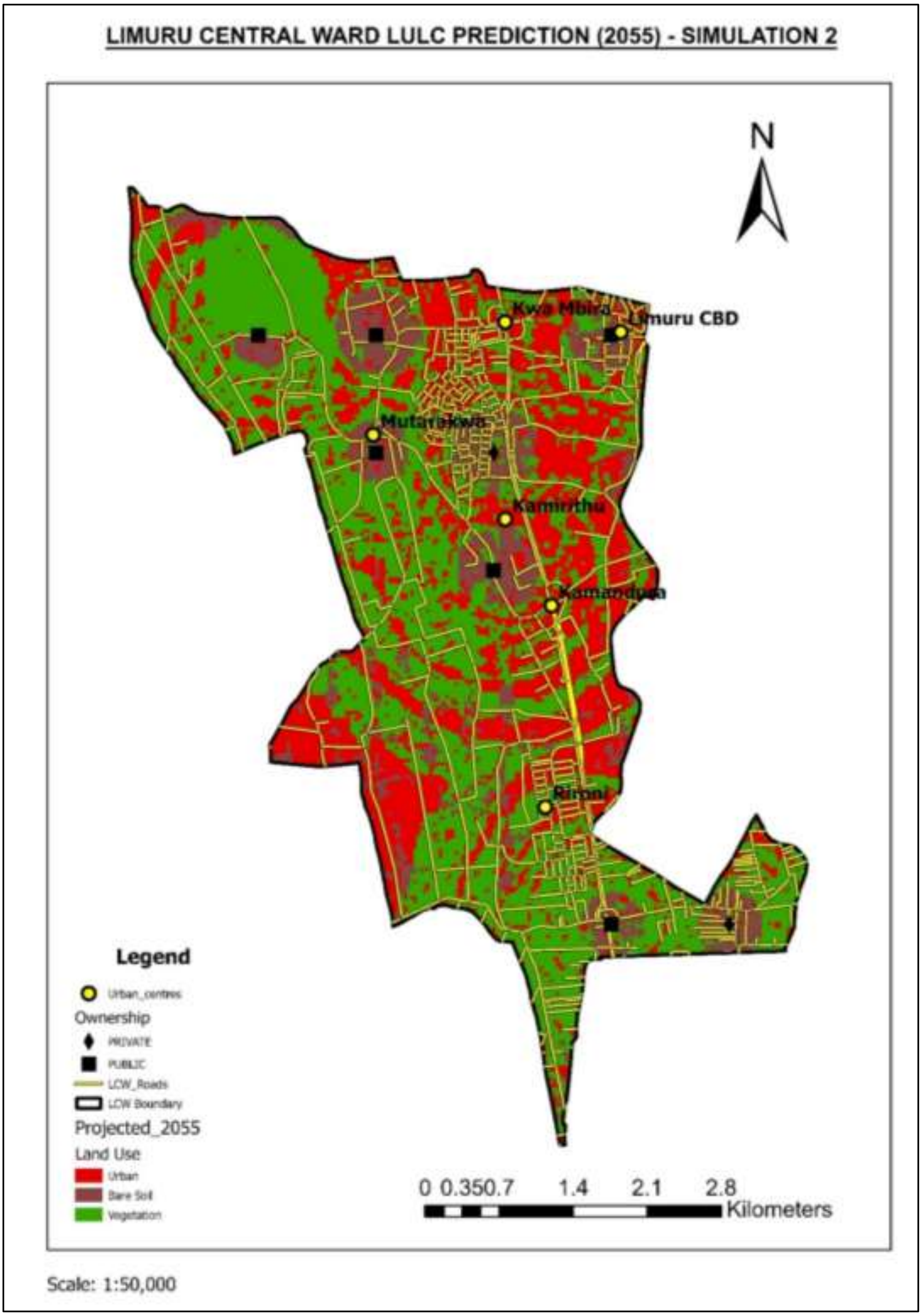


Figure 4.30 Limuru Central Ward LULC Prediction (2055) - Simulation 2

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary and Conclusions

This chapter has interpreted the research findings in relation to the objectives of the study and has discussed how the results have been used to draw conclusions and recommendations for this study, which serve as a basis for future research. Urban growth management strategies can be deduced from this chapter as well as insights as to how a study can work around limiting factors to give best results.

Limuru Central Ward, one of the most vibrant wards in Limuru Sub County, is located in Kiambu County. Its proximity to Nairobi and its cool climate, ensures its residents are not adversely affected by traffic congestion and excessive air pollution experienced in Nairobi. The main objectives of this study entailed the exploration of the potential use of GIS and Remote Sensing technologies or integrated technologies, in simulating growth trends of rapidly growing urban areas in Kenya. This study has shown that it is possible for urbanization to take place in areas away from the main administrative centres. It is for that reason that simulating the future urban trends was necessary to pinpoint the potential areas of growth and urban expansion. Based on the main objective and the study objectives, the study achieved an array of results.

From analyzing the trend analysis between 1999 and 2019 in the study area, it is evident that urbanization has encouraged widespread development of built-up areas further away from the main Limuru town center. With urban development restricted towards environmentally protected areas and farmlands, built up areas have emerged in the periphery, near existing built-up areas and along transport routes. Major roads present in the study area include Kiambu Road (C63), Eldoret - Malaba Road (A104), Ngenia Road, Limuru Road (B3). Rironi's growth is influenced by Limuru Road (B3), Eldoret - Malaba Road (A104), while Gatimu has grown around the Ngecha-Chungu-Mali-Road. Kamirithu and Mutarakwa have developed greatly due to their proximity to two Tertiary Roads, Dagoretti-Karen Road and Kamandura-Maai Mahiu-Narok

Road. However, the Limuru CBD or municipality may not grow further beyond its urban limit, seen as it is surrounded by private land and there is more land available for growth and expansion in the urban periphery.

It is observed that in future, the urban footprint is likely to increase near existing urban areas, along transport networks and near existing built-up areas such as schools. The urban footprint may likely adopt a mix of urban growth models – such us the multi nuclei and sector models, however, majority of the urban areas may most likely be located within proximity to the transport network – transport-oriented development. The study area is predicted to have a vibrant economic sector - evidently seen as a result of urban expansion, spanning from the bordering tea farms and existing experimental farms in the Northeast, to the existing built-up areas within the region and presence of a growing transport network.

To summarize the study can conclude that

- Development of major administrative centres, like the Limuru CBD, came first then the surrounding urban development across regions, with crisscrossed - interconnected transport patterns, came later.
- A region, such as the Limuru Central Ward, has a higher chance of growth, if it exhibits multiple urban spatial structures altogether as opposed to adopting one.
- Application of GIS and Remote sensing technologies in observing past and present urban growth trends will pave the way for predicting future urban patterns, which act as a basis of sustainable planning especially in developing countries.
- Predicted urban development in the study area will encourage growth of urban areas within the region. In future, its location may avail land as a resource for sustainable urban expansion, if properly planned at present.
- Predicting, monitoring and assessing urban growth trends will introduce more practical ways of spatial planning and policy development in Limuru and other emerging urban areas.

5.2 Recommendations

Arising from the results and findings the following recommendations are drawn. The following recommendations may serve to improve the process of predicting and simulating urban growth trends if properly harnessed.

1) Policy Changes

The current urban planning process in Kenya has not fully utilized the use of GIS and remote sensing technologies and regular planning intervals of some spatial plans. This has in turn led to development of urban plans which are not frequently renewed to accommodate the needs of the future population. This study recommends the adoption of new policy changes and increases in the potential use and application of geoinformation technologies such as GIS and Remote sensing, to curb the effects of urbanization to a reasonable extent, as a result of poor long-term planning. This will offer solutions to pending spatial problems in any given region, today and in the future.

2) Policy Adherence

Storing data in a geodatabase eases the collection, updating, and editing data, the prediction process and the land use, physical or urban planning process as a whole. The widespread use of geoinformation technologies will assists practitioners to simulate future urban growth trends and plan for future urban areas in a more informed way, to accommodate the needs of several groups of people while still preserving the existing natural resources in the planning areas. Similar to the recommendations of the Kenya National Spatial Plan (2015 – 2045), this study recommends that researchers use spatial data to promote sustainable development. This will contribute to adaptable future planning interventions in small urban centres such as Limuru Central Ward (LCW) and sustainable overall growth of the county or region.

3) Planning and implementation of Small Urban centres

Effective planning of smaller spaces allows one to look at the solutions to solve local problems and eventually build up to solving spatial problems in larger spaces, thus embracing the bottom-up planning procedure, as opposed to the top to bottom method, which rarely yields accurate results. Proper financial budgeting gives the government a better understanding of the financial resources required in future to alleviate future spatial problems.

This study recommends that, with money set aside for development needs, there is a continuous responsibility for the urban and regional planners to come up with better sustainable plans. Planning should be quickly succeeded with implementation, which is the responsibility of the county governments since the functions of the national government were devolved to the county. This allows other practitioners in the built environment to contribute their skills and knowledge to cater for the infrastructure needs and set up locations for potential services and industries, that eventually support the future populations.

4) Data Relevance and Processing Accuracy

To accurately capture how future urban areas may grow, we recommend that Town or Urban planners employ the use of geoinformation technologies to support their findings and prepare feasible strategies, to capture the needs of the people. In order for this to work effectively, GIS data needs to be accurately captured, stored in a geodatabase, processed, manipulated, and updated. This in turn assists the users to see the changes in the structure of data, administrative boundaries and the gaps needed to perfect the existing data.

Mishandling of data leads to inaccurate findings and hence inaccurate results. The currency of the data needs to be checked, to ensure that any spatial changes have been captured at present, for future projections and accurate prediction and simulation. It is recommended that, conventional urban planning processes and procedures should be modified to allow extensive software use and a multi-disciplinary approach towards solving urbanization, within local contexts.

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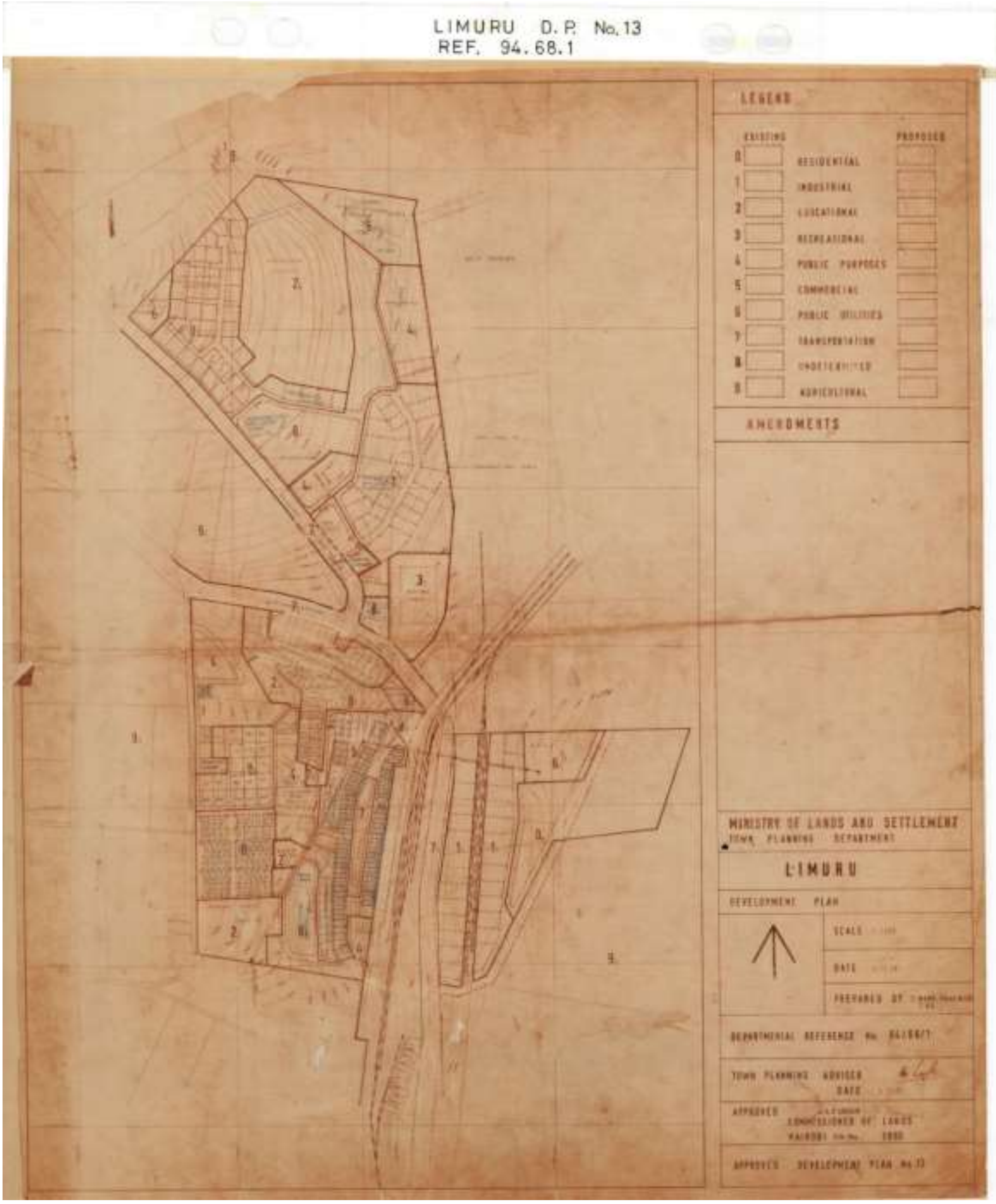
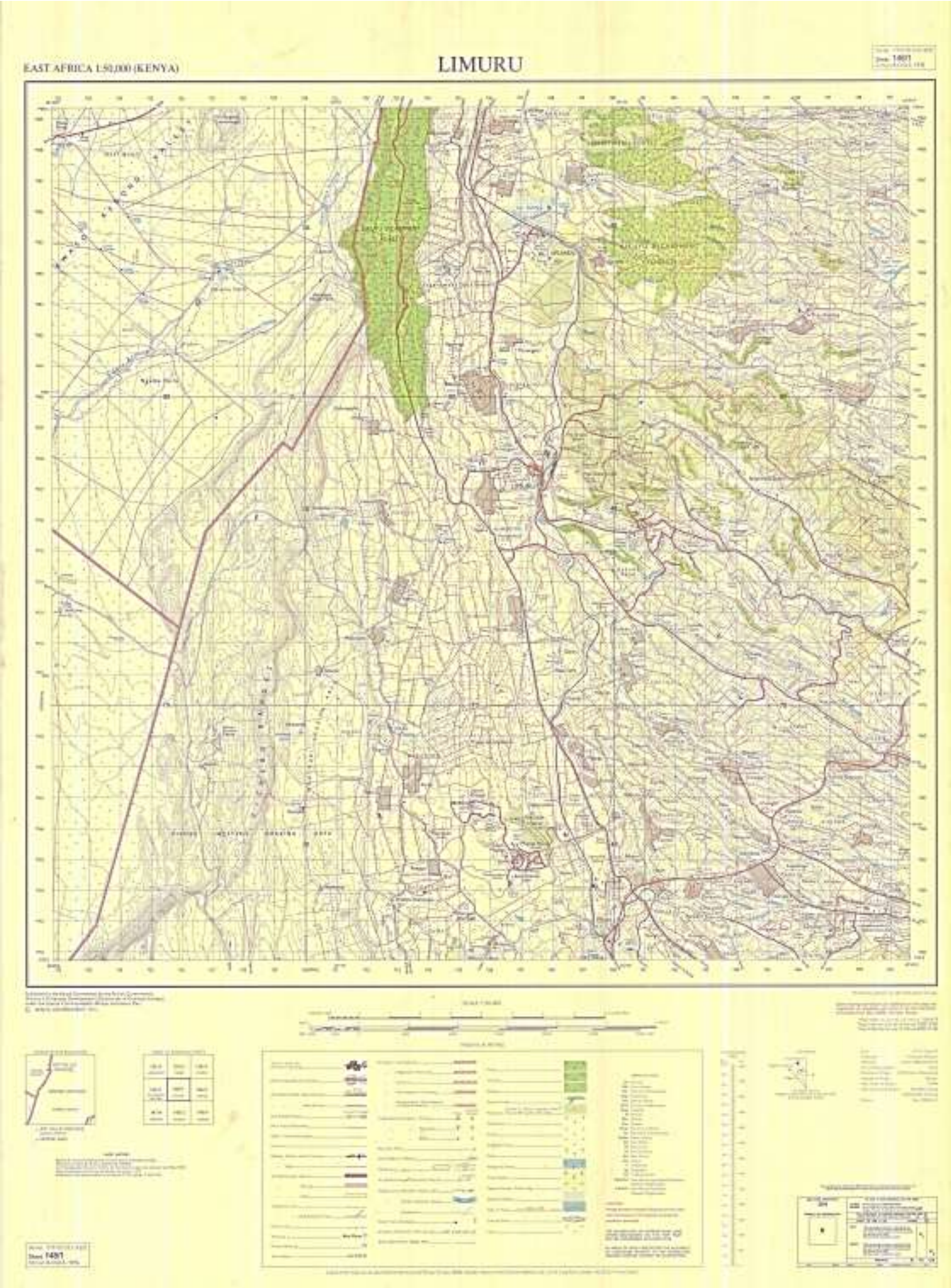
APPENDICES

Appendix I: Limuru Town Development Plan No. 13 of 1969



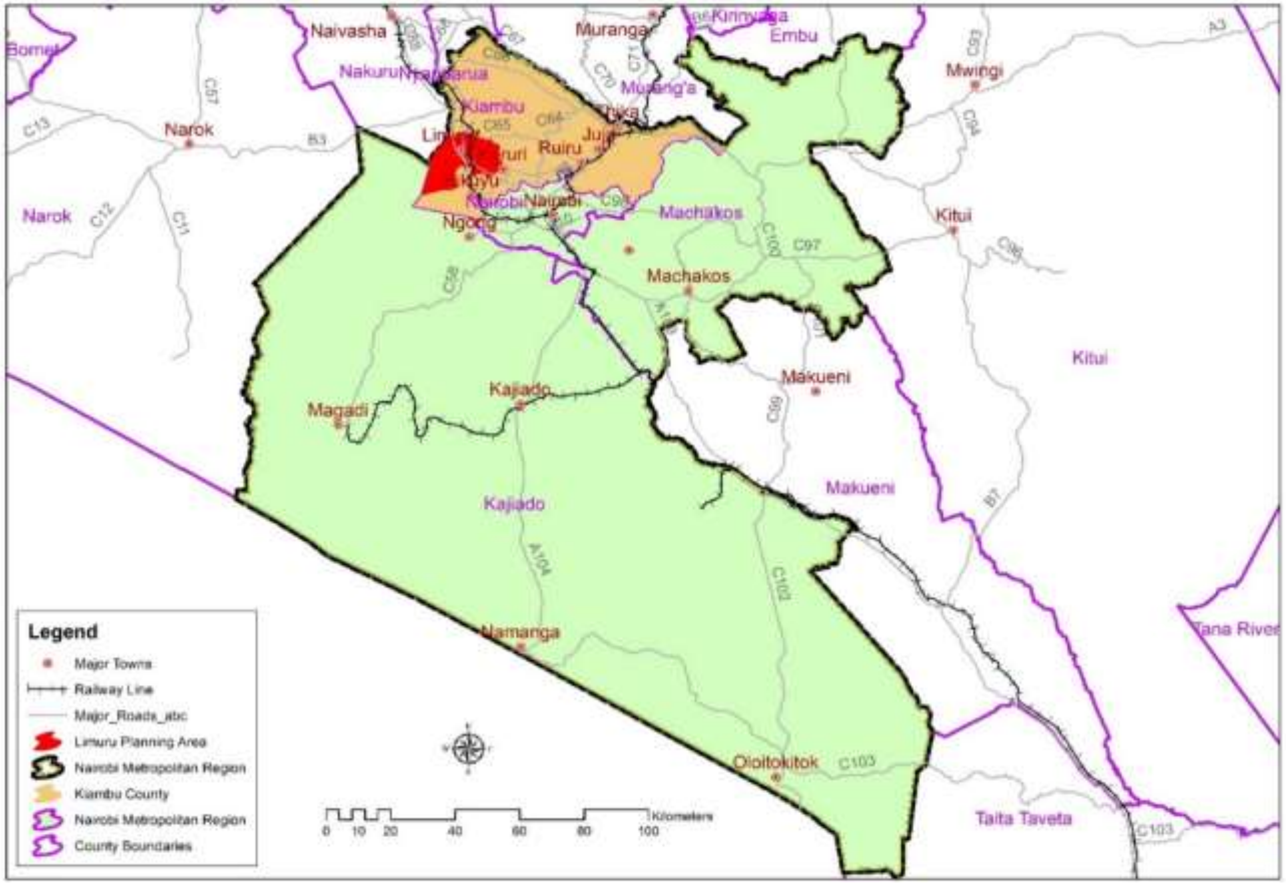
Source: Ministry of Lands Records, Kenya

Appendix II: Limuru Toposheet 148/1, Kiambu County, Kenya



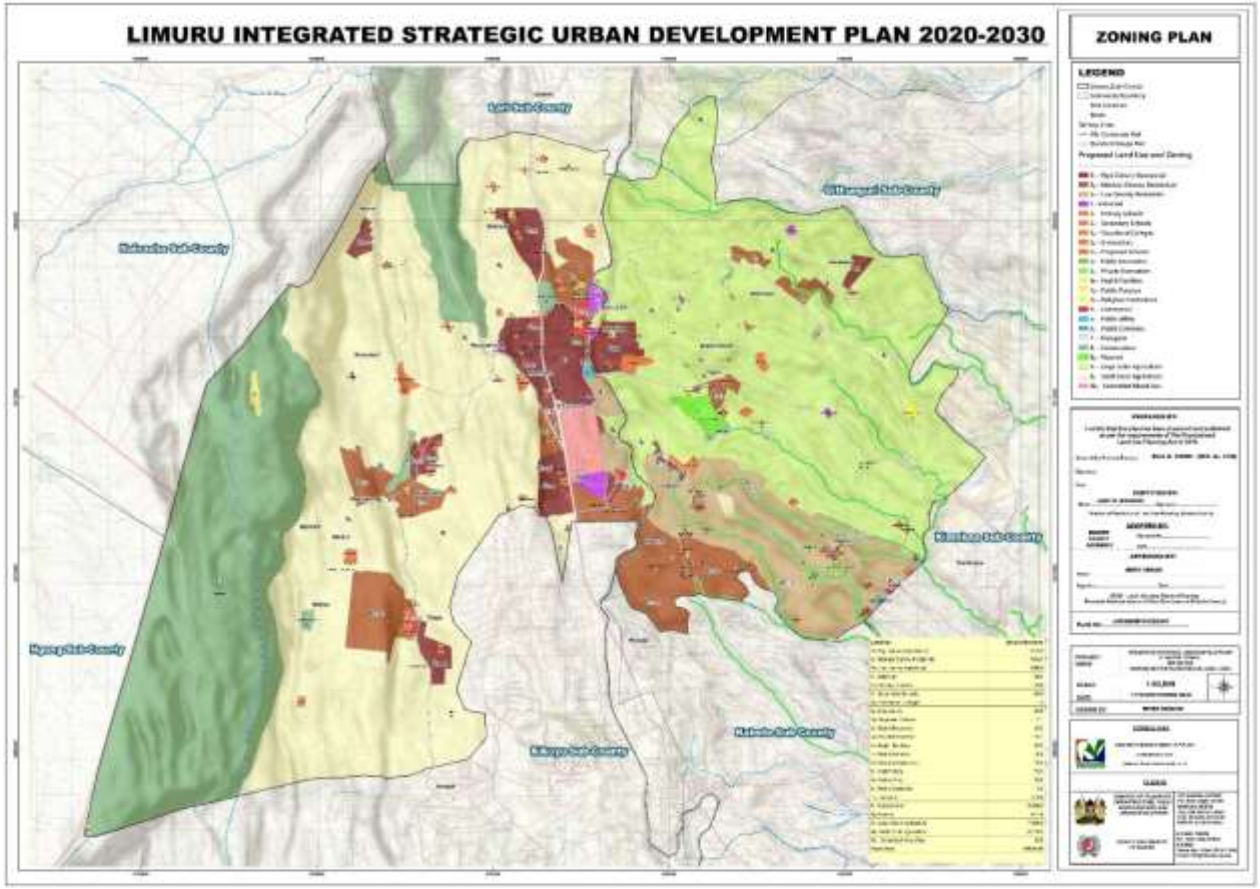
Source: (Survey of Kenya)

Appendix III: Limuru Context within the Nairobi Metropolitan Region



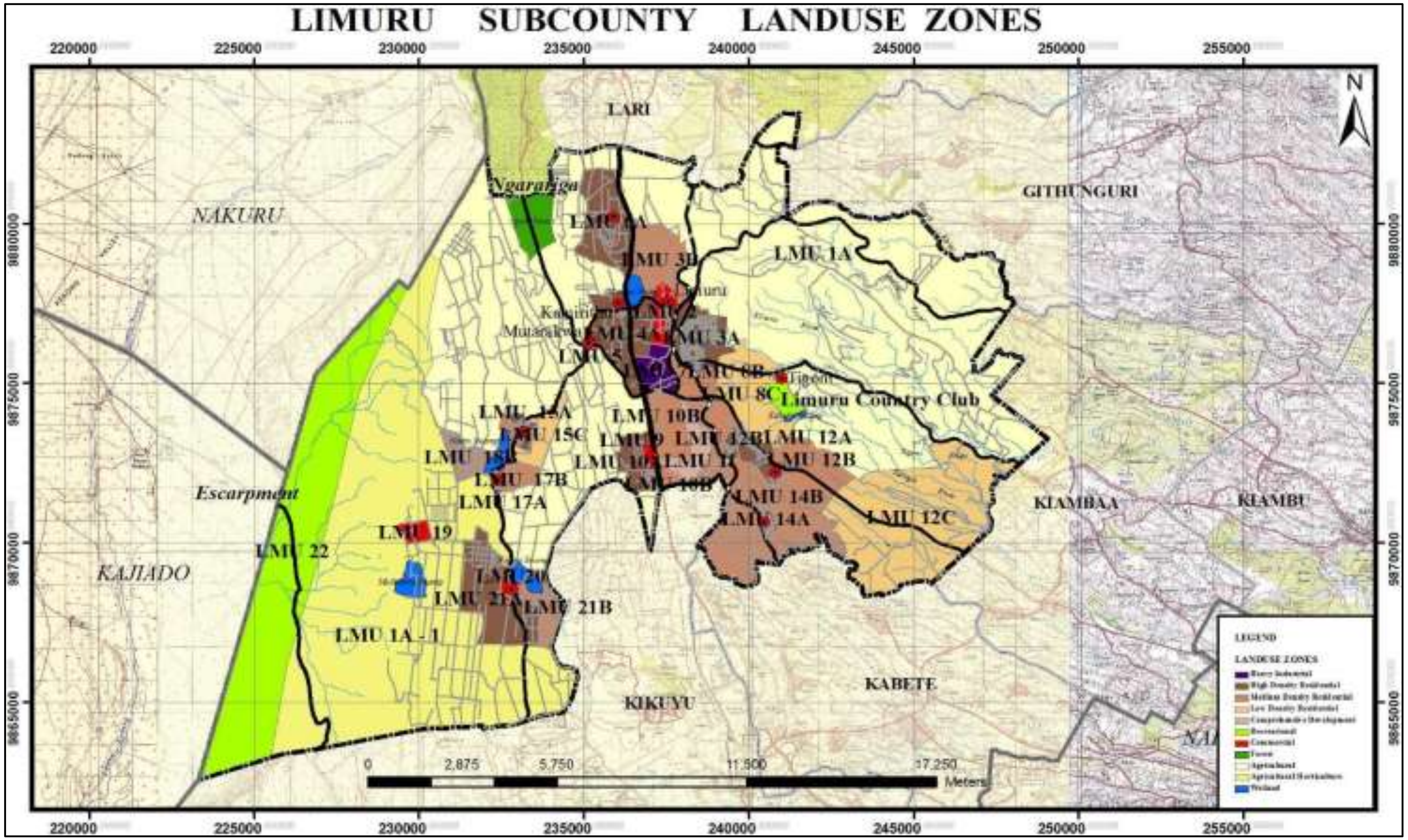
Source: Limuru Integrated Strategic Urban Development Plan (Limuru ISUDP)

Appendix IV: Limuru Integrated Strategic Urban Development Plan 2020 - 2030



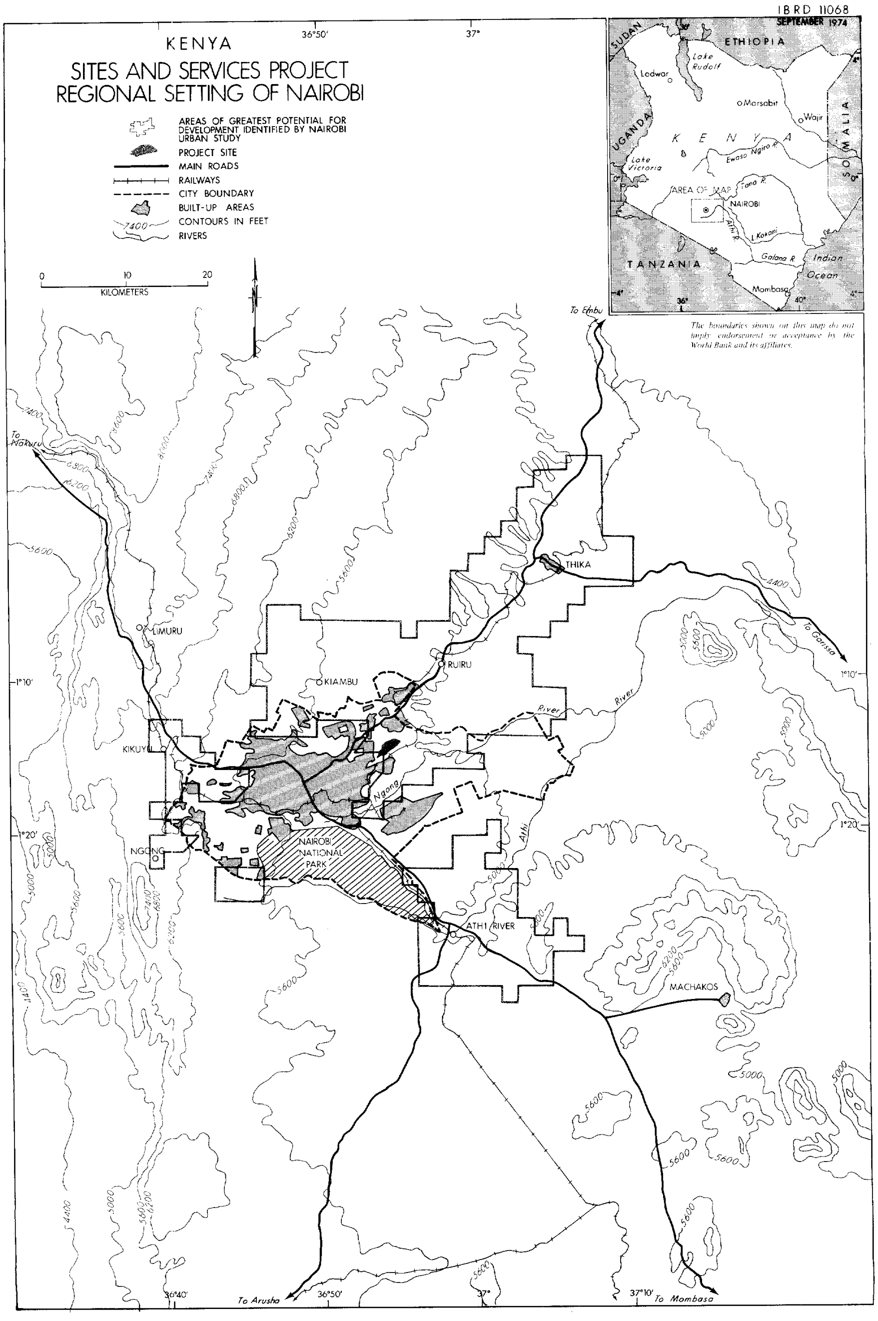
Source: Limuru Integrated Strategic Urban Development Plan (Limuru ISUDP)

Appendix V: Limuru Sub County Land Use Zones



Source: Kiambu County Land Use Zones (Kiambu ISUDP)

Appendix VI: Areas of Greatest Potential for Development by Nairobi Urban Study (Nairobi and its Environs – Nairobi Metropolitan Region)



Source: (Repo1t & Vitian, 1975)