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Analysis of the correlation between Land Use Land Cover Changes and Urban Heat Island Effect using Geospatial Techniques; Case Study Kiambaa Sub-County, Kiambu County

BY

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Declaration

I, Johnson Kamau Njeri, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a project in any other university.

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Name of student	Signature	Date

This project has been submitted for review with my approval as university supervisor.

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Name of supervisor	Signature	Date

Dedication

This research is dedicated to my family for their love, motivation and support.

Acknowledgement

I thank God for granting me this opportunity.

My profound thank to my family for their love, support and motivation throughout my life.

I would like to express my appreciation to my supervisor, Dr. Faith Karanja, for her support, guidance and valuable advice, ideas and recommendations that were instrumental in making this project a success. Special thanks to my lecturers as well as my classmates for their remarkable assistance throughout the course of the research.

Abstract

Most studies on the Urban Heat Island (UHI) phenomenon in Nairobi have proved its presence, however, little is documented about its effect in the urban fringe, areas often characterised by rapid urbanization. Amongst them is Kiambaa sub-county, Kiambu County, which has recorded a significant land use change over the last 25 years. In this light, this study was aimed at analysing the correlation between Urban Heat Island (UHI) effect and Land Use Land Cover (LULC) changes in the sub-county from 1995 to 2018 by use of Landsat imagery. It was achieved by converting the Landsat images to their spectral radiance and calculating the at-satellite temperature as well as the land surface emissivity thereafter. The Land Surface Temperatures (LST), rate of LULC change and Normalised Difference Vegetation Index (NDVI) were then estimated and the correlation between the LULC changes and UHI effect analysed. The study area was classified into three classes namely; agricultural land, built-up area and water bodies. The results indicated reduction of the proportion of vegetation cover and shrinking water bodies from 1995 and 2018 as well as an increase in the built-up area over the said time period. The highest (42.81℃) and lowest (19.57℃) LST was estimated in year 2000 and 1995 respectively. The study revealed that these temperatures had increased over time and that the change was inversely proportional to the loss of vegetation cover. Furthermore, the UHI effect increased from 12.62℃ to 21.02℃ from 1995 to 2000 and later reduced to 19.46℃ and 16.38℃ in 2015 and 2018 respectively. The correlation analysis between the variables indicated two different scenarios that occurred between 1995 to 2000 and 2000 to 2018. The first scenario indicated a negative correlation of -1 between the LULC changes (agricultural land and built-up areas) and UHI in the time period 1995 to 2000. In the second time period, the results revealed a positive correlation of 0.946 between the UHI and agricultural land and a negative correlation of -0.947 between UHI and built-up area. It can then be concluded that the rapid urbanization being experienced in Kiambaa sub-county as well as other areas of the larger Nairobi urban fringe has resulted into increase of the surface temperatures and resultant reduction of the UHI effect. It is therefore recommended that proper urban planning policies be formulated and implemented to counter the rapid urban sprawl as well as reduce the LST. This study can be extended to include other areas in the Nairobi urban fringe such as Ruai and Ongata Rongai which are also experiencing a high rate of urbanization and the methodology can also be used in UHI studies in other urban areas in the country.

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Abbreviations and Acronyms

°C	Degree Celsius
CIA	Central Intelligence Agency
EPA	Environmental Protection Agency
ETM+	Enhanced Thematic Mapper Plus
FCC	False Colour Composite
GHO	Global Health Observatory
GoK	Government of Kenya
Ha	Hectares
KWCo	Karuri Water Company
LULC	Land Use and Land Cover
LST	Land Surface Temperature
LSE	Land Surface Emissivity
NDVI	Normalized Difference Vegetation Index
OLI	Operational Land Imager
SDGs	Sustainable Development Goals
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
UHI	Urban Heat Island
UN	United Nations
UN DESA	United Nations Department for Economic and Social Affairs
USGS	United States Geological Survey
WGS	World Geodetic System
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

1.1 Background

Through urbanisation, cities have extended their spatial coverage over the years. Karuga (1993) observes that this growth is due to expansion of the industrial, economic and social sectors as well as better utilisation of land resources and rural-urban migration. However, the growth results in land use and land cover (LULC) changes through clearing of vegetation in place for more productive and lucrative real estate investments. These changes, if well analysed, can help natural resource managers make informed decisions for the continued preservation and conservation of our ecosystems (Kiio, 2015).

The Urban Heat Islands (UHI) refers to the rise of temperature in urbanised or built-up areas as compared to the surrounding rural areas. Voogt (2004) indicates that the temperature difference between the two regions can be up to 12°C. EPA (2008) supports this view by observing that the annual mean temperatures for cities with a population of approximately 1 million or more are 1-3℃ warmer than the peri-urban area and that the daily temperature difference can be as high as 12℃. It is also worth noting that the effect also differ amongst the urban land uses with the industrial areas recording a higher temperature when compared to low density residential areas. Alhawiti et al. (2016) established a strong correlation between selected land uses and the thermal spatial patterns of a city. Their study indicated that the UHI effect in an urban area was represented by a concentrically shaped pattern with the temperatures gradually increasing inwards towards the central business district.

Nairobi's population has been growing at a steady rate of 4 per cent annually and it is projected that there will be approximately 7 million people living in the city by 2030. Since land is finite and scarce as a resource and due to the increasing demand for residential houses, developers have in the past two decades turned their investments to the virgin lands in the urban fringe i.e. Ruaka, Ruai and Ongata Rongai (Mwangi, 2008). This growth has exerted pressure on the existing land resources resulting to the change of agricultural land to multiple dwelling residential apartments and the apparent transformation of their landscapes into "concrete jungles". There is therefore a definite need to establish if this change affects their surface heat signatures. Kiambaa sub-county was chosen to be the case study for this research due to its rapid growth over the past few years with particular reference to Ruaka and Karuri areas. It is in fact among the most urbanised sub-county within the urban fringe.

1.2 Problem Statement

According to Global Health Observatory (GHO) data (n.d), the world's annual urban growth rate is approximately 1.84 per cent and more than 60 per cent of the world's population will live in cities by year 2030. The increasing urban population has exerted pressure on the surrounding hinterlands and as a result, developers are now replacing agricultural lands with high density residential developments.

Various researches have been done to investigate the UHI effect within the spatial extent of Nairobi, Makokha et al. (2010) and Odongo (2016). However, it was discovered that there was limited research or spatial-temporal data to correctly depict the status of the Land Surface Temperature (LST) as well as the resultant UHI in the peri-urban areas. Furthermore, the exiting data provided air temperature values which were acquired by use of conventional techniques and whose results were not well distributed and could not be easily intra or extrapolated. The gap will be filled by this research with its results establishing the relationship between UHI effect and LULC change in the urban fringe.

Kiambaa sub-county with particular reference to Ruaka, at the boundary of Kiambu and Nairobi counties, is deemed to be among the fastest growing areas in the country (Cytonn, 2016) with a high housing uptake of approximately 93 per cent. The area was therefore selected as the research study area.

1.3 Objectives

The overall objective of this study was to analyse the correlation between UHI effect and LULC changes in Kiambaa sub-county, Kiambu County, from 1995 to 2018 using geospatial techniques.

The specific objectives were namely to:

i. Map the LULC changes of Kiambaa sub-county between 1995 and 2018
ii. Estimate the Land Surface Temperatures of the study area from Landsat images
iii. Determine the UHI intensity of the study area
iv. Analyse the correlation between UHI effect and LULC change

1.4 Justification for the Study

The study is significant because of the following reasons:

a. Enhancing decision making: The results from this study, particularly on the current state of the LST and UHI will allow professionals in the built environment, for example architects and engineers, make informed decisions as well as designs that reduce the impact of UHI.
b. Enhancing better policy formulation: Physical planners in the county, bearing in mind the rate of land use and temperature change will be able to formulate better preventive policies geared at reducing UHI effect in the upcoming urban areas.

   The study can easily be replicated across all areas undergoing rapid urbanisation. Its findings can form basis for better planning, zoning as well as sensitizing the general public and professionals on the temperature changes.

1.5 Scope of work

This research explores the correlation between land use land cover change and urban heat effect in Kiambaa sub-county by use of Landsat data. In this regard, analysis was done to calculate the LST as well as the rate of urbanisation or land use change. Due to time limitations, the study neither involved making projections nor suggesting preventive measures on how to mitigate the negative effects of the UHI.

1.6 Assumptions

For the purpose of this study, it was assumed that:

i. The temperature values obtained from the estimated Land Surface Temperatures of the study area are similar to those of canopy layer air temperature
ii. The UHI effect discussed in this study means the Surface Urban Heat Island effect as described by Khalid (2014).

1.7 Organization of the report

This study is organized into five chapters, namely; Introduction; Literature review; Materials and methodology; Results and discussions; and Conclusions and recommendations.

The first chapter provides a background of the research topic, problem statement, objectives and scope of work and justification of the study. The primary and secondary data have been reviewed, in the second chapter, to discuss the concept of UHI as well as its determinants, impacts and measures that can be implemented to reduce it. Furthermore, the study links this effect to international and local development policies and provides an overview of past research done on the topic. A description of the study area as well as the materials used and procedure followed have been discussed in the third chapter.

Chapter four provides a detailed analysis and discussion of the; LULC changes; LST estimate for the study area and the resultant UHI; and correlation between UHI and LULC changes as well as that between LST and LULC changes.

The last chapter concludes the report by summarizing the discussions as well as recommending strategies based on the findings of the report.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction to Urban Heat Island (UHI) Phenomenon

According to the CIA (2018), through its World fact book, the urbanisation rate of Kenya is approximately 4.15 per cent annually and the urban population is likely to increase steadily at a rate of 26.5 per cent over the next five years. This increment exerts pressure on existing social and economic developments. As a result, agricultural as well as vegetated areas are cleared to pave way for the development of real estates. These new landscapes often have lower solar reflectance as compared to vegetated areas (Folorunsho et al., 2017). This in turn makes urban areas hotter than the surrounding rural regions, a phenomenon called Urban Heat Island (UHI) (Figure 2.1).

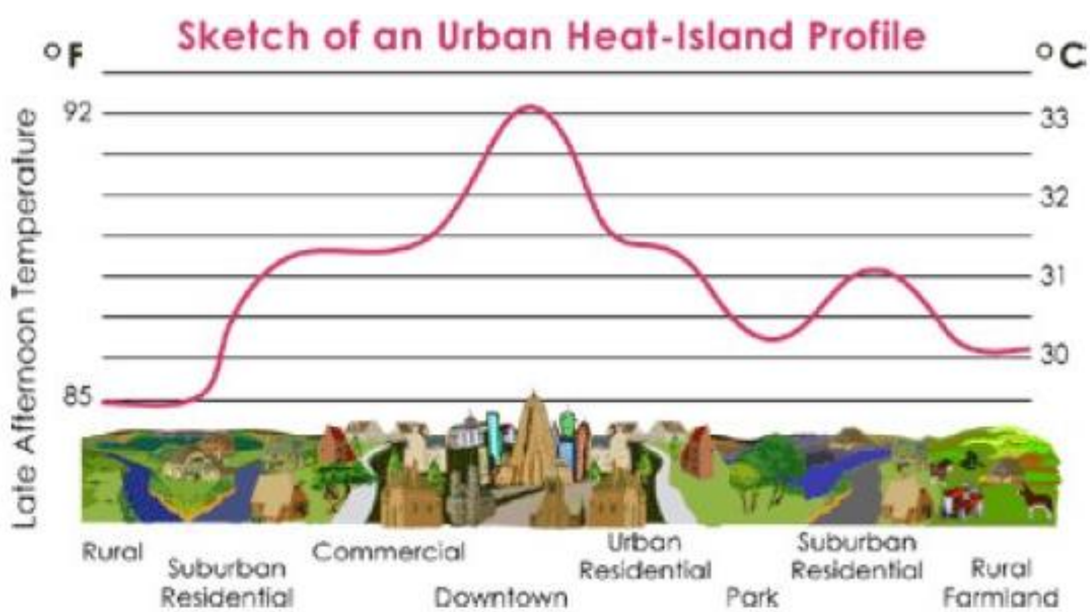

Figure 2.1: An illustration of typical UHI (Reproduced from EPA, 2008)

These temperature discrepancies have been observed by EPA (2008) to be more than 12°C. The effect is easily noticeable in the first few hours of the evening where the rural areas cool faster than the urban areas. Concrete surfaces tend to release the trapped energy slowly as infrared heat hence the change in temperature.

2.2 Types of UHI

There are two types of UHI namely; surface UHI and atmospheric UHI. The former refer to the surface temperatures of elements found on the earth's surface while the latter represent the air temperature above the earth's surface. Atmospheric UHI can be further described as either Canopy layer UHI- air temperature between the ground surface and the top of the built environment, or Boundary layer UHI- atmospheric temperature above the rooftop level but below the point at which urban landscapes temperature can affect the atmosphere (Khalid, 2014). Studies on the relationship between surface and air temperatures- especially in the canopy layer indicate that surface temperature has an indirect but significant influence on air temperature (Figure 2.2). This effect is well pronounced at night. For example built-up areas tend to lead to warmer air temperatures when compared to vegetated area.

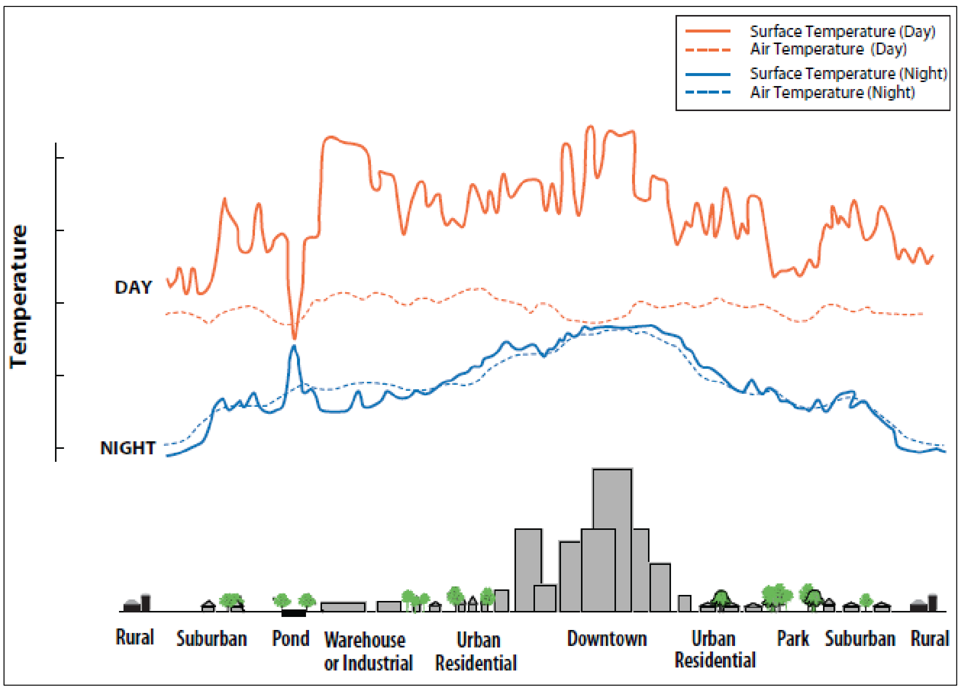

Figure 2.2: UHI effect (Reproduced from EPA, 2008)

2.3 UHI determinants

2.3.1 Reduced vegetation cover

According to studies done by Khalid (2014) and Rose et al. (2009), areas with low vegetation cover tend to have higher temperatures than the surrounding vegetated regions. Both researchers state that vegetation such as trees help in reducing air temperature through evapotranspiration and releasing energy by long-wave radiation.

The use of green buildings as well as incorporating green roofs in developments is now becoming popular. Plants work as insulators during the day by absorbing some of the sun's radiation. They also cool their environments through evapotranspiration and providing shade therefore making the underlying surface cooler (Adeyeri et al., 2017). Developers as well as governments should be encouraged into planting more trees in the urban areas. Just like green roofs, these open regions would absorb carbon dioxide, reflect solar radiation and also cool their surrounding hence reducing the effects of UHI.

2.3.2 Urban materials properties

Van Hove et al. (2011), notes that the chemical compositions of elements as well as the colour of surfaces affect their emissivity, solar reflectance and absorption. This in turn influences the development of UHI. Surfaces of high emissivity tend to cool more rapidly since they release heat faster. Khalid (2014) observes that surfaces such as concrete have a lower solar reflectance when compared to bare soil and vegetation prevalent in rural areas. This means that they absorb and retain energy rather than release it by emitting long-wave (infrared) radiation. Similar remarks were made by Folorunsho et al. (2017), where they noted that surfaces such as pavements, sidewalks, roads, rooftops and parking lots contribute to increase in LST values.

To solve this, researchers have recommended the use of light-coloured materials. This includes the painting of elements located in urban areas. By doing so, the solar reflectance of the materials is improved and more radiation is reflected than absorbed.

2.3.3 Urban geometry

This is the dimension and spacing of objects such as buildings in a built-up area (Van Hove et al., 2011). The geometry of these elements influence wind flow, energy absorption and release of absorbed energy back into the atmosphere. A case example is the effect of urban canyons which are developed when narrow streets are lined with tall buildings. As much as the buildings provide shade during the day, their geometry lowers surface albedo by absorbing radiation reflected by elements on the streets. This in turn makes the surface and canopy air temperatures higher than those of boundary layer or that in the peri-urban areas of a city.

2.4 Impacts of UHI

2.4.1 Energy consumption

EPA (2008) observes that there had been a steady increase of 5-10 per cent on the demand for electricity to compensate for heat island effect in most of the United States of America (USA) cities. UHI increases the demand for the use of cooling and air condition equipment which contribute to higher electricity bills and occasional power blackouts due to power overloads.

Strategies to lower the UHI should be implemented to lower the energy use. Van Hove et al. (2011) points out that a study done by Taha et al. (1999) revealed that large-scale increase in surface albedo in U.S cities resulted into a reduction of the canopy air temperature by approximately 1 kelvin and a proportional 10 per cent decrease in demand for electricity.

2.4.2 Air quality

Due to the power blackouts and shortages as stated herein above, people result into using fossil fuels which have high level of greenhouse gas emission. Air pollutants due to this combustion include; sulphur dioxide (SO_2), mercury (Hg), carbon dioxide (CO_2), carbon monoxide (CO) and nitrogen oxides (NO_x).

The continued use of fossil fuel pollutes the air and threatens the health of urban dwellers. According to an air quality investigation carried out by the UN in 2014 by use of modeled data derived from satellites and ground level measurements, none of the urban dwellers in sub-Saharan countries breathe clean air- air that meets the annual World Health Organization (WHO) particulate matter guidelines (United Nations Department for Economic and Social Affairs (UN DESA) (2017)).

2.5 Linking UHI with International and Local Policies

2.5.1 Sustainable Development Goals (SDGs)

These are 15 year strategies that came into force on the first day of January 2016 with an aim of alleviating poverty, fight inequality and promote sustainable development. They call for action from all countries to promote continuous development while protecting the planet through a multi-sectorial approach. Although there are 17 goals related to the economic, social and environmental protection spheres, this review covered 2 key goals, namely; Goal 11- Make cities inclusive, safe, resilient and sustainable; and Goal 13- Take urgent action to combat climate change and its impacts.

Goal 11: Make cities inclusive, safe, resilient and sustainable

According to the United Nations (n.d), close to half, 3.5 billion people, of the world population live in cities today. The population has exerted pressure on existing housing units and infrastructure such as water supply, sewer as well as the general human health. The goal identifies cities as the centres of urbanization and social development. It is also evident that such urbanization comes at a cost and that there is need to strike a balance ensuring that urban areas continue being functional as well as thrive and grow while utilizing natural resources and reducing all forms of pollution.

Although the rate of urbanization is unprecedented, the expansion of urban land is outpacing urban population growth at an average ratio of approximately 1.25 between 1990 and 2015 (UN DESA, 2017). The report further states that the average ratio of land consumption rate to population growth rate is approximately 1.17 (Figure 2.3). Urban sprawl is being experienced in all cities world over with the Nairobi urban fringe being amongst the rapidly changing ones. Kiambaa Sub-county is faced by challenges induced by rapid urbanization- amongst them being the UHI effect. This study can therefore be used to propel sustainable developments in the sub-county.

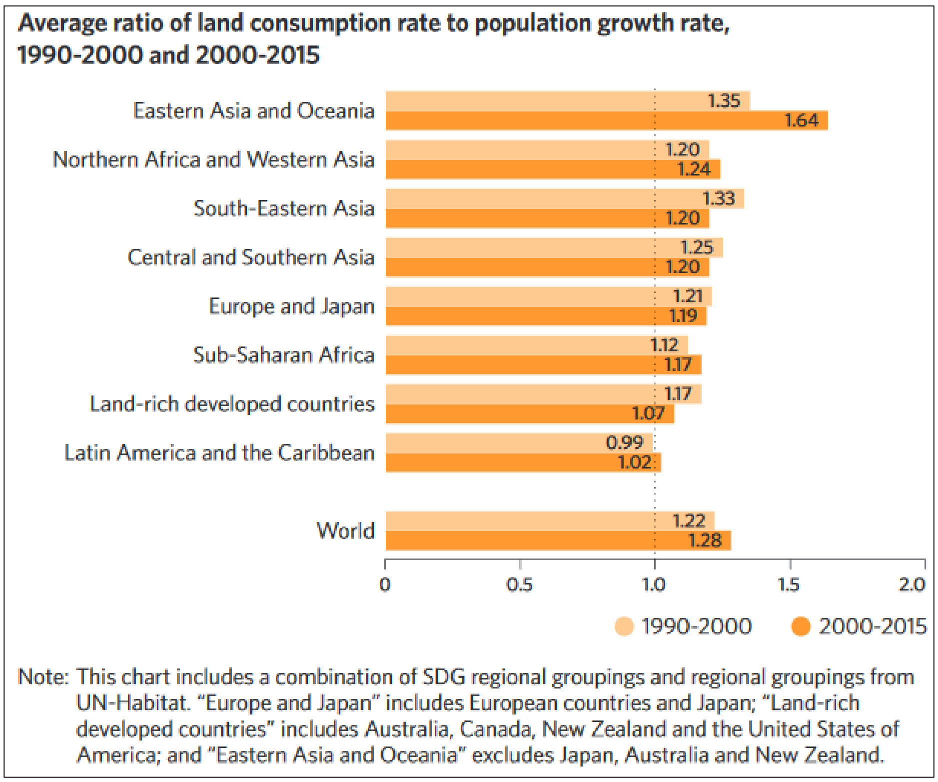

Figure 2.3: Urbanization versus Population growth rate (Reproduced from UN DESA, 2017)

Goal 13: Take urgent action to combat climate change and its impacts

The average global temperature has increased by approximately 0.85°C over the last two centuries (UN, n.d). This rising temperature can be linked to the rapid urbanization and industrialization both in the developed and developing countries. As a result, on one hand, the global food productivity has reduced by over 40 megatons per year from 1981 to 2002 with an estimated 5 per cent grain yield reduction for every 1°C temperature change. On the other hand, there is an estimated 19cm rise of the average sea level from 1901 to 2010 and the loss of approximately 1.07 million km2 of Artic sea ice.

Due to the rapid urbanization being experienced in the country, it is estimated that the average carbon emission has increased by 5 per cent since the early 1990s. Closely related to this is the surface air temperature which has also increased due to the impervious and low emissivity surfaces associated with building being erected in the growing urban areas. These surfaces impact the UHI levels in the sub-county- a phenomenon that was established in this research.

2.5.2 Kenya Vision 2030

After its launch in 2010, the Vision 2030, which is said to be Kenya's Development Blueprint, provided the much needed development backbone that would propel Kenya into becoming globally competitive and prosperous with her citizens living a high quality life by year 2030. It aims at transforming the country into middle income economy supported by industrialisation as well as a clean and secure environment (GoK, 2007).

Through the guidance of these objectives, the government has laid down procedures, structures and strategies that have resulted to unprecedented growth in the social, economic and political spheres. This growth has led to LULC changes in the urban and peri-urban areas to cater for the increasing demand for residential houses. Recently the president, Uhuru Kenyatta, vowed to construct 500,000 housing units across the nation over a period of five years. Although there is a definite need for such low cost houses, there is a risk that such constructions would increase the UHI effect currently being experienced in the city and its environs. Therefore, all developments should be designed in accordance to the principles of environmental sustainability while keeping in mind upcoming issues such as climate change and UHI.

2.6 Previous studies and findings

Sharifi and Lehman (2014) examined the effect of UHI in Sydney (Australia). It was found out that the city was already experiencing UHI effects with the temperatures in urban areas increasing from 1.1°C to 3.7°C while those in rural areas registered increments of 0.8°C to 2.6°C. In their conclusion, it was projected that the UHI when combined with global warming would increase the temperatures by up to 3.7°C based on urban growth. These results are similar to most of other studies carried out throughout the world. They show that there is indeed an Urban Heat Island effect, a phenomenon of utmost importance.

Studies on UHI in Istanbul revealed a strong correlation between urban growth and UHI. Ezbel et al. (2007) found that the rate of change of UHI in Istanbul was consistent with the rapid expansion of the city that occurred from 1951 to 2004. The city temperatures were observed to have increased by almost 1°C at the time of the study with the period 1981-2004 recording the highest increment of approximately 0.82°C. On the other hand, by use of the temperature data provided by the State Meteorological Office of Turkey, Karaca et al. (1995), observed that the Istanbul urban temperature increased significantly, especially on the most industrialised and populated parts, as compared to its surrounding rural areas. The results were similar to those obtained by Aslan and Koc-San (2016) while analysing the relationship between urban heat island effect and land use/cover type in Antalya. The study observed that the highest LST differences were in urban and industrial areas which had increased in spatial extent by a significant rate.

UHI studies have also been carried out in Africa as well as in the country. Particular reference is made to a study done by Folorunsho et al. (2017) where they sought to establish the correlation between LST and NDVI over Ibadan Metropolis. The study revealed that; (a) there was a negative correlation between the two variables (b) the temperature difference between urban and rural areas was approximately 5.32°C; and (c) that the changes could be associated to the rapid reduction of the vegetation cover. In his conclusion, it was noted that the presence of vegetation cover in urban areas reduce the UHI effects hence the temperature changes.

Based on the surface air temperature in Nairobi, Makokha and Shisanya (2010) reported that the city was also experiencing high temperature changes most of which was evident during the hot-dry periods. The study was based on data collected for 30 days in four periods in 2007 namely; February/March (hot-dry months); April/May (hot and wet); July/August (cool-dry); and

October/November (warm-wet). The results placed maximum warming (8 hours before sunset) and cooling (1 hour after sunset) rates to be 2.7°C and -1.9°C respectively. The study concluded by stating that the UHI effect in Nairobi was highest during the months of February and March and lowest in July and August. The duo recommended the incorporation of proper planning and design techniques that would allow more open spaces in the urban areas.

A more recent study would be the one done by Odongo (2016) where he sought to establish the presence of UHI in Nairobi City by use of Landsat-8 OLI/TIRS and DMSP/OLS images. The study revealed that there was a strong correlation between the UHI and land use. The correlation coefficient of -0.41 between LST and NDVI and that of 0.71 between LST and urbanisation obtained meant that vegetated and agricultural areas had a lower heat island effect than urban areas. This cemented his assumption on the presence of UHI phenomenon in the city and that rapid urbanization was directly proportional to increased LST.

Musa and Odera (2015) studied the effects of Land Use and Land Cover change (LULC) on agricultural land in Kiambu County by use of satellite images from Landsat TM and ETM+. The study revealed that agricultural land reduced from 39.7 to 15.8 per cent while the built-up area increased from 1.9 to 33.5 per cent over a period of 30 years. It was later identified that the change was due to population increase, demand for residential houses and accelerated social and economic activities in the county. The researchers concluded by recommending further investigations in the effects of land use and land cover change on climate and temperature changes; a recommendation that forms the basis of this research. A similar study was done by Njiru (2016) where she evaluated urban expansion and its implications on the land use in Kiambu County from 1986 to 2014. The research revealed that the county was experiencing a high rate of urbanization, approximately 41.6 per cent, while the forests, bare land, water and agricultural land decreased by 10.3, 1.8, 0.22 and 29.3 per cent respectively. It was stated that more than half of the agricultural land was converted to the built-up land by 2014. The study recommended that zoning regulations be developed and implemented to regulate the rapid conversion of agricultural land to real estate developments.

CHAPTER 3: MATERIALS AND METHODS

3.1 About the Study Area

3.1.1 Location and size

Kiambaa sub-county is located in the south of Kiambu County. It is on the border of Nairobi and Kiambu counties (Figure 3.2), and lies between latitudes 1°6'20.00''S and 1°14'00.00'S and longitudes 36°42'30.00''E and 36°48'30.00''E. It is made up by 5 wards namely; Cianda, Karuri, Muchatha, Ndenderu and Kihara (Figure 3.1). It is approximately 83.22 square kilometres (Table 3.1) ("Political units," n.d).

3.1.2 Climate

The area has a fairly cool climate. The mean monthly temperature is 22℃ with a high of 27℃. It has a bi-modal rainfall pattern with the long rains season occurring between March and May and the short rains between October and December. The mean annual rainfall is 900 mm.

3.1.3 Topography

Kiambaa is approximately 1800m above sea level. The land slopes gently towards Runda and Roselyn areas of Nairobi City County, as well as the different rivers found in the sub-county, with a differential height of approximately 200m over an 8 kilometre stretch along Banana-Raini road.

3.1.4 Geology and Soil characteristics

The soils in the area can be classified in two categories namely red loam and black cotton soils. The former is prevalent in most parts of the study area and support both agricultural activities and real estate development while the latter is common along the river bed and riparian reserve.

3.1.5 Hydrology and Drainage systems

There are two main rivers in the area namely River Ruaka and River Rueru on the west side of the sub-county. The two form the administrative boundaries of Ruaka town with the former marking the boundary between Ndenderu and Muchatha wards and the latter indicating the boundary between Ndenderu and Kihara wards. Both of them drain into Nairobi River (Maina, 2010).

Besides the rivers, other hydrological features include dams, wells and boreholes. The area lack well maintained storm water drains.

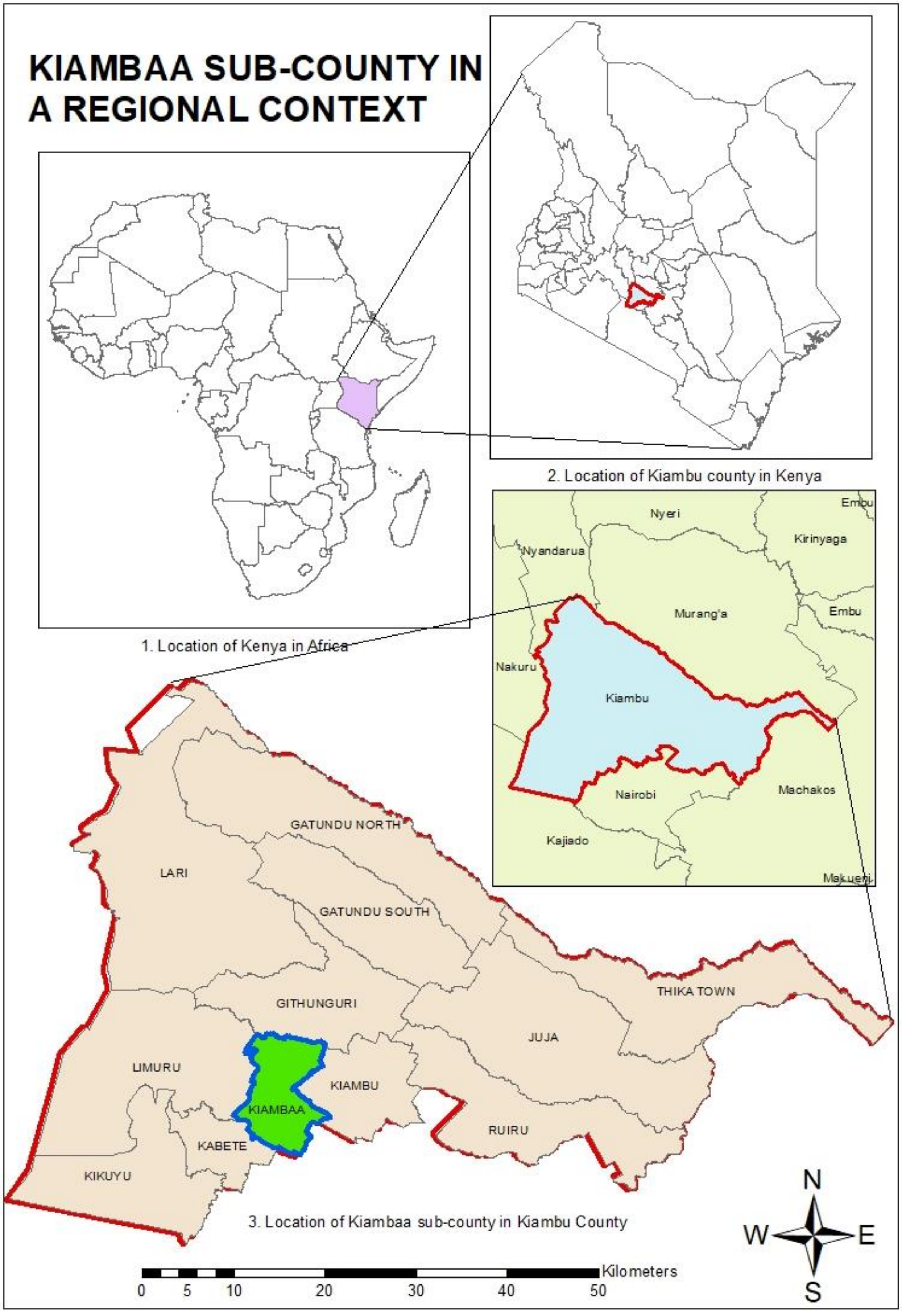

Figure 3.1: Kiambaa sub-county in a regional context **Source: Author, 2018**

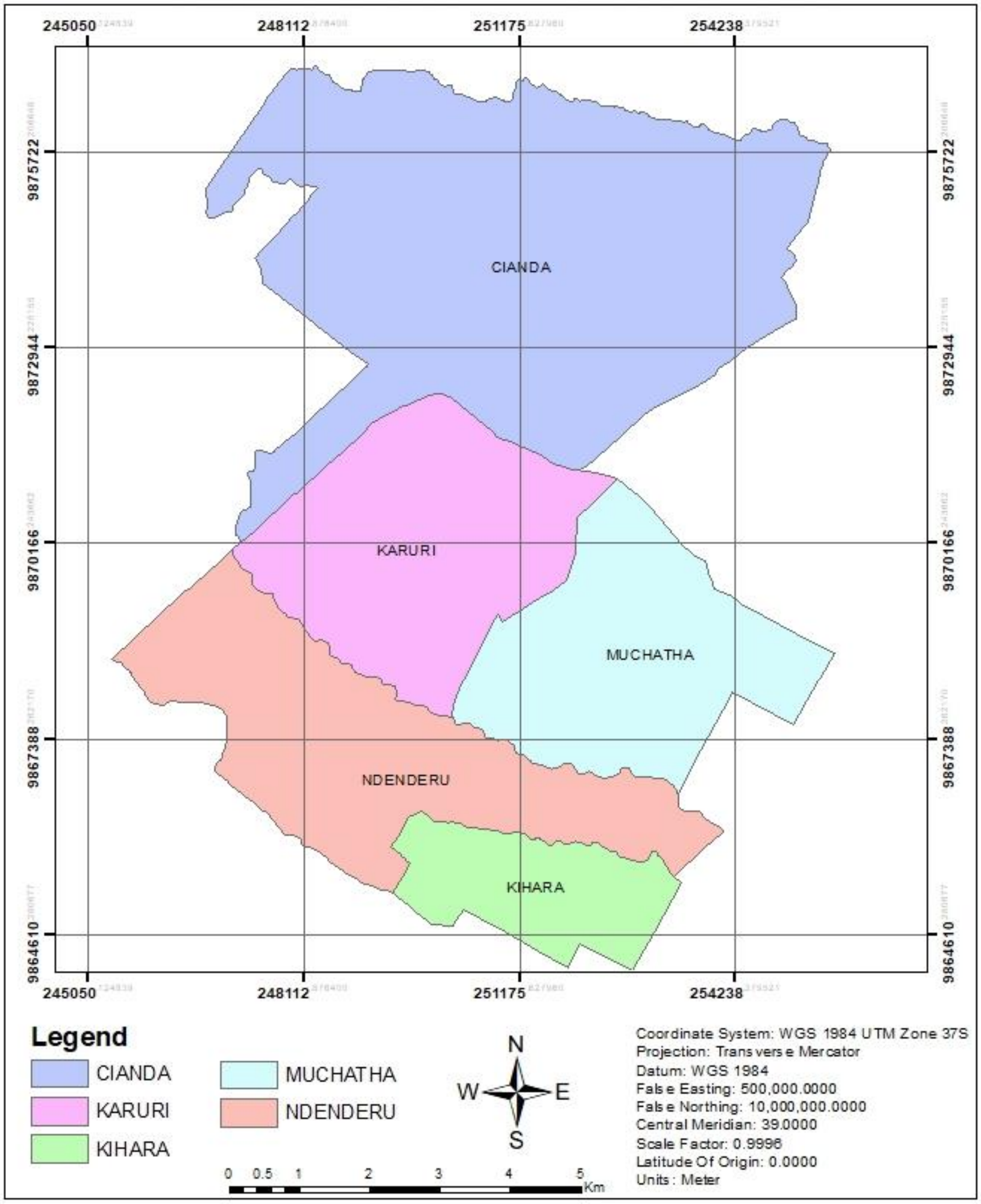

Figure 3.2 Kiambaa sub-county wards **Source: Author, 2018**

Table 3.1: Kiambaa sub-county wards

	Ward	Sub-locations	Area (Km^2) (Approx.)
1.	**Cianda**	Cianda and Kawaida	36.70
2.	**Karuri**	Njiku, Kiambaa and Karuri	14.50
3.	**Ndenderu**	Ndenderu, Ruaka, Karura, Wangunyu and Mahindi,	7.40
4.	**Muchatha**	Njoro, Gathanga and Muchatha	11.80
5.	**Kihara**	Gachie and Kihara	2.70

3.1.6 Vegetation

The vegetation in the study area ranges from trees to shrubs and grass as shown on plate 3.1. The former can be classified into two categories namely; natural and exotic trees and is common in the riparian reserve while the latter was observed to have grown along the road reserve and un-cultivated agricultural lands. The natural trees include acacia and cider while the exotic ones are eucalyptus, grivellia and pine (Maina, 2010). There are also tea and coffee plantations.

It is wise to note that due to the increasing demand for residential houses, large tracts of agricultural land have been cleared to pave way for constructions, plate 3.2. The resultant has left local farmers practicing subsistence agriculture and the larger population depending on food grown elsewhere in the county.

Plate 3.1: Vegetation cover in the rural areas

3.1.7 Infrastructure

3.1.7.1 Roads and Accessibility

The study area is well served by major roads such as Limuru Road, Banana-Raini Road, Ndenderu-Kikuyu Road, Ndenderu-Banana Road, Kiambu Road, Nazareth Hospital Road and Raini-Kanunga Road. These roads are all tarmacked and in good condition, plate 3.3.

There are other access roads which are dry weathered. Therefore, all areas in the sub-county are well connected to each other and can be easily accessed.

3.1.7.2 Water

The general area is served with water supplied by Karuri Water Company (KWCo). Moreover, there are registered vendors who supply the resource in case of shortages in the normal supply. Most residents also employ rain harvesting techniques by use of gutters and storage tanks while others have sunk private boreholes and wells as shown in plate 3.3.

3.1.7.3 Liquid and solid waste

Since the area is not served by a conventional sewer system, residents dispose the liquid waste on septic tanks and soak pits as well as pit latrines. These techniques are often not advised since they can contaminate underground water.

Although solid waste collection and disposal services are provided by the Environmental department of Kiambu County, area residents also employ services provided by private garbage collectors.

3.1.7.4 Electricity

Kenya Power is the leading supplier of electricity in the area. Residents also employ green sources of energy such as solar panels.

3.1.7.5 Communication

The most used form of communication in the area is telephone. The service is facilitated by mobile service providers such as Safaricom, Airtel, and Telcom.

Internet providers such as Jamii Telecom and Zuku have also extended their services into the area.

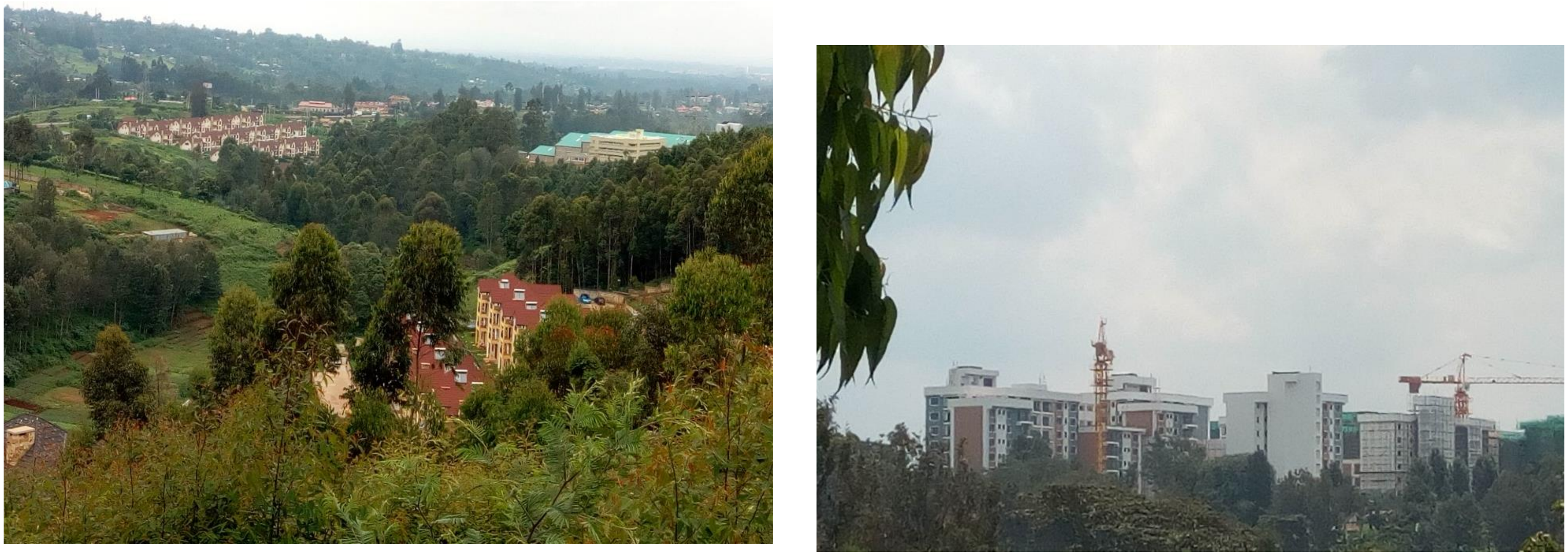

Plate 3.2: Land use changes **Source: Author, 2018**

Plate 3.3: Infrastructure: Banana-Raini Road, Transformer, water tank and well **Source: Author, 2018**

3.1.9 Population

The census data collected by the Kenya Population and Housing Census (2009) indicated that the sub-county had an urban population of approximately 145,053 people in 2009. The population would increase to approximately 184,617 by the end of 2017 (Table 3.3). Majority of this population would be housed in areas such as Ruaka, Karuri, Gachie and Kawaida (Table 3.2 and 3.4) ("Political Density and Distribution," n.d).

Table 3.2: Population projection of Karuri urban center

2009 Census			2012 Census			2017 Projections		
Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
53,735	53,981	107,716	58,461	58,729	117,190	67,280	67,588	134,868

Table 3.3: Population distribution and density for Kiambaa sub-county

2009 Census		2012 Census		2017 Projections	
Population	**Density (/Km^2)**	**Population**	**Density (/Km^2)**	**Population**	**Density (/Km^2)**
145,053	1,979	157,811	2,153	181,617	2,478

Table 3.4: Population of Kiambaa sub-county by wards (2009 census)

	Ward	Population
1.	**Cianda**	15,119
2.	**Karuri**	30,660
3.	**Ndenderu**	35,853
4.	**Muchatha**	26,544
5.	**Kihara**	36,877
	Total	**145,053**

3.1.8 Neighborhood characteristics

The area is generally characterized by a mix of different uses. Ruaka as well as the larger Kiambaa sub-county was previously an agricultural area with low density housing such as bungalows and maisonettes. Although the skyline was maintained at low levels, the trend appears to be changing, perhaps due to the increasing demand for more housing units, with developers constructing apartments, plate 3.4. The area has also seen an increasing number of other developments, such as educational institutions, churches and the general commerce sector due to the increased demand arising from the increasing population.

The different education facilities found in the area include; Royal Brains School, Bloomsfield Kindergarten, Fortune house School, Karuri High School amongst others. Religious institutions in the neighborhood mosques, temples and churches such as ACK Ruaka Church, ACK Karuri Church, PCEA Ruaka Church, Joseph Allamano Catholic Church among others. Other uses include commercial and light industry (petrol station) activities located along Limuru and Banana-Raini Roads. The major health institutions in the region are Kihara and Karuri Sub-county Hospitals, Nazareth Hospital, The Nairobi Hospital and Kenyatta National Hospital.

3.2 Materials and Methods

3.2.1 Materials

The data used for the purpose of this research consisted of Level 1 Landsat images downloaded from the United States Geological Survey's (USGS) website in particular Landsat-5 Thematic Mapper (TM), Landsat-7 Enhance Thematic Mapper plus (ETM+) and Landsat-8 Operational Land Imager (OLI) and Thematic Infrared Sensor (TIRS) images.

Table 3.5: Data and their characteristics

	DATA	SENSOR	BAND	RESOLUTION	SOURCE	DATE
1.	Landsat-5	TM	2, 3, 4 & 6	30m	USGS (Online)	1995
2.	Landsat-7	ETM+	2, 3, 4 & 6	30m	USGS (Online)	2000
3.	Landsat- 8	OLI	3, 4 & 5	30m	USGS (Online)	2015 & 2018
		TIRS	10	100m		
4.	Administrative boundary maps				Muthami (2011) and OCHA ROSEA (2012)	

a) On-going constructions in Ruaka Town

b) Karuri shopping center

c) Apartments constructed by Cytonn

d) A petrol station in Karuri shopping center

Plate 3.4: Neighborhood character **Source: Author, 2018**

3.2.2 Methods

The UHI effect was estimated using a series of algorithms embedded in software such as ESRI ArcGIS and Erdas Imagine. The methodology involved; (a) Mapping of the LULC changes; (b) Estimating the LST; (c) Determining the UHI effect; and (d) Analysing the correlation between UHI and LULC. A conceptual framework has been shown on figure 3.3.

a) Mapping Land Use Land Cover (LULC) Changes

1. *Image pre-processing*

   The images were layer stacked, clipped to the extent of the study area and re-projected.

2. *Creating a spectral signature*

   The false color composite (FCC) image was loaded into the Erdas Imagine 2015 and the signature editor window activated using the raster tab on the menu bar. A signature set for use in performing the supervised classification was then created and saved.

3. *Performing land use classification*

   The major uses relevant to the research were built-up areas, agricultural land and water bodies, as shown in table 3.6. Supervised classification, by use of the signature files generated in step 1 and a maximum likelihood algorithm, was carried out for all images.

   A map composition analysis, to identify the area of each class, was later done by loading the resultant images into an Arc Map environment. It was noted that the spatial resolution of the images was 30m i.e. each pixel represented a grid of 900 square meters and that 1 acre is equivalent to 4046.8 square meters.

4. *Accuracy assessment*

   The assessment is used to check the accuracy of the classified image. The process was done in an Erdas environment and the comparison points were generated by the use of the stratified random technique. An accuracy report for each image was generated. For the purpose of this study, an accuracy of more than 80% was deemed sufficient.

5. *Change detection*

   The analysis was determined by checking the difference between two consecutive images. This was done by use of the change detection analysis window that is activated by selecting the Image Difference tool in the Zonal Change drop-down menu in Erdas Imagine. The overall rate of change between consecutive epochs was then estimated by calculating the differences between same classes in the said images.

Table 3.6: Land uses classified

	LAND USES	DESCRIPTION	COLOURS
1.	Built-up areas	Residential, commercial and industrial areas	Brown
2.	Agricultural Land	Bare land, rain -fed and irrigated land, areas with vegetation cover such as trees	Green
3.	Water bodies	Dams	Blue

b) Estimating the Land Surface Temperature (LST)

The LST was estimated from the Landsat data. Folorunsho et al. (2017) notes that TM and ETM+ band 6 and TIRS band 10 are the best bands for capturing multifaceted urban temperature differences. The changes were noted over different time periods. The steps followed were as suggested by the USGS (2018) and USGS (2009);

1. Converting Landsat TM and ETM+ images to spectral radiance using equation 3.1;

$$L_\lambda = \left(\frac{\text{LMAX}-\text{LMIN}}{\text{QCALMAX}-\text{QCALMIN}}\right) \times \; (DN-1) + LMIN \qquad (3.1)$$

   Where;

   L is Spectral radiance at the sensor's aperture in $Wm^{-2}sr^{-1}um^{-1}$; LMAX is Spectral radiance that is scaled to QCALMAX in $Wm^{-2}sr^{-1}\mu m^{-1}$; LMIN is spectral radiance that is scaled to QCALMIN in $Wm^{-2}sr^{-1}\mu m^{-1}$; QCALMAX is the maximum quantized calibrated value (corresponding to LMAX) where DN = 255; QCALMIN is the minimum quantized calibrated pixel value (corresponding to LMIN) in DN = 1

   For Landsat 8, equation 3.2 was used;

$$L_\lambda = (\text{M} \times \text{DN}) + B \qquad (3.2)$$

   Where M and B represent the radiance multiplier and the add values given in the metadata

2. Obtaining the at-sensor brightness

   This was done by using the Plank's inverse function.

$$T_k = \frac{\text{K2}}{ln\left(\frac{\text{K1}}{L_\lambda}+1\right)} \qquad (3.3)$$

Where Tk is the radiant surface temperature in Kelvin; K2 and K1 are the calibration constants in $Wm^{-2}sr^{-1}\mu m^{-1}$; and L is the spectral radiance measured at the sensor in $Wm^{-2}sr^{-1}\mu m^{-1}$

3. Deriving the Normalized Difference Vegetation Index (NDVI). The index is used to measure the densities of vegetation in vegetated areas. It was index was defined as shown in equation 3.4;

$$NDVI = \frac{R_{\mathrm{NIR}} - R_{\mathrm{RED}}}{R_{\mathrm{NIR}} + R_{\mathrm{RED}}} \quad (3.4)$$

Where R_{NIR} and R_{RED} are spectral reflectance from the near-infrared band and the red band respectively.

It is noteworthy that the satellite imagery provided by Landsat TM, ETM+ and OLI present the reflectance on different bands.

The formula shown in equation (3.4) can be described by individual bands as shown in equations 3.5 and 3.6,

For Landsat-7 ETM+ and Landsat-5 TM,

$$NDVI = \frac{\text{Band 4} - \text{Band 3}}{\text{Band 4} + \text{Band 3}} \quad (3.5)$$

For Landsat-8 OLI,

$$NDVI = \frac{\text{Band 5} - \text{Band 4}}{\text{Band 5} + \text{Band 4}} \quad (3.6)$$

4. Estimation of the Land Surface Emissivity (LSE)

The temperature values generated using equation 3.3 refers to that of a black body. However, there were different land uses in the study area whose elements had unique spectral emissivity. In this regard, the values were corrected to account for the heterogeneous nature of the area.

For the purpose of this study, equation 3.7, as suggested by Sobrino et al. (1990), was used.

$$\varepsilon = \varepsilon_{v\lambda} \times f_v + \varepsilon_{s\lambda} \times (1 - f_v) + C_\lambda \quad (3.7)$$

$$f_v = \left(\frac{NDVI - NDVI_S}{NDVI_V - NDVI_S}\right)^2 \quad (3.8)$$

$$C_\lambda = (1 - \varepsilon_{s\lambda}) \times \varepsilon_{v\lambda} \times F' \times (1 - f_v) \quad (3.9)$$

Where f_v represent the proportion of vegetation in each pixel estimated by equation 3.8; C_λ is the cavity effect that occurs due to the surface roughness calculated by equation 3.9 and factor F whose mean is 0.55; NDVI is as generated using equations 3.5 & 3.6 and $NDVI_S$ (0.97) and $NDVI_V$ (0.99) is the index for soil and vegetation pixels respectively; and ε_s and ε_v represent the emissivity on the soil and full vegetation pixels.

5. Estimation of the Land Surface Temperature (LST)

   This was done by using equation 3.10,

$$LST = \left(\frac{T_B}{1 + \left(\lambda \times {}^{T_B}/_{\rho} \right) \times ln\varepsilon} \right) \quad (3.10)$$

   Where TB is the radiant surface temperature; λ is the emitted radiance wavelength; ρ is $h^x c/\sigma$, h is the Plank constant (6.626×10^{-34}Js), c is the speed of light (2.998×10^8m/sec), σ is Stefan Boltzmann's constant (1.38×10^{-23}JK^{-1}); and ε is emissivity.

6. Conversion of the LST temperature to Celsius

   Since the temperatures obtained in equation 3.10 were in kelvin, the units were converted into Celsius by using equation 3.11:

$$LSTc = LST - 273.15 \quad (3.11)$$

c) Determining the UHI

The UHI intensity was calculated by finding the difference between the maximum and minimum LST as described in equation 3.12;

$$UHI = LST_{max} - LST_{min} \quad (3.12)$$

Where LST_{max} and LST_{min} represent the maximum and minimum temperatures

d) Analysing the correlation between UHI and LULC change

Using the results obtained from the equations explained above, the relationship between the land use land cover change and the urban heat island effect was established by use of the Pearson's formula in Microsoft Excel.

3.3 Validation of the results

In order to achieve the best practices and standards while carrying out the analysis, the following strategies were used;

a) Kappa values: The Kappa represents a measure of accuracy between a classification map and the reference data. Best practices dictate that values that are less than (<) 0.4 represent a poor kappa, those more than or equal to (>=) 0.4 but less than (<) 0.8represent a good kappa value while those that are more than or equal to (>=) 0.8 represent an excellent kappa value as shown in table 3.7. For the purpose of this study, kappa results that were more or equal to 0.75 were accepted and the images used for further analysis.

Table 3.7: Best Kappa Values

Best Kappa Values (K)		
K <0.4	Represents poor kappa	Not acceptable
0.4 <=K <0.8	Represents good kappa	Not acceptable
K>= 0.8	Represents excellent kappa	Acceptable

b) Land use classification: The Maximum Likelihood algorithm was used while defining the classes. Several images, a minimum of three, were derived and the best amongst them-image with the highest accuracy, was chosen to represent the classification for that year.

c) Accuracy assessment: The assessment was done before a classified image was used for the calculation of the LULC changes. Since the ideal range of reference points is usually quoted as between 30 to 50 points, 40 points were used to carry out accuracy assessment for each image. The stratified random technique, with a minimum of seven (7) points per each class, was used to distribute the reference points on the study area. Furthermore, an accuracy value of more than 80 per cent was deemed sufficient. Images that resulted to a lower accuracy assessment were discarded and new ones produced.

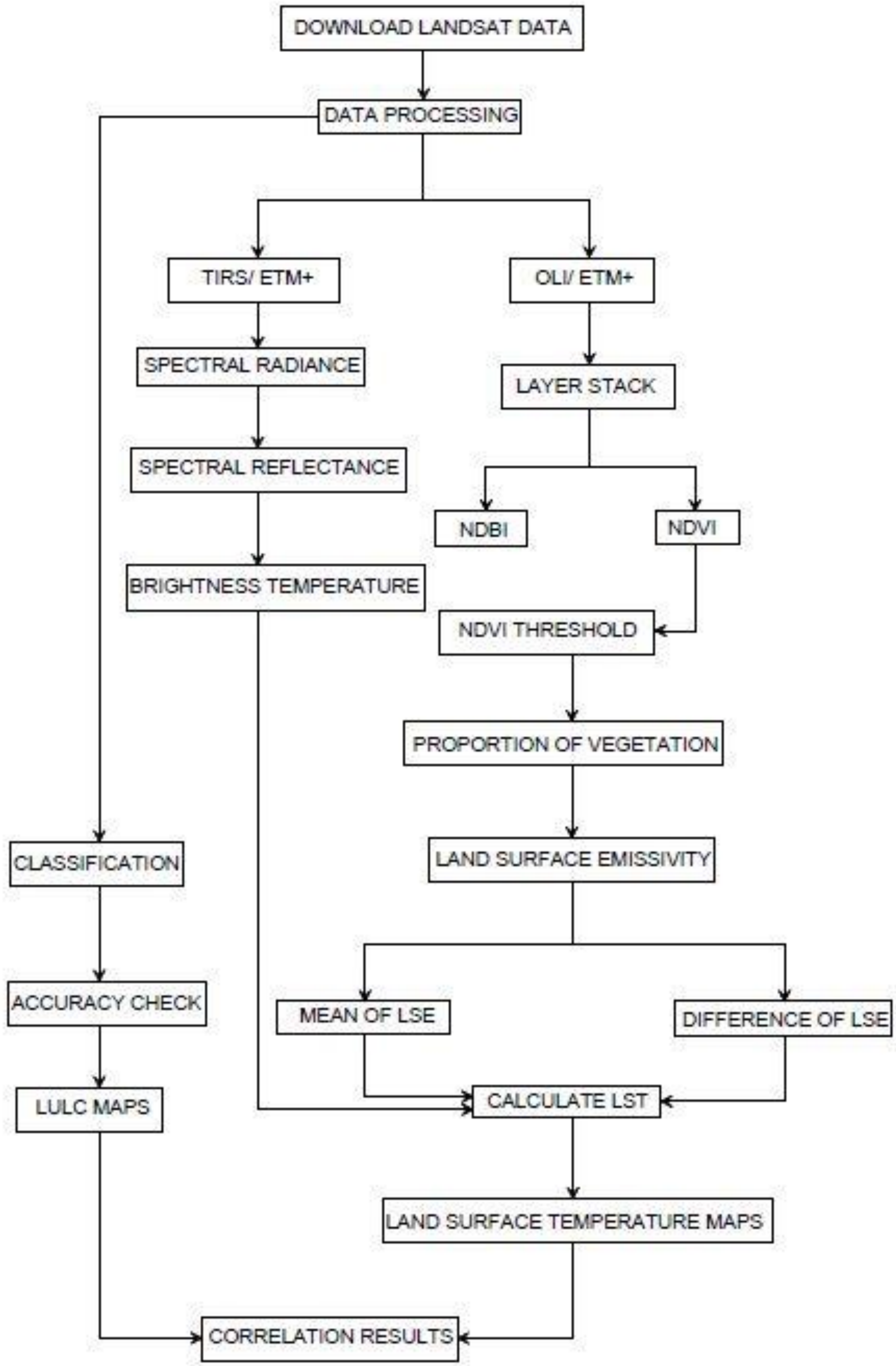

Figure 3.3 Conceptual flow chart of the methodology adopted for this study

(Reproduced from Alhawiti, 2016)

CHAPTER 4: RESULTS AND DISCUSIONS

4.1 Land Use and Land Cover Changes

Objective: To map the LULC changes of Kiambaa sub-county between 1995 and 2018

4.1.1 Land use classification

The images were classified into three distinct classes, namely;

a) **Agricultural land:** The class represented parcels of land which had a high percentage of vegetation cover. The specific uses grouped into this class included bare land, rain-fed and irrigated land and areas with vegetation cover such as trees. Cianda and Ndenderu wards were among the areas that had the highest proportion of vegetation throughout the research period as compared to other wards due to the several tea and coffee estates predominant in the area, table 4.1. The cover also extended to other wards especially along the riverine.

b) **Built-up area:** It represented areas covered by buildings. The specific uses grouped into this class included residential, commercial and industrial areas. Although the images revealed that approximately 50% of the land was under residential use in 1995, the use was most predominant in Muchatha, Karuri and Kihara wards. The results were generalized hence the classification of the peri-urban area as part this class.

c) **Water bodies** signified the presence of dams. The features were identified in Cianda ward. Further field survey revealed that they were privately owned and were situated in tea and coffee estate.

These classes are as shown on figure 4.1.

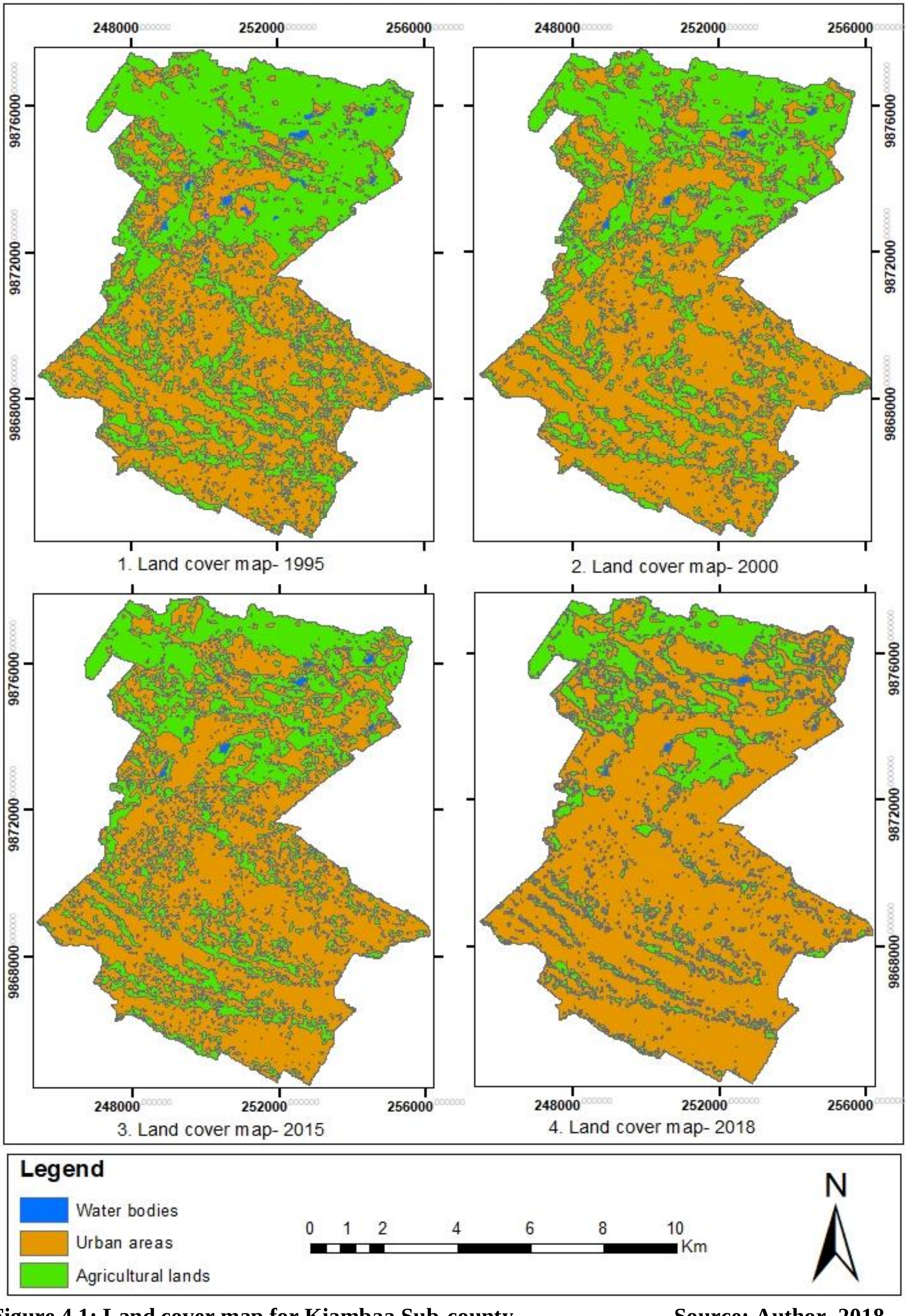

Figure 4.1: Land cover map for Kiambaa Sub-county **Source: Author, 2018**

Table 4.1: Land uses of Kiambaa sub-county in hectares

Land uses of Kiambaa sub-county					
	1995 (Ha)	**2000 (Ha)**	**2015 (Ha)**	**2018 (Ha)**	**Colours**
Agricultural land	4159.89	3378.06	2485.71	1949.49	Green
Built-up area	4206.87	4990.77	5879.52	6421.41	Brown
Water bodies	36.9	32.22	34.2	29.43	Blue

4.1.2 Accuracy assessment

The assessment was carried out for each image and its resultant classification. The accuracy mean for the four images was 88.75 per cent. The highest value was recorded in 2018 while the least was in 2000 (Table 4.2). The changes in the accuracy of the classified images were due to the capturing of the Landsat images using different satellite sensors. The Kappa statistics ranged between 0.7214 to 0.8848 for the 2000 and 1995 images respectively (Table 4.3).

Table 4.2: Accuracy assessment results for year 1995, 2000, 2015 and 2018

Accuracy Assessment Results					
1995					**Type of image:** Landsat-5 TM
Class	**Reference total**	**Classified total**	**Correct values**	**Producer accuracy (%)**	**User accuracy (%)**
Water bodies	9	10	9	100.00	100.00
Built-up areas	17	16	15	88.24	93.75
Agricultural land	14	14	13	92.86	92.86
Overall Classification Accuracy				**92.50%**	
2000					**Type of image:** Landsat-7 ETM+
Water bodies	7	7	7	100.00	100.00
Built-up areas	17	18	14	82.35	77.78
Agricultural land	16	15	12	75.00	80.00
Overall Classification Accuracy				**82.50%**	
2015					**Type of image:** Landsat-8 OLI
Water bodies	7	7	7	100.00	100.00
Built-up areas	18	19	16	88.89	84.36
Agricultural land	15	14	12	80.00	85.71
Overall Classification Accuracy				**87.50%**	

2018	**Type of image:** Landsat-8 OLI				
Water bodies	7	7	7	100.00	100.00
Built-up areas	19	22	19	100.00	86.36
Agricultural land	14	11	11	78.57	400.00
Overall Classification Accuracy				**92.50%**	

Table 4.3: Kappa statistics

Kappa Statistics				
Conditional Kappa for each category				
Class	**1995**	**2000**	**2015**	**2018**
Water bodies	0.8710	1.0000	1.0000	1.0000
Built-up areas	0.8913	0.6135	0.7129	0.7403
Agricultural land	0.8901	0.6667	0.7714	1.0000
Overall Kappa statistics	**0.8848**	**0.7214**	**0.7998**	**0.8774**

4.1.3 Land use and land cover changes

The research revealed two dominant changes:

1. **Reducing agricultural land:**

   Although approximately 49.50 per cent of the land was used for agricultural purposes in 1995, the cover later reduced to 40.21 and 29.59 per cent in 2000 and 2015 respectively. Only 23.21 per cent of the total area was being used for agricultural purposes by end of January 2018, table 4.4. The mean rate of change was estimated to be 8.76 per cent (Table 4.5). The research further revealed that the loss of agricultural land was inversely proportional to the increase of built-up areas (Figure 4.2).

2. **Increasing urban areas:**

   The built-up area increased tremendously from 50.06 to 76.44 per cent in 1995 and 2018 respectively, table 4.4. This can be attributed to the massive developments that took place during that period. The research further established that approximately 888.75Ha of agricultural land was converted to built-up area between 2000 and 2015 (Table 4.1). It is worth noting that the development was being experienced in both agricultural and urban areas. The mean rate of change was estimated to be 8.79 per cent (Table 4.5).

Table 4.4: Land uses of Kiambaa sub-county in percentage

Class	**1995** (%)	**2000** (%)	**2015** (%)	**2018** (%)
Agricultural land	49.50	40.21	29.59	23.21
Built-up area	50.06	59.41	70.00	76.44
Water bodies	0.44	0.38	0.41	0.35
Total	100.00	100.00	100.00	100.00

Table 4.5: Land use and land cover change

Land use and land cover change				
Class	**1995 – 2000** (%)	**2000 – 2015** (%)	**2015 – 2018** (%)	**Average change** (%)
Water bodies	0.06	0.03	0.06	0.05
Built-up areas	9.35	10.59	6.44	8.79
Agricultural land	9.29	10.62	6.38	8.76

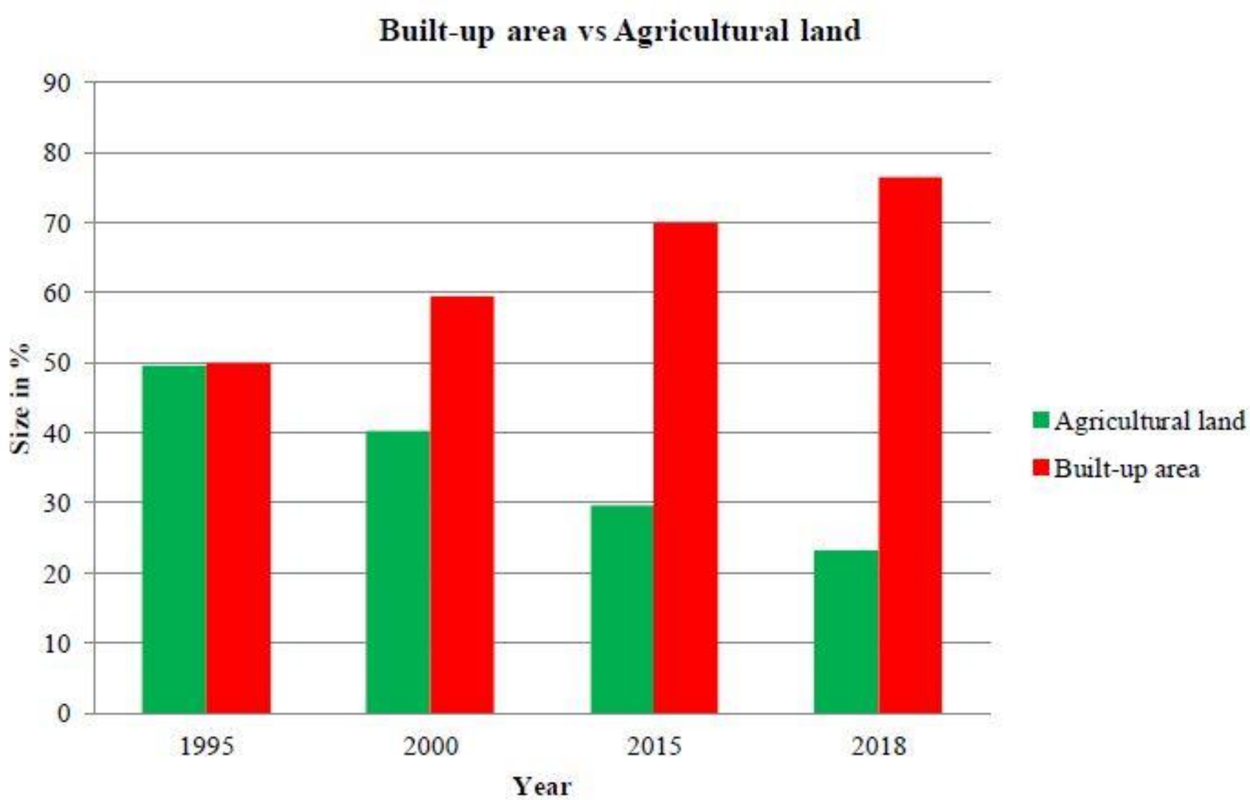

Figure 4.2: A bar chart representing the trend in agricultural and urban areas

4.2 Land Surface Temperature (LST)

Objective: To estimate the land surface temperatures of the study area using Landsat images.

4.2.1 Normalized Difference Vegetation Index (NDVI)

The index is used to estimate the measure of vegetation densities and the values were inversely proportional to the rate of urbanization i.e. the value decreased as urban areas expanded/ increased.

The results obtained from the Landsat-5 image of 1995 had its highest and lowest values as 0.78022 and -0.282051 respectively. The former could be associated with the vegetation cover while the latter showed presence of hard surfaces.

Those from the Landsat-7 ETM+ captured in 2000 revealed an NDVI ranging from 0.6 to -0.574468. The index from the image captured in 2015 range between 0.595103 and -0.157018 while that from 2018 range from 0.606818 to -0.137092.

Using the results indicated above, it was noted that there was a drastic change on the land cover throughout the study period i.e. 1995 to 2018 with the former indicating a high presence of vegetation cover and the latter showing a reduced cover. This rate of change was similar to the LULC changes established herein above and therefore explains the increase of LST in the study area.

The spatial extents of these values are shown in the figure 4.3.

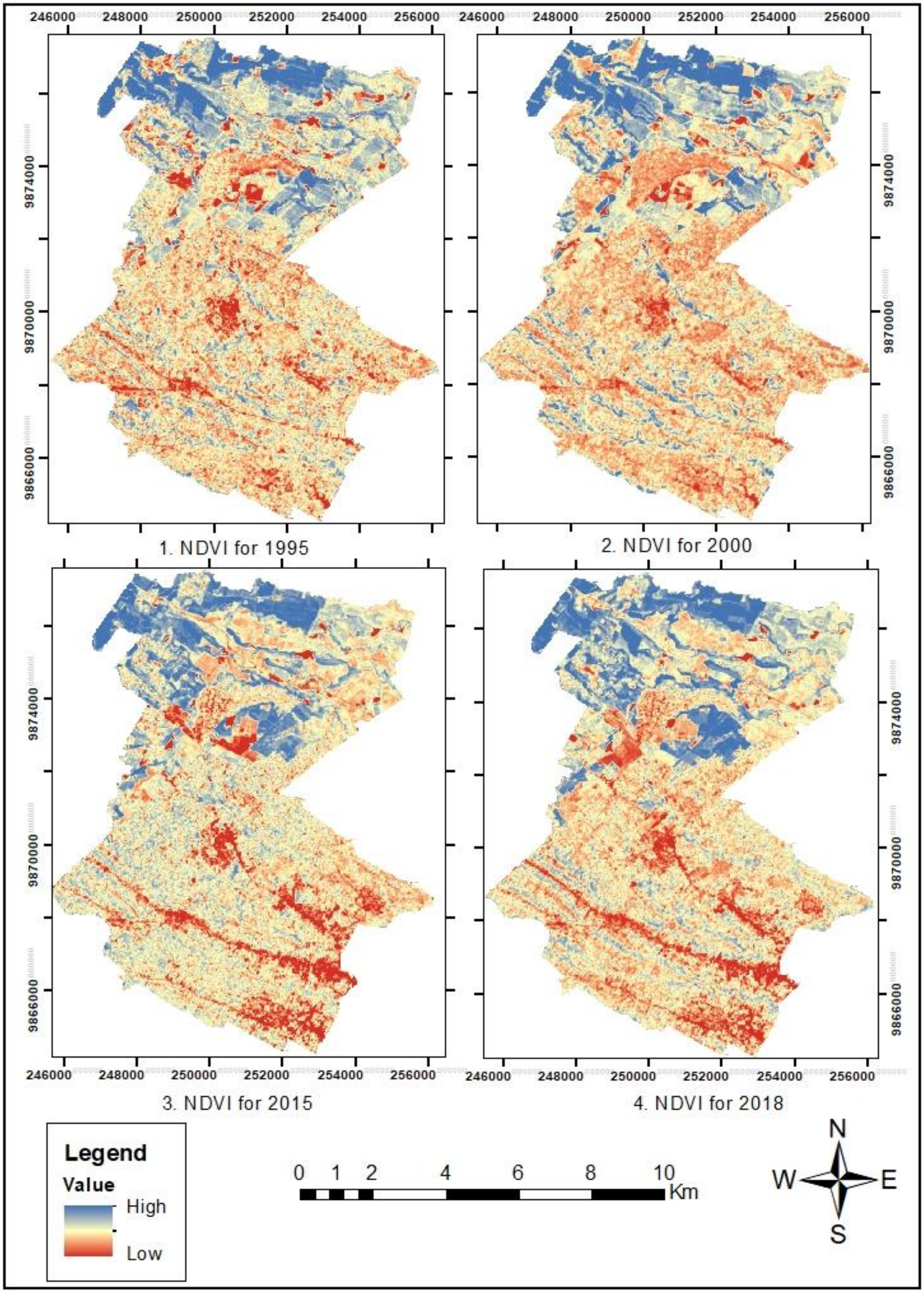

Figure 4.3: NDVI for year 1995, 2000, 2015 and 2018 **Source: Author, 2018**

4.2.2 Land Surface Temperature (LST)

The images, 1995, 2000, 2015 and 2018, were converted to their spectral radiance equivalent. The radiance- high and low, of these images were 9.82 and 8.22, 11.53 and 8.59, 11.78 and 8.91 and 11.75 and 9.30 respectively. The at-sensor brightness calculated by use of this radiance indicated a mean value of 298.1855, 304.448, 306.1775 and 306.0985 respectively. These values were higher in Karuri, Ndenderu, Kihara and Muchatha wards than in Cianda ward.

Since the sub-county was observed to have a heterogeneous surface, there was need to calculate its emissivity while putting into consideration its cavity effect. By use of the results provided above and the estimated cavity effect of approximately 8.34E-3, the Land Surface Emissivity (LSE), whose mean value is 0.988 and a standard deviation of 4.94E-4, was obtained. It is noteworthy that LSE was the same throughout the period.

The hottest surfaces in the study area were estimated to have a temperature of approximately 42.81℃ (in 2000) while the lowest had a temperature of 19.57℃ (in 1995). The high and low temperatures were observed in urban areas of Kihara and Karuri Wards and Cianda wards respectively. The study further revealed that the minimum LST values were increasing at an annual rate of approximately 0.25℃ while the maximum LST values increased by 10.62℃ between 1995 and 2000 and later dropped by 0.75℃ from 2000 to 2018.

Table 4.6 provides the maximum, minimum and mean of the LST calculated.

The spatial extents of the LST in the different epoch are shown on figure 4.4.

Table 4.6: LST for Kiambaa sub-county

Land Surface Temperature (LST)				
	1995	**2000**	**2015**	**2018**
Maximum	32.19	42.81	42.28	42.06
Minimum	19.57	21.79	22.82	25.68
Mean	25.88	32.3	32.55	33.87

Note: Temperature is in Celsius

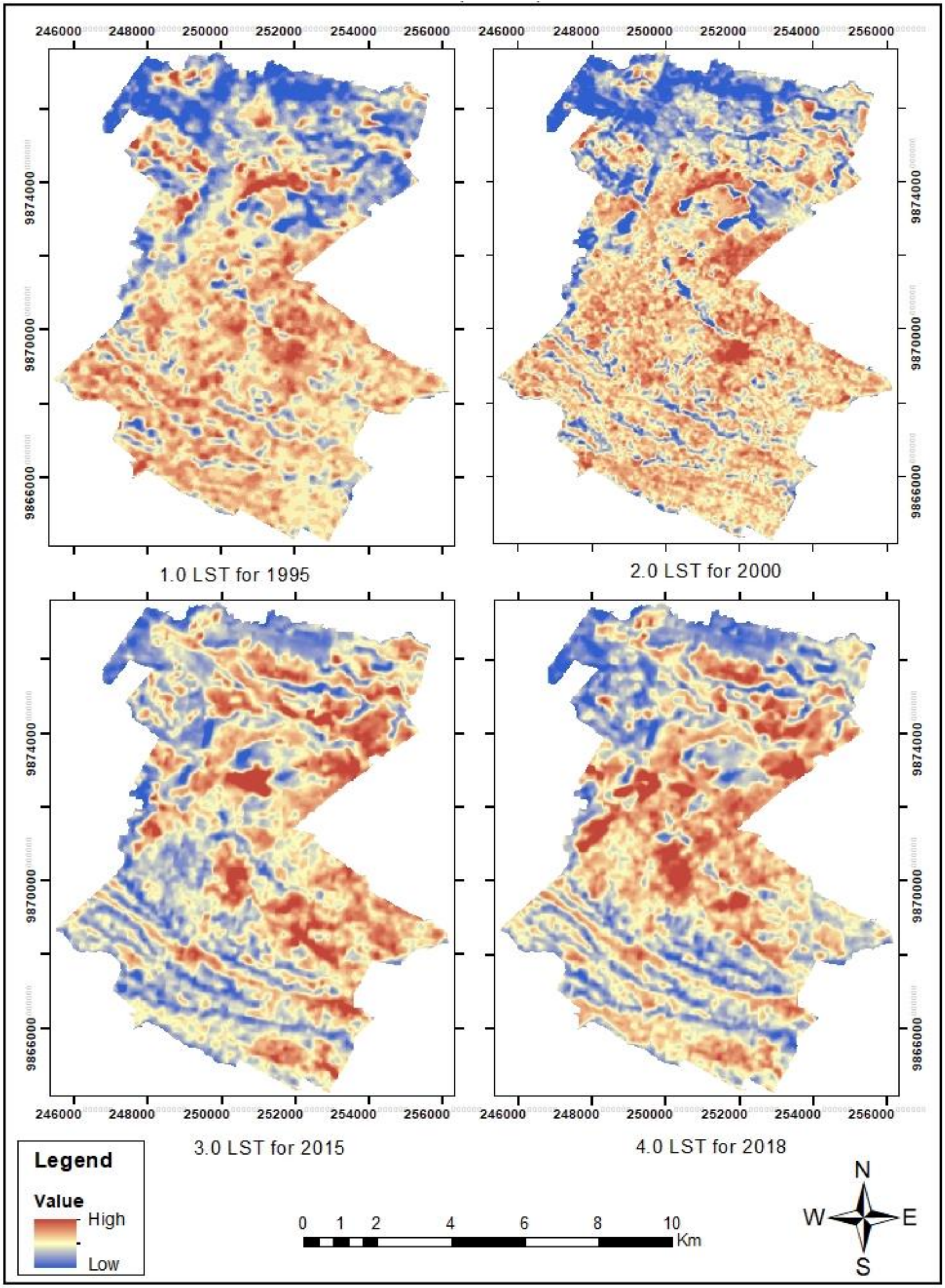

Figure 4.4: LST for year 1995, 2000, 2015 and 2018 **Source: Author, 2018**

4.3 Urban Heat Island Intensity

Objective: To determine the UHI intensity of the study area

The study revealed that there was UHI in the sub-county. This was due to the distinct temperature differences between surfaces in the urban and rural areas. These surfaces were represented by high/ hot temperatures and low/ cool temperatures respectively. The intensity for 1995, 2000, 2015 and 2018 were 12.62°C, 21.02°C, 19.46°C and 16.38°C with an average of approximately 17.37°C as shown in table 4.7.

Table 4.7: UHI for Kiambaa sub-county

Urban Heat Island (UHI)				
	1995	**2000**	**2015**	**2018**
Maximum	32.19	42.81	42.28	42.06
Minimum	19.57	21.79	22.82	25.68
UHI	12.62	21.02	19.46	16.38

Note: Temperature is in Celsius

It was also observed that the UHI intensity had drastically changed over the time period. When plotted on a line graph as shown in figure 4.5, the results could be grouped into two distinct clusters, namely; A and B.

i. **Group A:** The classification represents the drastic increase of the UHI between the years 1995 and 2000. The increase in temperature difference between the rural and urban areas was influenced by the rapid development taking place in the urban places such as Karuri and Ndenderu shopping centres. The development was limited to the extent of the urban areas the temperatures of the urban areas were hotter than those in the surrounding agricultural areas hence the increase.

ii. **Group B:** It represents the UHI changes that were experienced between 2000 and 2018. The reducing UHI can be linked to the rapid rate of urbanization being experienced in the rural areas of the sub-county with the previously agricultural lands being replaced with residential buildings, therefore, making the areas warmer i.e. from a minimum temperature of 21.79°C to 25.68°C in 2000 and 2018 respectively. The resultant led to the reducing temperature difference between the rural and urban areas over the 18 year period.

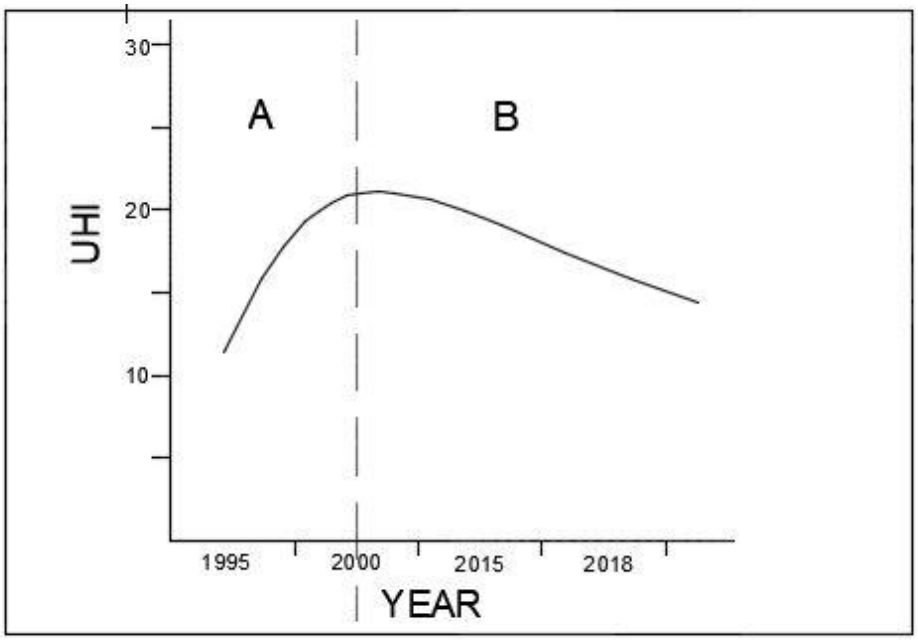

Figure 4.5: A graph showing UHI intensity between 1995 and 2018

4.4 Correlation between LULC and UHI

Objective: To analyse the correlation between UHI effect and LULC change

4.4.1 Correlation with Agricultural Land

4.4.1.1 Correlation between UHI effect and Agricultural areas

The analysis was done by use of the Pearson method in a Microsoft Excel environment. The results indicated both a positive and a negative correlation between the UHI effect and LULC changes from 2000 to 2018 and 1995 to 2000 respectively as shown in table 4.8.

The results can be summarized as follows:

a) A positive correlation of 0.946 between years 2000 to 2018: The correlation showed that the UHI effect in the study area was directly proportional to the size of land under agricultural use, therefore; it decreased as the agricultural areas decreased in size. This was due to the rapid development being experienced in the rural areas that made their surface temperatures higher hence the reducing overall UHI effect.

b) A negative correlation of -1 between years 1995 to 2000: This indicated that the UHI effect in this epoch was inversely proportional to the size of agricultural land. Therefore, the temperature difference increased as the vegetated or agricultural land reduced.

4.4.1.2 Correlation between LST and Agricultural areas

The analysis indicated a negative correlation, -0.867 and -1, between the LST and the size of agricultural land for epoch 2000 to 2018 and 1995 to 2000 respectively. This means that a decrease in the size of land under agricultural use resulted to an increase in LST values.

Table 4.8: Correlation analysis results

Correlation analysis for UHI effect		
Class	**1995-2000**	**2000-2018**
Agricultural lands	-1	0.946
Built-up areas	1	-0.947
Water bodies	-1	0.652

Correlation analysis for LST		
Agricultural lands	-1	-0.869
Built-up areas	1	0.87
Water bodies	-1	-0.782

4.4.2 Correlation with Built-up Areas

4.4.2.1 Correlation between UHI effect and Built-up areas

The results obtained from the analysis indicated that there was a positive as well as a negative correlation between the two variables. The former, represented by a correlation value of 1, was experienced between years 1995 and 2000 and meant that the effect increased at almost the same rate as the built-up area while the latter, a negative correlation of -0.947 experienced between years 2000 and 2018, indicated that an increase in the size of the built-up area resulted to a decrease of the UHI effect.

4.4.2.2 Correlation between LST and Built-up areas

A strong or positive correlation, 0.87 and 1 for the epoch 2000 to 2018 and 1995 to 2000 respectively, was recorded between the two variables. Like in many other studies, the changes in the size of urban areas were directly proportional to the LST changes. Urban sprawl lead to replacement of soft surfaces, such as vegetation cover, which have high emissivity with hard surfaces such as concrete block which have low emissivity.

4.4.3 Correlation with Water Bodies

On one hand, the results indicated a negative correlation i.e. -1 between both the UHI effect and LST and the water bodies in the epoch 1995 to 2000. This means that the variables were inversely proportional to each other hence an increase in the size of water surface area would reduce both the LST and the resultant UHI effect. A larger water surface area increases the rate of evaporation which in turn reduces the surface temperature of the water as well as the surrounding surfaces.

On the other hand, the 2000 to 2018 epoch was represented by two different correlation results namely:

i. A weak but positive correlation of 0.652 between the water bodies and the UHI effect where a decrease in the UHI would lead to a proportional decrease in surface area of the water bodies. In this case the reducing UHI is caused by the rapid urbanization experienced in the rural areas therefore leading to the cutting down of trees and reduced precipitation.

ii. A negative correlation of -0.782 between the surface area of the water bodies and the LST. The mean LST in the epoch had increased gradually due to the construction of real estates in the rural areas. Although the rapid urbanisation would increase surface run-off, dams were the main source of water both during the construction phase of buildings and intensive agricultural activities such as large-scale irrigation and greenhouses being practiced in the area. It can also be argued that the water bodies shrunk in size due to climate change.

4.5 Discussions of the Results

The study, on one hand, revealed that the size of the agricultural lands reduced from 49.50 per cent to 23.21 per cent between 1995 and 2018 respectively. An increase of the built-up area from 50.06 to 76.44 per cent was also recorded over the same period. This can be attributed to the rapid urbanisation being experienced in the area where agricultural land is converted to real estate development. The rate of loss of agricultural land was therefore inversely proportional to the increase of built-up area i.e. reduction in the size of land under agricultural use resulted to a proportional increase of built-up areas.

On the other hand, the LST results indicated an increase in the highest temperatures estimated using the Landsat images from 32.19℃ to 42.81℃ in 1995 and 2000 respectively and a slight decrease to 42.06℃ from 2000 to 2018. The lowest temperatures also increased from 19.57℃ to 25.68℃ in 1995 and 2018 respectively. The resultant UHI effect increased from 12.62℃ to 21.02℃ between 1995 and 2000 respectively and later decreased to 16.38℃ in 2018. It was noted that the increased effect was due to the concentration of developments in the extents of former municipalities and shopping centers. It was, however, observed that the effect is reducing at an annual rate of approximately 0.26℃ due to the rapid urbanization being experienced in the rural areas which have made them warmer and the resultant effect lower.

The correlation analysis between the LULC changes and UHI revealed the following:

a) Correlation between UHI and changes experienced in built-up areas
   - A positive correlation of 1 was noted between 1995 and 2000. The epoch was characterized by rapid development within the extents of urban areas hence these areas hotter than the surrounding rural areas.
   - A negative correlation of -0.947 between 2000 and 2018 where rapid urbanization in rural areas was observed. The agricultural land was converted to real estate developments such as apartments. These changes made these areas warmer hence the negative correlation.

b) Correlation between UHI and changes in the size of land under agricultural use
   - A positive correlation of 0.946 was observed between 2000 and 2018. This meant that the variables were directly proportional to each other and that the reducing size of vegetation cover led to a decrease in UHI effect
   - It was also noted that the two variables were inversely proportional to each other between 1995 and 2000. The relationship was represented by a negative correlation of -1.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In this study, the relationship between the UHI effect and the LULC changes by use of Landsat images was analysed. Using images acquired on 30th January 1995, 21st February 2000, 5th January 2015 and 29th January 2018, the LULC changes were mapped, the LST and NDVI estimated, the resultant UHI effect determined and the correlation between the variables analysed.

The study area was classified into three classes namely; built-up areas, agricultural land and water bodies. The resultant images were within the required accuracy range and the results obtained showed that the built-up area increased from 50.06 to 76.44 per cent in 1995 and 2018 respectively while vegetation cover and/or agricultural land reduced from 49.5 to 23.21 per cent over the same time period. These changes were more dominant in Karuri, Ndenderu, Kihara and Muchatha wards than in Cianda ward where there was no significant change on the lands under agricultural use.

The LST values estimated revealed that the lowest temperature was in 1995 (19.57°C) while the highest was in 2000 (42.81°C). The study further indicated that the lowest temperatures were increasing at an annual rate of approximately 0.25°C, over the 24 year period, while the highest values increased by 10.62°C from 1995 to 2000 and later dropped by 0.75°C from 2000 to 2018. These changes could be attributed to the rapid rate of urbanization being experienced in the area. It was also evident that the UHI effect increased as well as decreased between 2000 to 2018 and 1995 to 2000 respectively. The effect ranged between 12.62°C to 21.02°C in 1995 and 2000 respectively and reduced to 16.38°C in 2018.

From the foregoing, it is evident that the rate of urbanisation is inversely proportional to the loss of agricultural land and/or vegetation cover. These changes also influence the Land Surface Temperatures and ultimately the Urban Heat Island effect. The correlation analysis carried out revealed a negative correlation between UHI and built-area and a positive one between UHI and agricultural land, therefore, the UHI is inversely proportional to the rate of urbanization and directly proportional to the loss of agricultural land or vegetation cover.

In general, the UHI effect has been decreasing over the past 18 years at an annual rate of approximately 0.26°C i.e. rural or agricultural areas have become warmer and the surface temperature difference between them has reduced. If the current rate of urbanization remains unchecked, the rapid conversion of agricultural lands to real estate developments will not only result to further increase of surface and air temperature to uncomfortable levels but also loss of arable agricultural land making the sub-county as well as the county food insecure. It is also evident that the rapid urbanization will lead to the formation of a regional heat island where the temperatures of the sub-county would be higher than those of the neighbouring sub-counties.

The results obtained from this study can therefore be used across the urban fringe to develop action area maps, zoning policies, planning strategies and regulations that reduce the effects of UHI as well as uncontrolled urban sprawl.

5.2 RECOMMENDATIONS

In order to reduce the loss of agricultural land and the rapid urbanization being experienced in the sub-county, county planners and policy makers should develop and implement land use planning policies and action area maps geared at reducing further urban sprawl. The policies will regulate the trend by ensuring that conversion of agricultural land to built-up areas is done while keeping in mind the effects of such change and make sure that buildings are erected only in designated spaces across the sub-county.

It was also evident that the urban areas had high surface temperatures which, if remain unchecked, can lead to health complications (UN DESA, 2017) as well as higher energy consumption (EPA, 2008). Therefore, planning regulations geared at maintaining and increasing the proportion of vegetation cover, public spaces and water bodies in urban areas should be implemented. According to Adeyeri et al. (2017), the presence of vegetation directly influences earth's albedo i.e. it is inversely proportional to surface temperature. The greenery aids in cooling the environment through evapotranspiration and provides shade hence lower both the surface and air temperatures. Furthermore, architects working in the sub-county should be encouraged to design green buildings. The structures would not only maintain a low carbon foot print but would also incorporate designs and techniques that reduce their overall energy consumption. As a result of reducing the high surface temperatures, the UHI effect would also decrease at the same proportion. It is worth noting that the current reducing trend of the effect is due to the warming rural/ agricultural areas.

There is need to adopt the use of geospatial technologies in the analysis of LULC changes, rate of urbanization as well as estimating the surface temperatures in the Nairobi urban fringe for better formulation and implementation of planning regulations that guarantee a safe, clean and sustainable environment as envisioned in the Constitution of Kenya, 2010. Njiru (2016) notes that prompt use of updated land use plans as well as remote sensing techniques can be beneficial for evaluating and monitoring urban growth.

Finally, further research should be carried out to investigate if the loss of agricultural land has any effect to the overall agricultural productivity of the area as well as factors that contribute to the rapid rate of urbanization being experienced in the area. Furthermore, the research can be extended using high resolution imagery for better land use classification as well as the analysis of the LULC changes, LST and UHI effect. Other correlation techniques can also be employed and the results compared to the ones published in this study. There is also need to map out the hot and cold spots in the sub-county for better development and implementation of area specific action plans and zoning policies.

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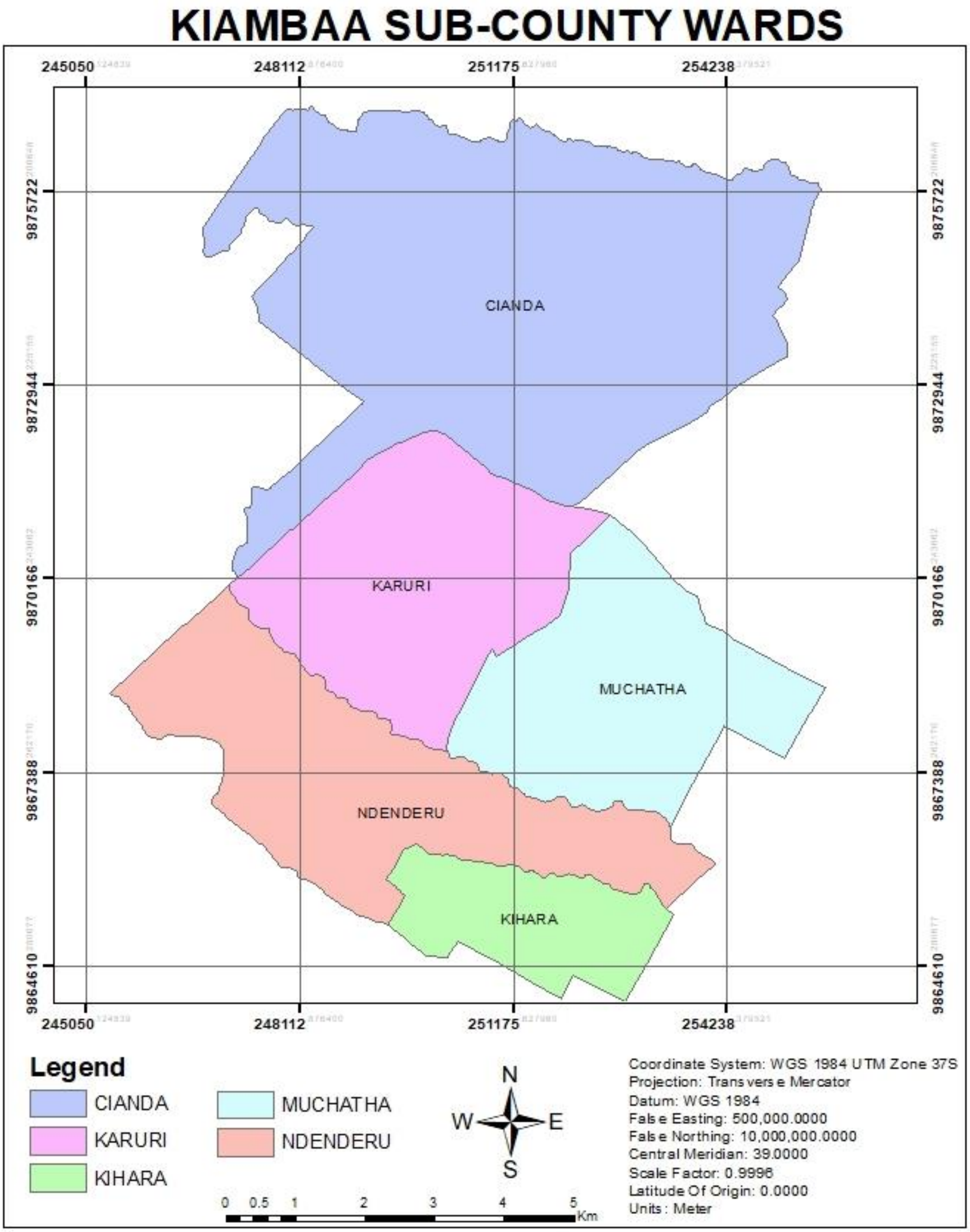
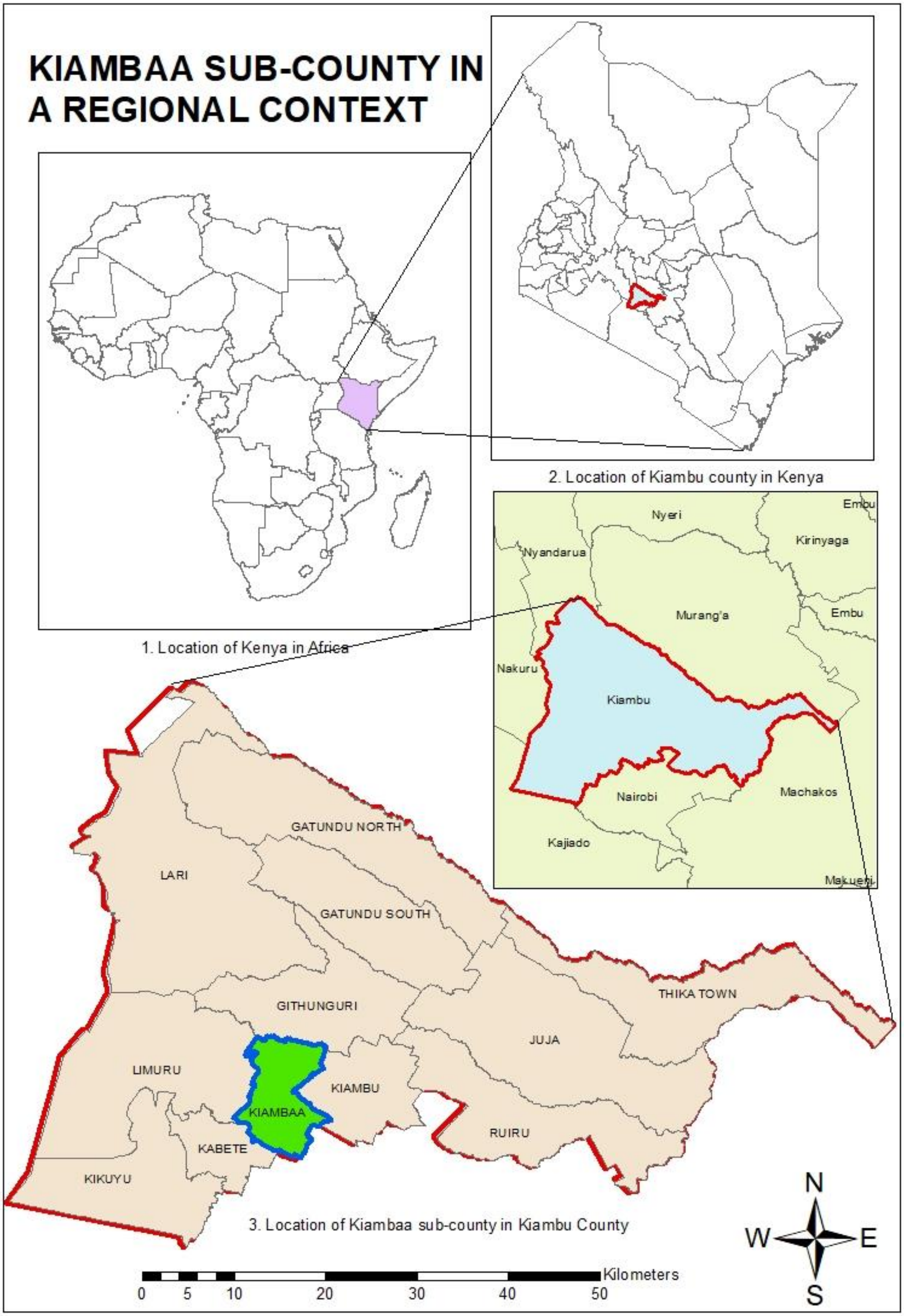
APPENDICES

Appendix A: Location of Kiambaa sub-county

Appendix A1: Kiambaa sub-county wards

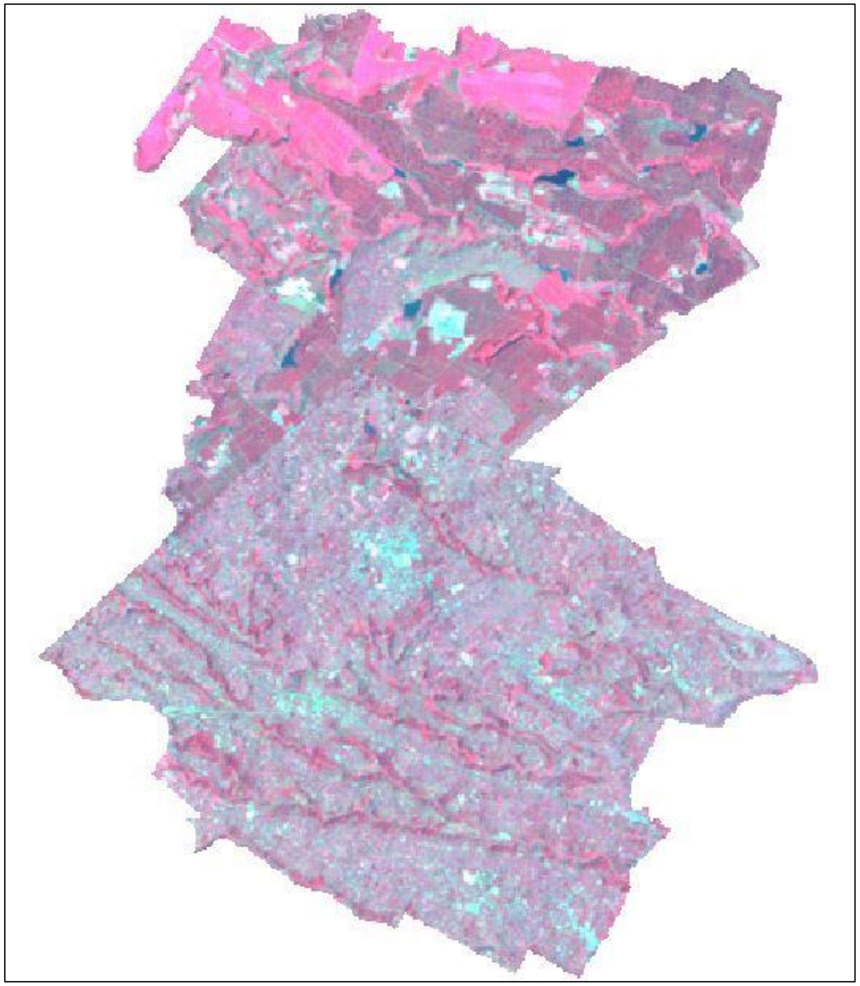


Appendix A2: Kiambaa sub-county in a regional context

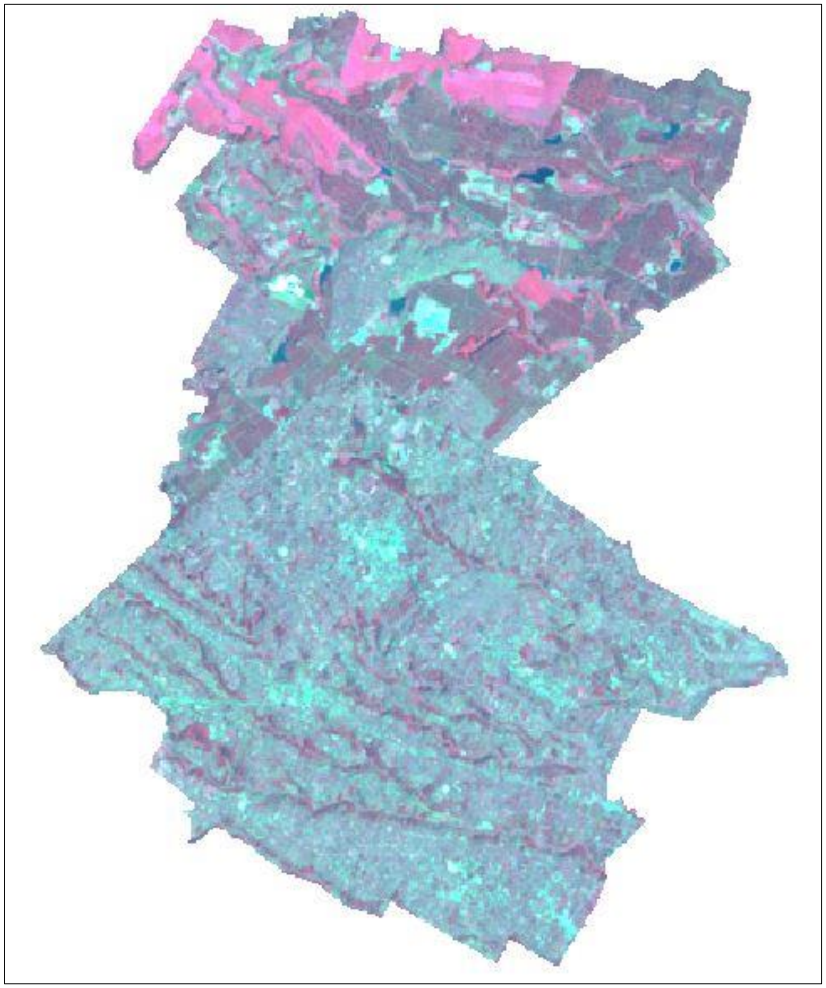


Appendix B: False Colour Composite (FCC) images

Appendix B1: FCC images for 1995 and 2000

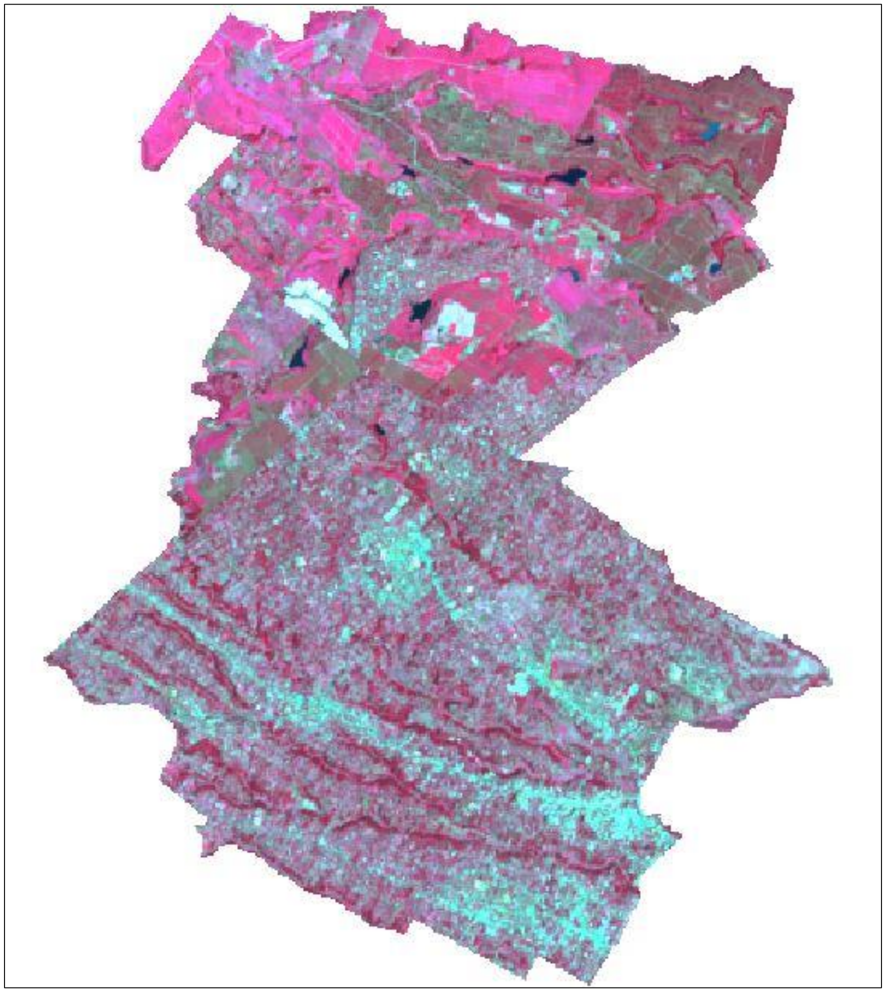


a) 1995

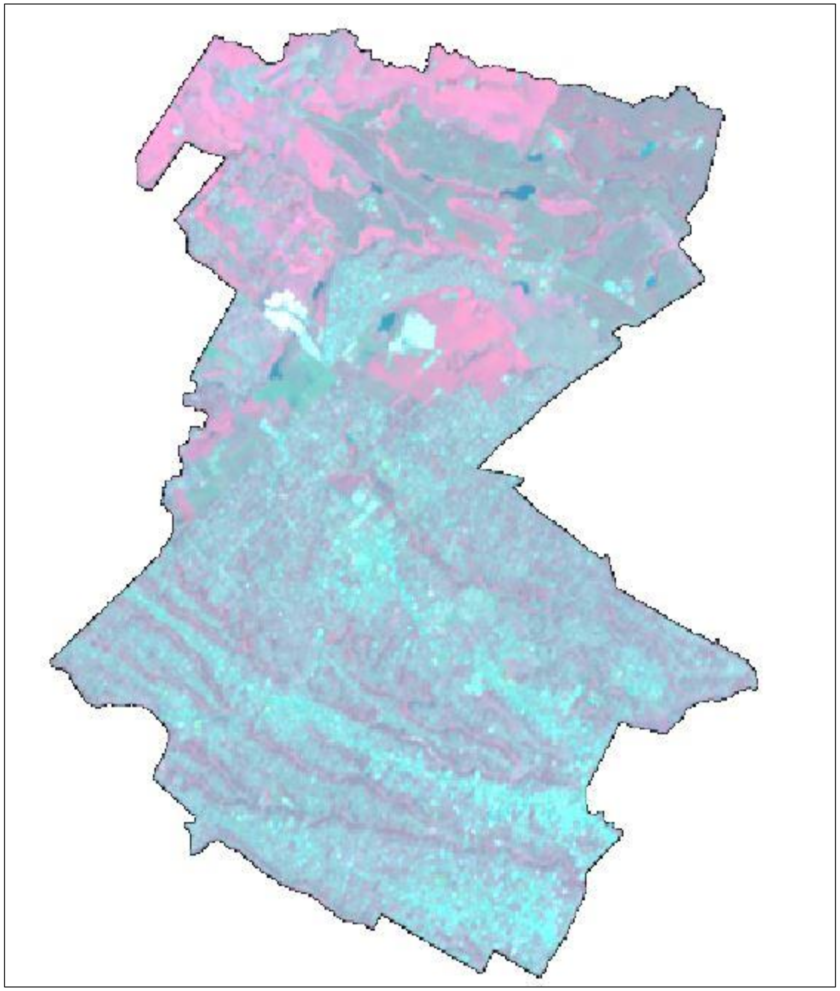


b) 2000

Appendix B2: FCC images for 2015 and 2018



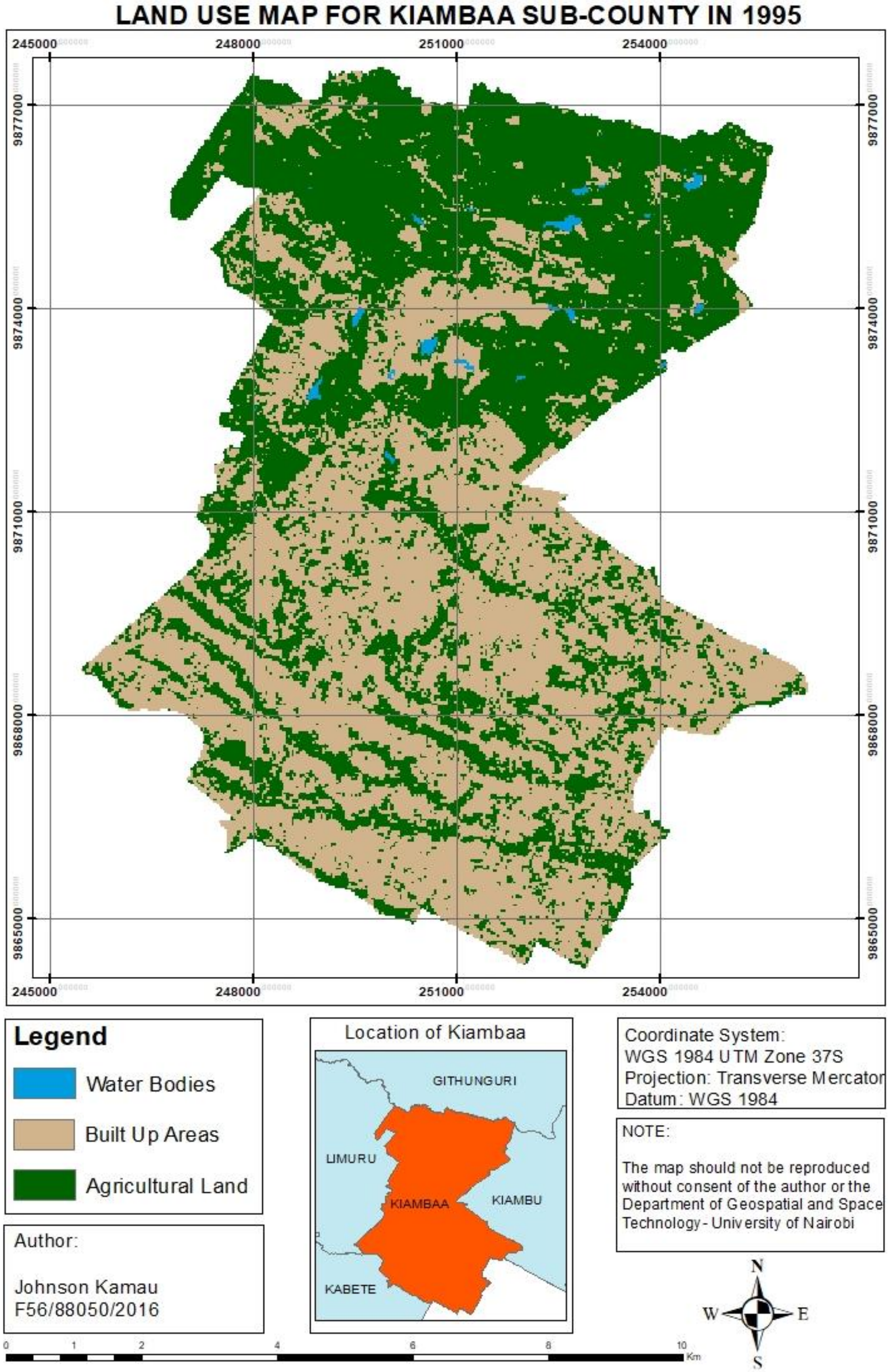
a) 2015



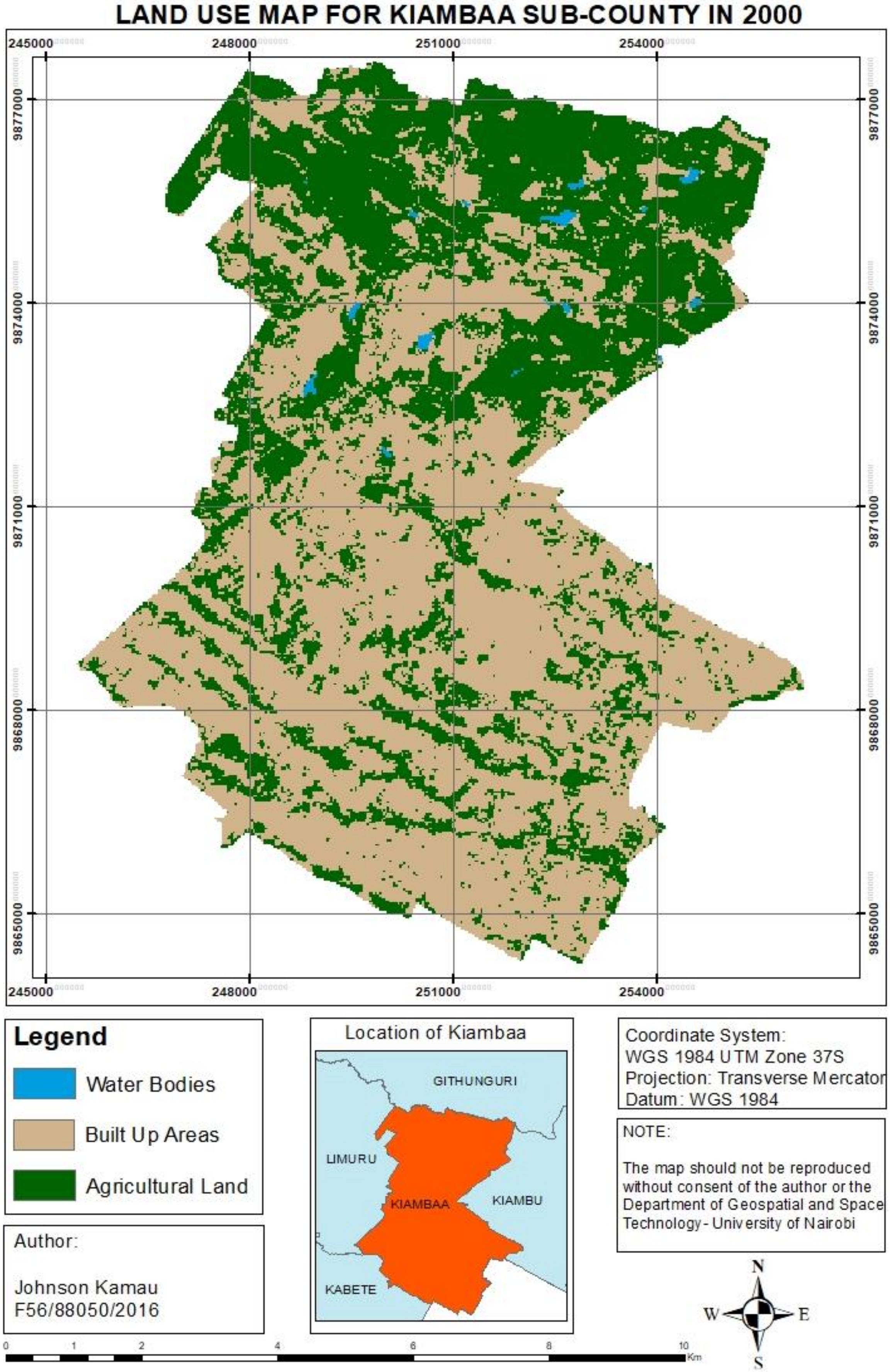
b) 2018

Appendix C: Land use classes

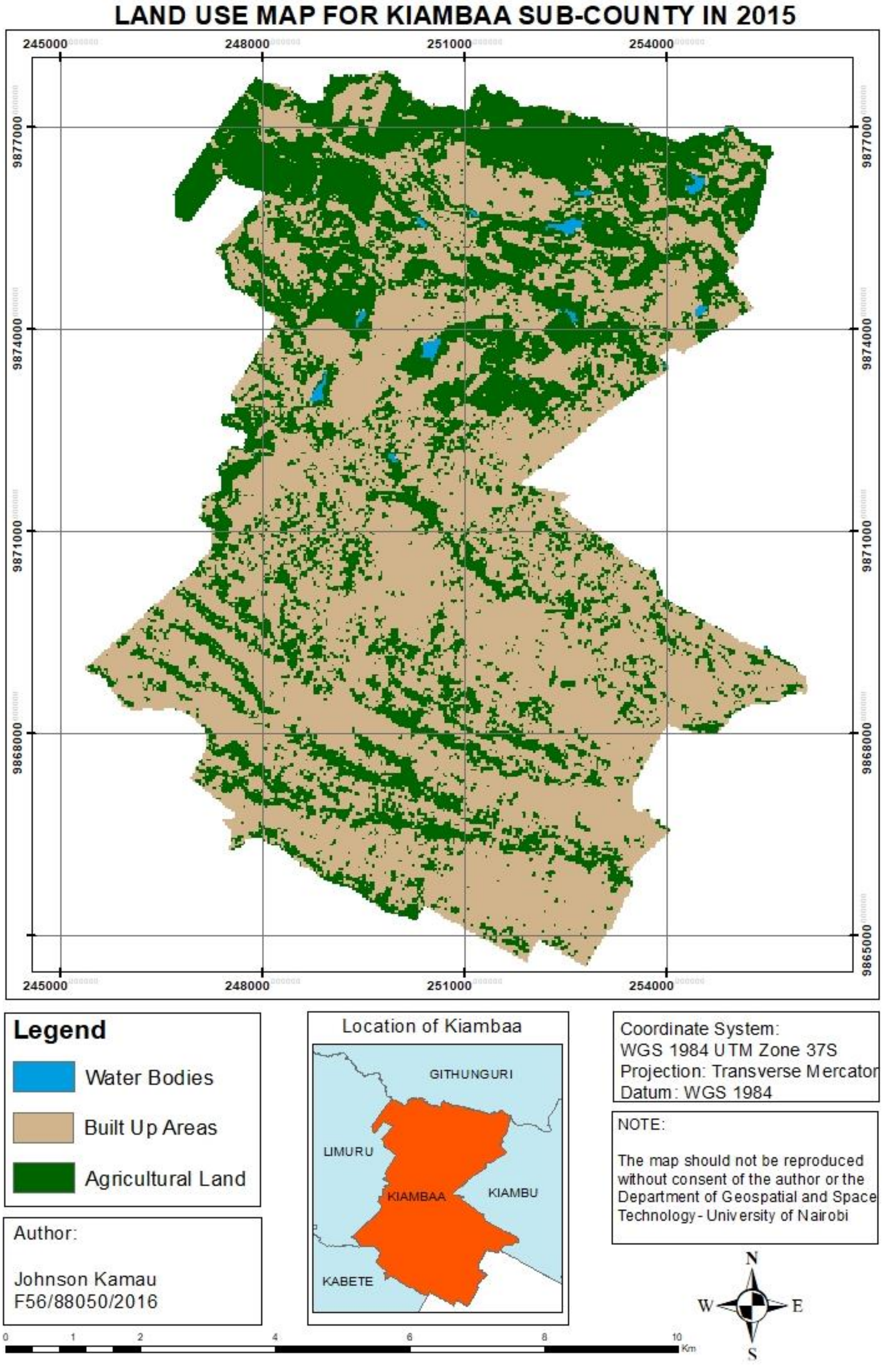
Appendix C1: Land use in 1995



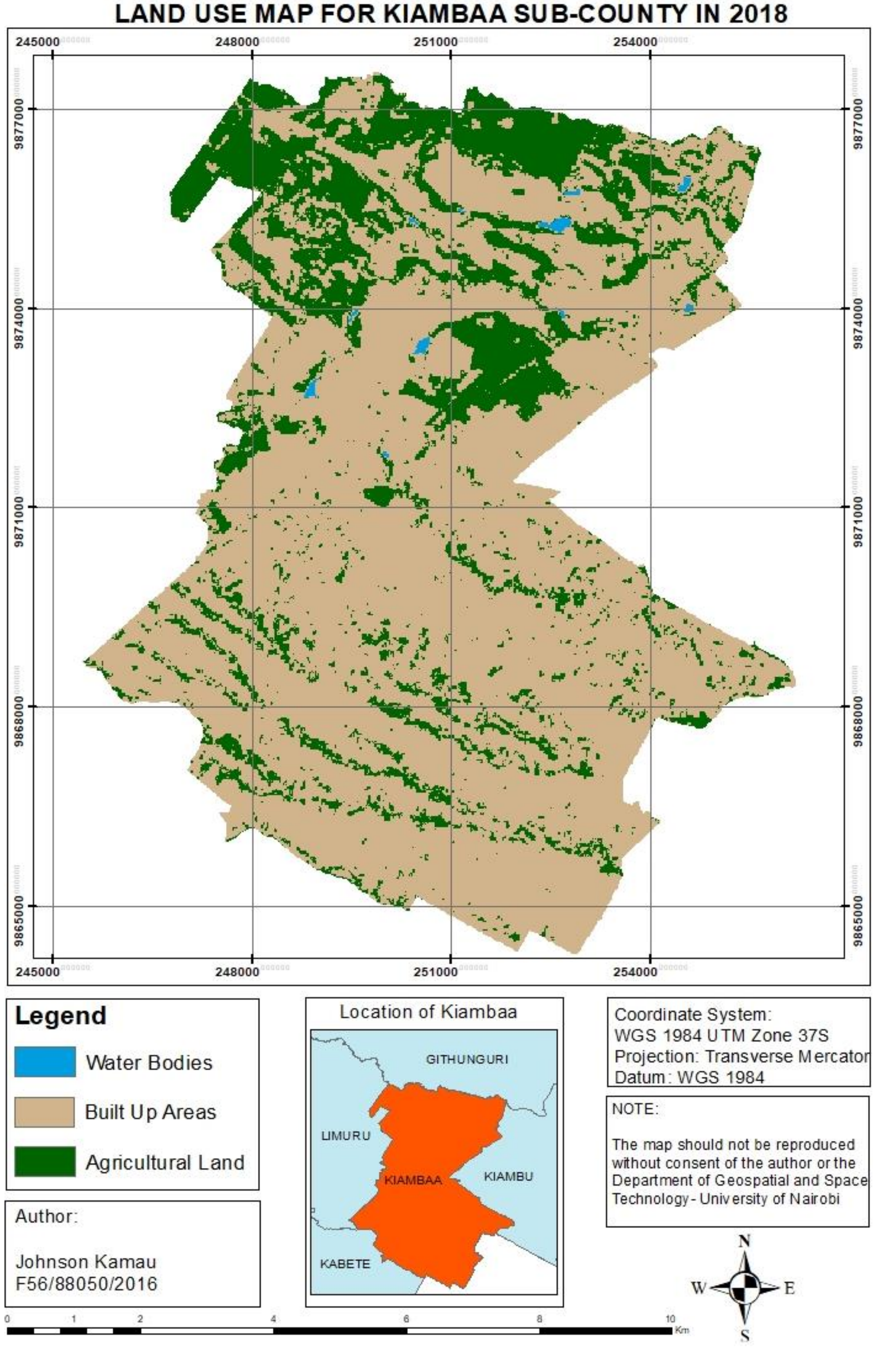
Appendix C2: Land use in 2000



Appendix C3: Land use in 2015

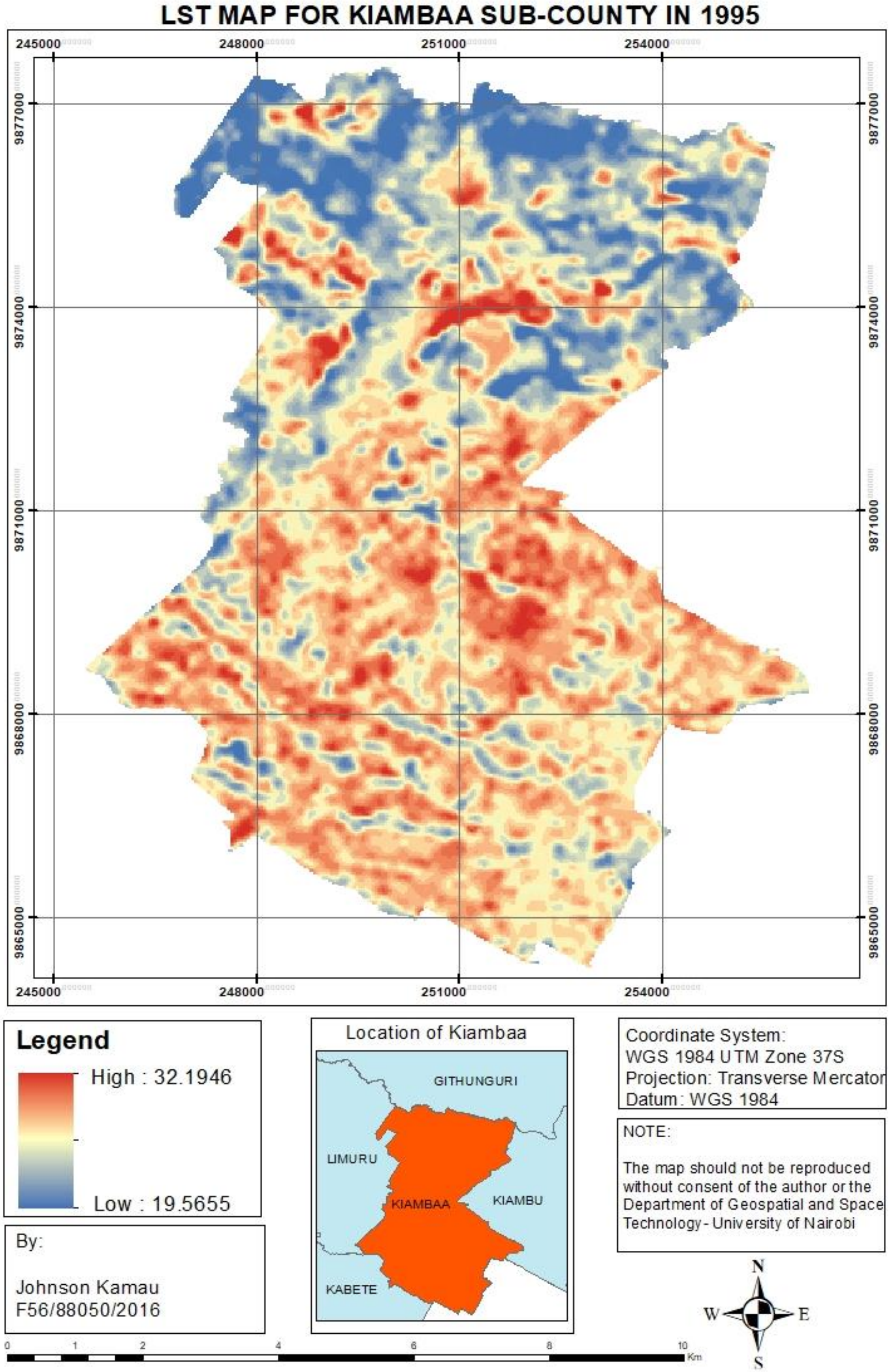


Appendix C4: Land use in 2018

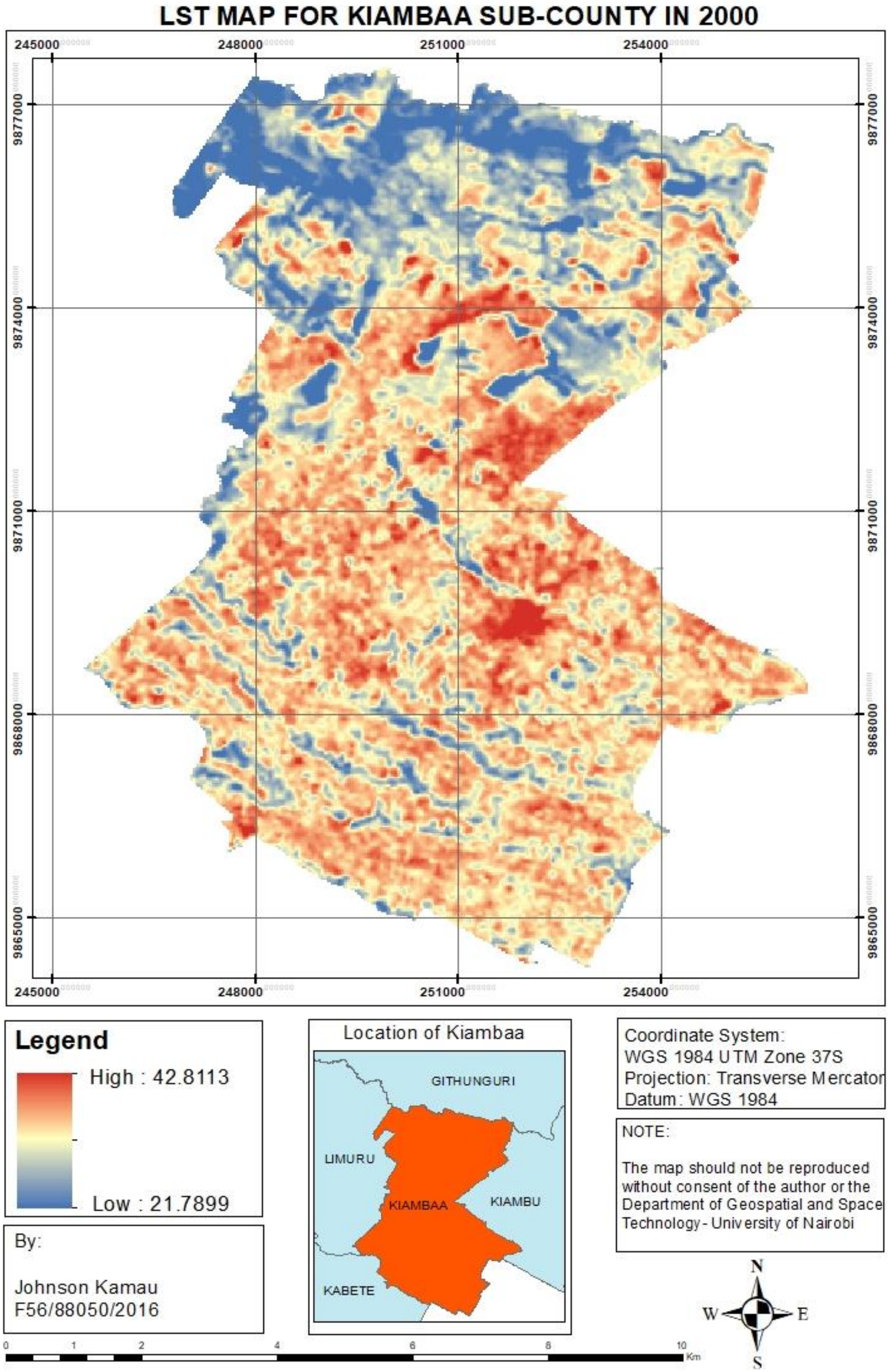


Appendix D: LST maps

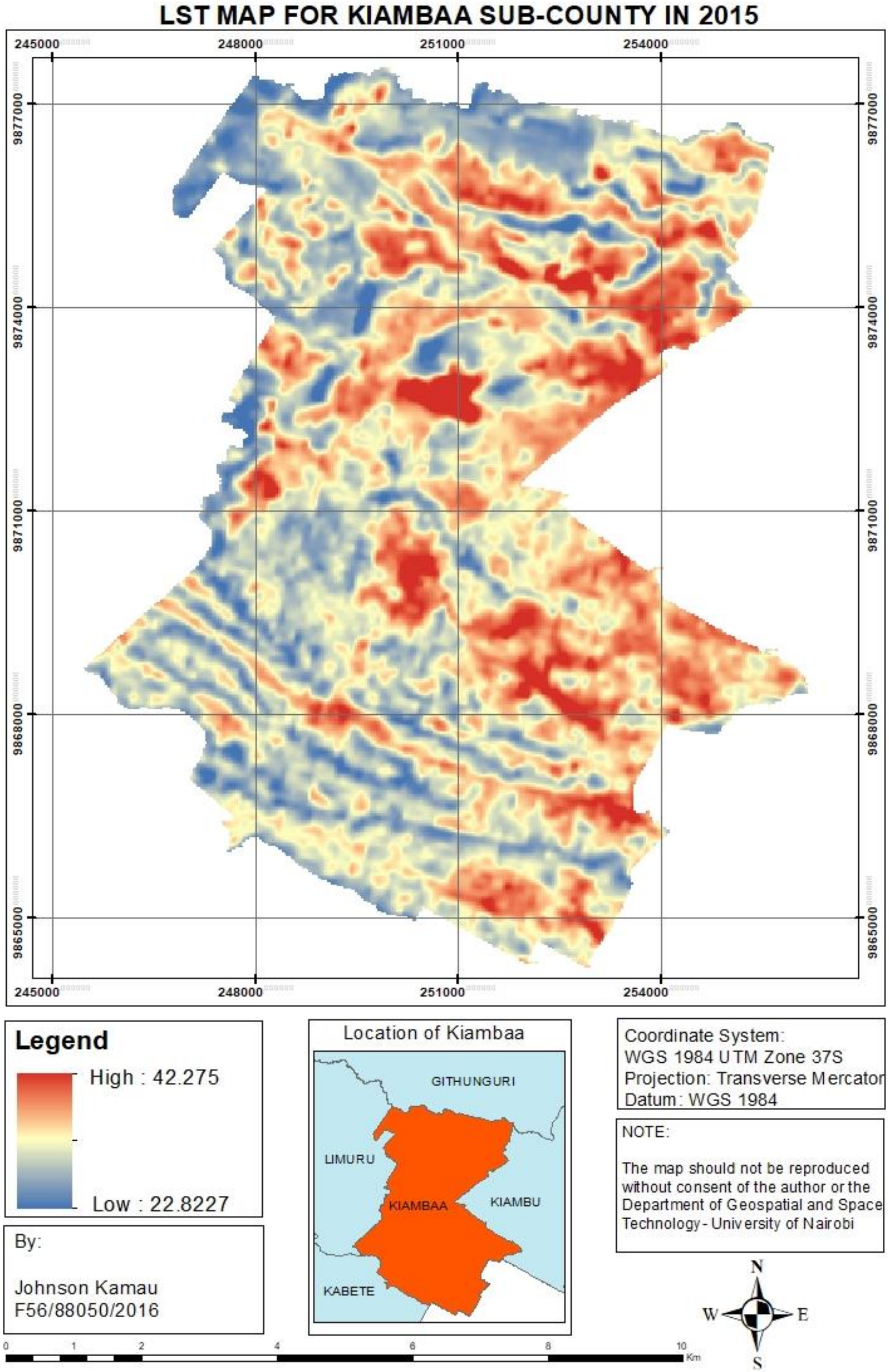
Appendix D1: LST in 1995



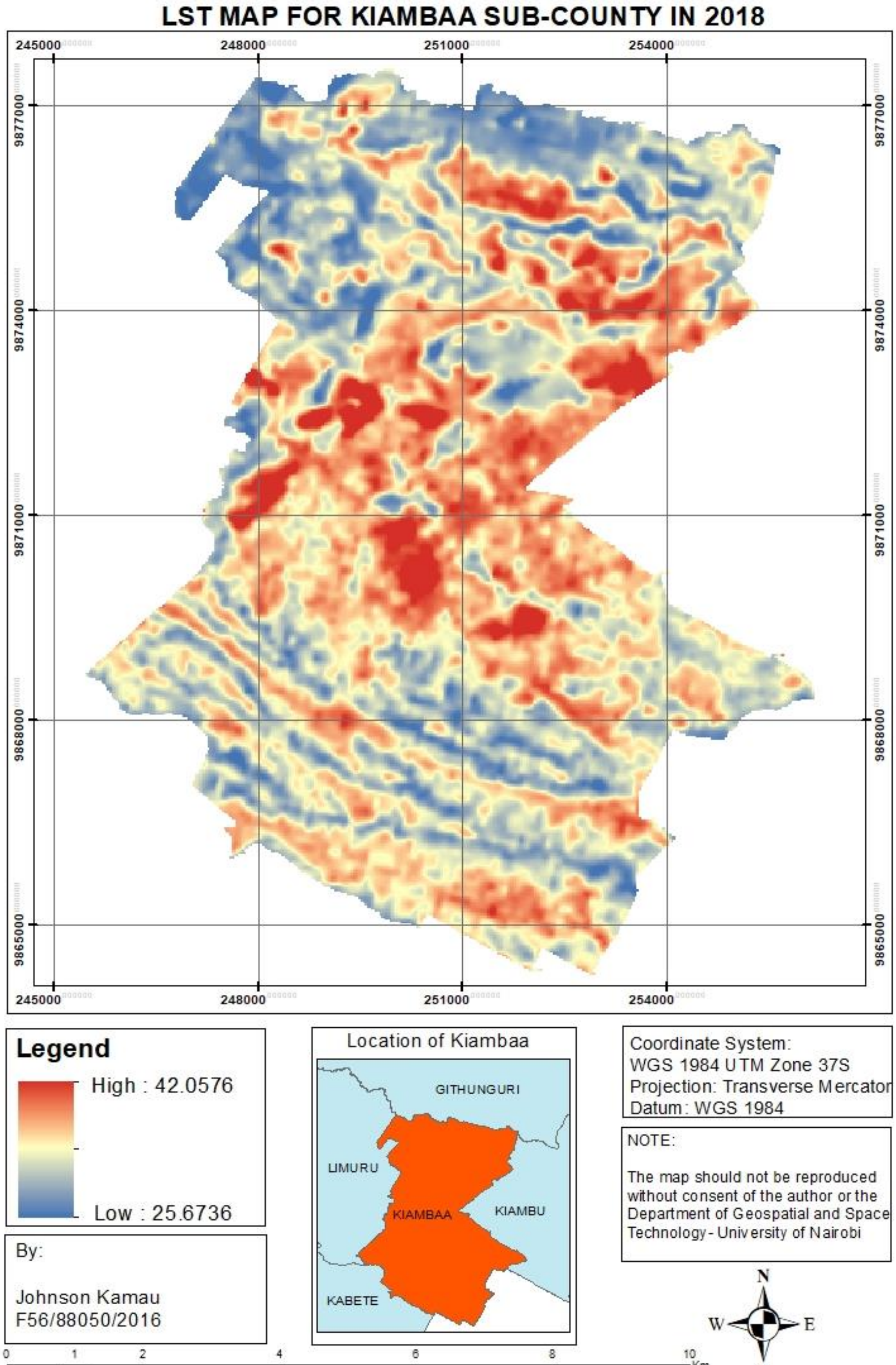
Appendix D2: LST in 2000



Appendix D3: LST in 2015

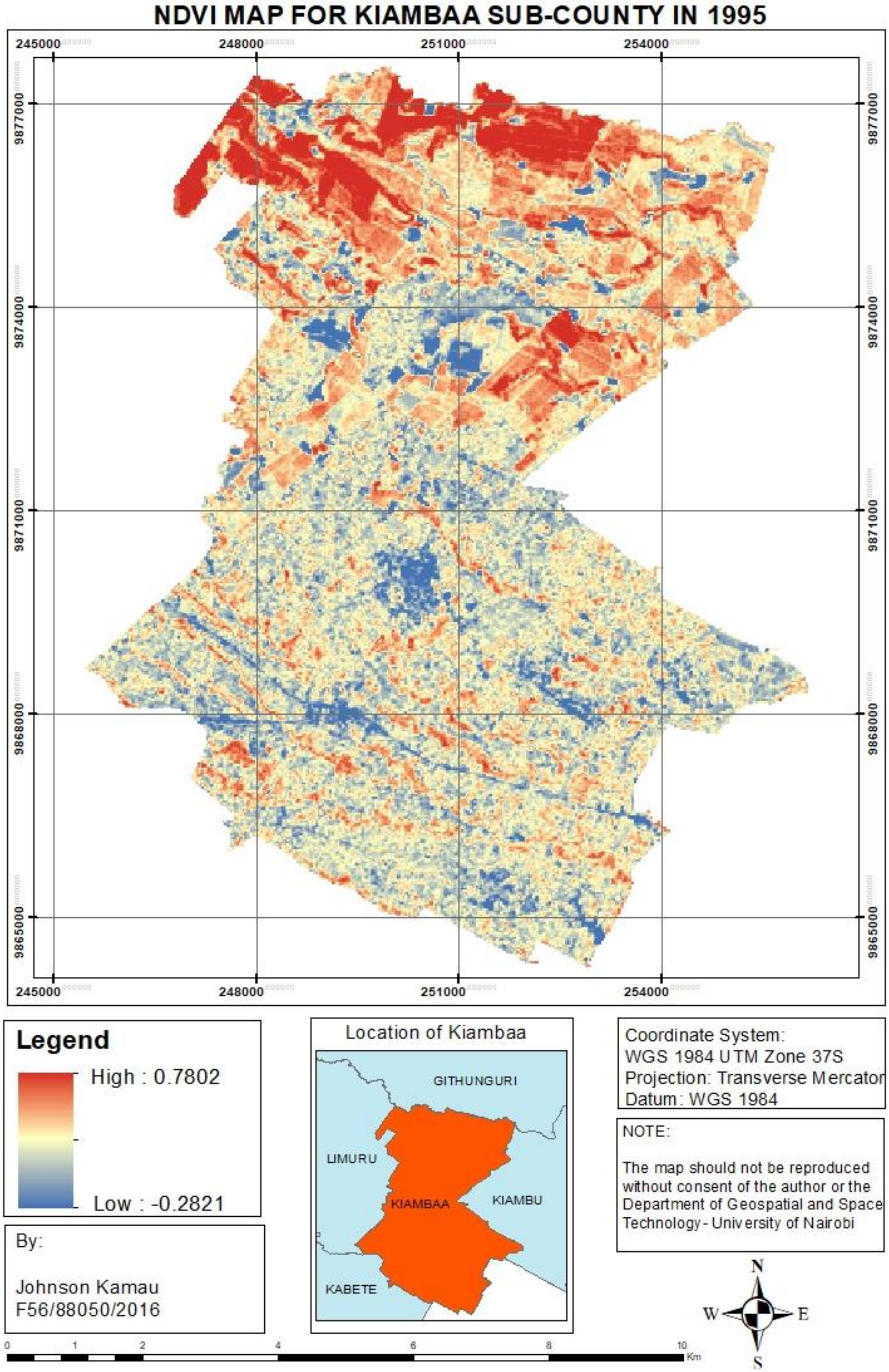


Appendix D4: LST in 2018

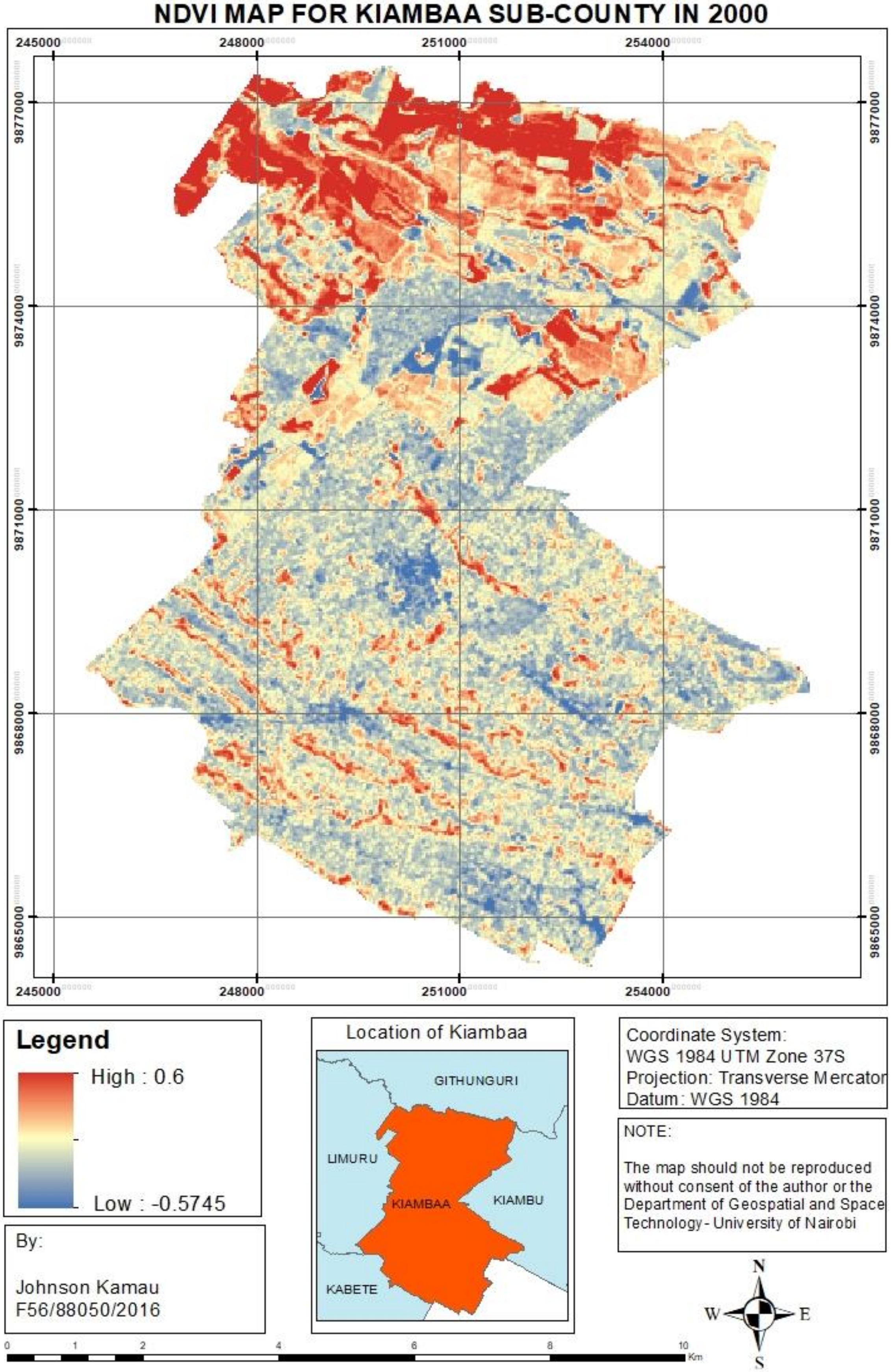


Appendix E: NDVI maps

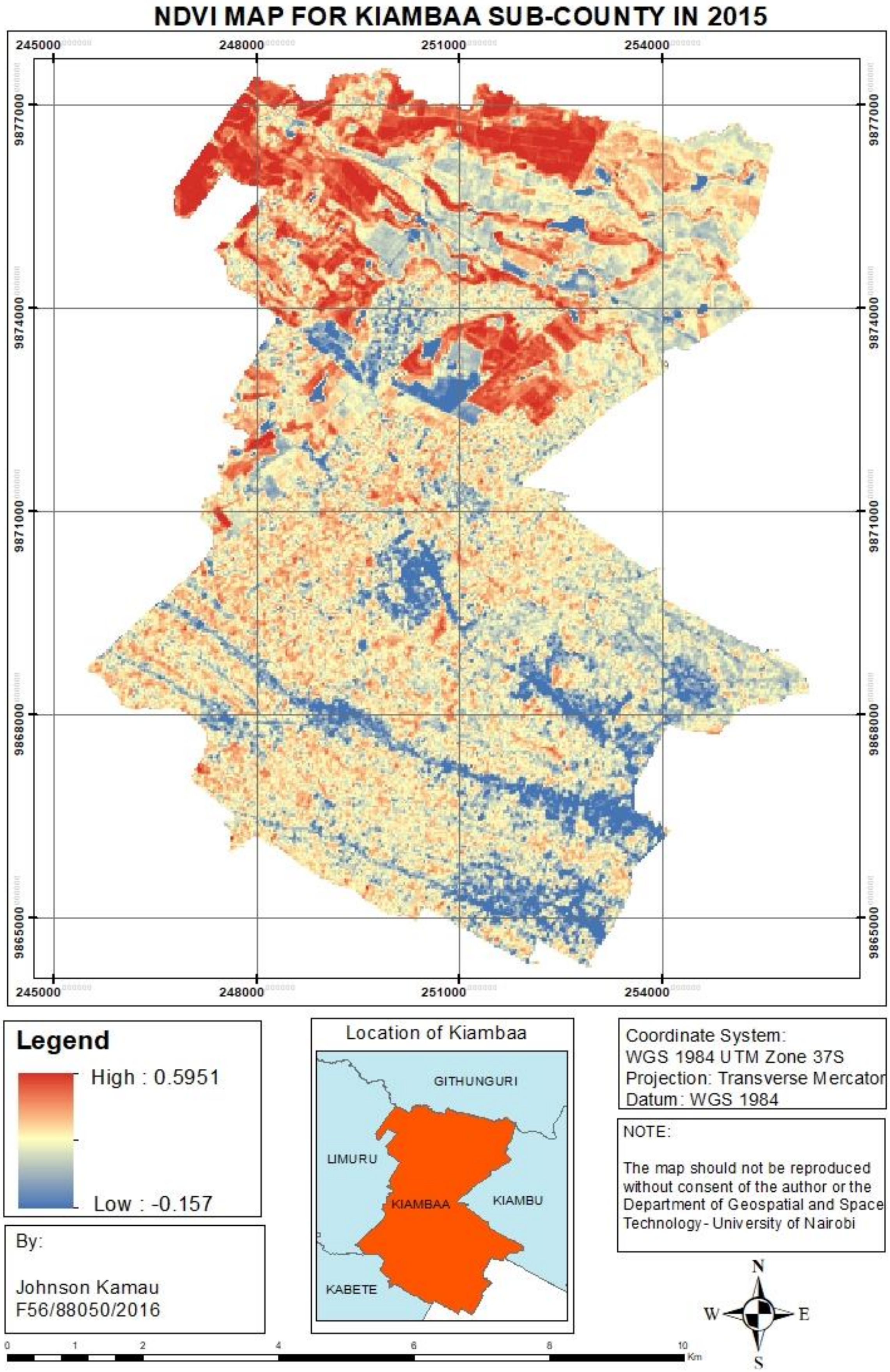
Appendix E1: NDVI in 1995



Appendix E2: NDVI in 2000



Appendix E3: NDVI in 2015



Appendix E4: NDVI in 2018