UNIVERSITY OF NAIROBI

ASSESSMENT OF LAND USE LAND COVER CHANGE AND ITS IMPLICATIONS ON AGRICULTURAL LAND: CASE STUDY; KIMININI SUB-COUNTY IN TRANS NZOIA COUNTY, KENYA.

CHEPKWONY TITUS KIPKOECH

F56/34670/2019

A Project Report Submitted to the Department of Geospatial and Space Technology in Partial Fulfillment of the Requirements for the Award of the Degree Of:

Master of Science in Geographic Information Systems

AUGUST, 2021

Declaration

I, Chepkwony Titus 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 degree in any other Institution of Higher Learning.

Chepkwony Titus Kipkoech ………………………… 06/09/2021

Signature **Date**

This project report has been submitted with approval of university supervisor.

Dr.-Ing. S M Musyoka ………………………… 06/09/2021

Signature **Date**

Abstract

Trans Nzoia County is commonly known as Kenya's bread basket due to large scale production of maize and seeds. The weather conditions and soil are favourable for agricultural production and more specifically maize, which is Kenya's staple food. However, past reports have showed that maize production in Kenya have been on a spiral fall in recent years forcing the government to import from neighbouring countries to cover up for the deficit. The spiral fall in production is as a result of increased population which has led to land use land cover change and subdivision of agricultural lands to smaller uneconomic units. This research project focussed on the use of GIS and remote sensing tools to analyse and detect changes in land use land cover and its implications on agricultural land in Kiminini Sub-county. The approach used, entailed the analysis of Landsat satellite images for the past 20 years with the support of ancillary data to help establish and detect changes in land use land cover. Landsat satellite images obtained for analysis were for the years 2000, 2010 and 2020, where multispectral images from the Earth Thematic Mapper (ETM+), Thematic Mapper (TM) and Operational Land Imager (OLI) were used respectively.

The research utilized ArcGIS and QGIS software's analysis tools to perform supervised and unsupervised classification of the satellite images. The analysis outputs revealed that agricultural land increased from 19729 Ha in the year 2000 to 32468 Ha in the year 2010. At the same time forested area dropped from 11236 Ha in the year the 2000 to 1143 Ha in the year 2010. The increase of 64.57% in agricultural land during these periods is attributed to the fact that more forested lands were converted to agricultural land. The research also revealed that agricultural land had reduced between the year 2010 and 2020 from 32468 Ha to 23542 Ha. The decline of 27.49% was as a result of factors such as urbanization, increased population and low economic returns from agriculture among others.

The research recommends the need for formulation and enforcement of land use policies that would protect against the various causes of land use land cover change. The drastic decline in agricultural land according to past studies poses a serious risk to food production and food security for poor countries experiencing rise in population. Land use policies should be formulated against the loss of agricultural land as a result of excessive land subdivision and the conversion of agricultural land to other land uses. Adopting modern technologies in GIS and remote sensing would allow for formulation of informed policies as they will ensure regular updates of land use plans and constant monitoring against land use land cover change.

Acknowledgement

First I would like to thank God for the gift of life, health and provision of resources to pursue my Master of Science in GIS.

A special gratitude goes to the Department of Geospatial and Space Technology, University of Nairobi for the opportunity they gave me to study Master of Science in GIS. I would like to specifically thank Dr.-Ing. Musyoka, my supervisor for the guidance and advice he gave me in undertaking my research project.

I would also want to thank my colleagues, Daniel Sakwa and Dominic Mathina for their constructive suggestions and criticism in doing this project.

Finally, I would like to thank my siblings for their financial support and encouragement to the completion of this research project.

Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

CIDP	County Integrated Development Plan
DN	Digital Number
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organization
GIS	Geographic Information Systems
GPS	Global Positioning System
GoK	Government of Kenya
Ha	Hectares
km^2	Square Kilometer
LULC	Land Use Land Cover
LULCC	Land Use Land Cover Changes
MS	Multispectral Scanner
NEMA	National Environmental Management Authority
OLI	Operational Land Imager
RCMRD	Regional Centre for Mapping of Resources for Development
SDGs	Sustainable Development Goals
TM	Thematic Mapper

CHAPTER 1: INTRODUCTION

1.1 Background

Land use and land cover are concepts that mean different things yet they are related. Land use refers to all operations or activities carried out on land that result in changes to its physical, chemical and biological nature with intentions to benefit from the resources. Land cover on the other hand, refers to all physical materials located on the earth's surface. These features could either be natural or human made. Land cover includes features such as vegetation, buildings, bare land, grass and water (Di Gregorio & Jansen, 1998).

According to FAO, (2016) modifications on land have implications on agriculture, forestry, ecology, hydrology and environment. The change in land use land cover technically reduces the size of land used for particular activity. In a case of Kenya, arable agricultural land has continually decreased due to fragmentations as a result of urbanization and population growth. Large state owned farms initially used for seed production have been subdivided and tenure changed from state owned to private. These private lands have been subdivided further and sold to other land owners who have used it for other uses (GoK, 2009).

The implications of the modifications mentioned have been a cause of concern and have attracted many studies in the past that have gathered more information to help understand these dynamics. The invention of technologies such as GIS and remote sensing have been beneficial by providing timely and accurate data on the land cover that have enabled analyse these changes. Studies by Poongothai, (2011) on the identification of land use and land cover using GIS and remote sensing concluded that agricultural land in the Tamilnadu watershed had decreased considerably due to human interference. Studies also by Mallupattu & Sreenivasula, (2013) on the land use and land cover change concluded that GIS and remote sensing is an effective tool for detecting changes in land use land cover. Their study concluded that there had been a significant expansion of the built up area as compared to agriculture in the urban area of Tirupati.

The study focused on the analysis of land use land cover change and its implications on agricultural land in Kiminini Sub-county, Trans Nzoia County using GIS and remote sensing technology. Trans Nzoia County is commonly known as Kenya's bread basket due to large scale production of maize and seeds (CIDP, 2018). The weather conditions and soil are favourable for agricultural production and more specifically maize, which is Kenya's staple food. Maize production, the most widely grown crop in the county has however been on a spiral fall in recent years, forcing a lot of importations by the government to bridge the deficit

(Kang'ethe, 2011). According to Limo, (2016) the cause of the shortfall is mainly due to increased population and urbanization which has led to the subdivision of lands that were initially used for maize production to smaller uneconomic units. The study finds it necessary to investigate the cause of continued shortfall of food production in the Sub-county by focussing on the aspect of land use land cover change and utilizing the more reliable technologies in GIS and remote sensing.

1.2 Problem Statement

Agricultural sector in Kenya contributes more than 50% to Kenya's GDP directly or indirectly through other linkages. The sector also employs more than half of Kenya's population and 70% of the rural population (FAO, 2014). The growth of this sector has been on a spiral fall in recent years as compared to two decades after independence. According to FAO, (2021) the spiral fall of the sector has been caused by land use land cover changes among other factors which has reduced the size of land under agriculture resulting into lower agricultural productions.

The changes in land use land cover in Trans Nzoia County started after independence when the land ownership changed to the Government of Kenya. Before independence, the white settlers utilized these lands for large scale maize and wheat production but after independence it was vacated by the white settlers (CIDP, 2018). The Government of Kenya later on utilized most of these lands for large scale seed production, promotion of agricultural schemes and production of essential agricultural inputs. However, lately these lands have been subdivided and ownership changed from state hold to private as a result of increased demand for land for settlement (GoK, 2009).

Studies by Limo, (2016) and Nekesa, (2019) in Trans Nzoia County discovered that land sizes have reduced greatly over time as a result of increased demand for land for settlement from the increased population. Their studies also found out that land use have changed from agriculture to residential use. Unfortunately, most of the past studies in the region have not employed GIS and remote sensing technology to map, quantify and investigate the extent of the changes in land use land cover. This technology has however been used in other regions such as studies Poongothai, (2011) in Tamilnadu and Mallupattu & Sreenivasula, (2013) in Tirupati that concluded that GIS and remote sensing technology is an effective tool for land use land cover change analysis.

Therefore, there is need for a study to map the changes in land use land cover and their implications on agricultural land in the Kiminini Sub-county using GIS and remote sensing technology. The findings of the study will enable policy makers make better decisions and formulate informed policies.

1.3 Objectives

The main objective of this research was to map land use land cover changes and their implications on agricultural land in Kiminini Sub-county using GIS and Remote Sensing tools.

Specific objectives

The specific objectives were to;

a) Review the causes of land use land cover change in Kiminini Sub-county.

b) Map land use land cover changes in Kiminini Sub-county from the year 2000 to 2020.

c) Quantify the changes in land use land cover in Kiminini Sub-county.

d) Investigate the implications of land use land cover change on agricultural land.

1.4 Justification for the Study

The continued influx and increase in population in Kiminini Sub-county has led to land fragmentation. The National Land Policy report of the year 2009 noted that the large state owned lands that were initially used for seed production and agricultural promotions in the County have changed ownership to private hold. These private lands have been further subdivided to small parcels for settlement use (GoK, 2009).

According to Limo, (2016) the continued subdivision and conversion of agricultural land to other uses possess a danger to food production. This is supported by a report done by Kang'ethe, (2011) for The Food and Agricultural Organization which noted that food production especially maize has started experiencing downfalls in recent years forcing government imports from neighboring countries to cover up the deficit. The decline could be attributed to land use land cover changes that have reduced the size of land under agriculture. This then necessitates the need to employ a more reliable technology in GIS and remote sensing to study and report the real situation on the ground.

The findings of the research will be helpful to physical planners from both the County and National Government as it will enhance their decision making. The report will spatially highlight various land problems such as land use land cover change, urban sprawl and land subdivision which are key issues for planners in formulating their land use policies. Increase in population and urbanization increases the demand for various resources such as land which planners must be aware of as they plan and set aside resources to sustain the rising populations.

The findings will also inform the Ministry of Agriculture both from the National and County Government, whose role is to increase productivity and enhance national food security of the trend of agricultural land in the Sub-county. The loss of agricultural land in Kiminini Sub-county which is Kenya's bread basket is a warning bell of the future crisis of agricultural production in not only the county but also nationally.

1.5 Scope of work

The study is limited to Kiminini Sub-county in Trans-Nzoia County. Kiminini Sub-county occupies 16% of the entire County with an area of approximately 366 km^2. It comprises of 6 wards; Kiminini, Waitaluk, Sirende, Hospital, Sikhendu and Nabiswa. The study focuses on analysing land use land cover changes and its implications on agricultural land in Kiminini Sub-county using GIS and remote sensing. The study will identify, map out and carry out a change detection analysis for land use land cover for the year 2000, 2010 and 2020 in the Sub-county. The study will then go ahead to review the causes of land use land cover change and investigate the implications of the land use land cover change on agricultural land.

1.6 Project Layout

The study is structured into five chapters as follows;-

Chapter one on introduction contains background information, problem statement, objectives of the project, justification of the study and scope of work.

Chapter two on literature review provides detailed summary of previous information relevant to the topic of study.

Chapter three on materials and methods contains information on description of the area of study as well as materials and procedure followed when carrying out the research.

Chapter four on results and discussions contains detailed analysis and discussions of the results.

Finally, chapter five which contains conclusion, recommendations and areas for further studies concludes the report as well as recommending strategies and areas for further research.

CHAPTER 2: LITERATURE REVIEW

2.1 Land use and Land cover

Land use and land cover are terms that are mostly used when referring to landscape patterns and its ability to provide service to the human beings. These two terms have previously been often confused. Land use refers to all activities and operations carried out by human on land that result into changes in its original state. The changes on land could be physical, chemical and biological nature as human tries to derive benefits from it (Di Gregorio & Jansen, 1998). FAO, (1997) describes land use as basically the purpose of which land is being used for. Therefore, land can be used by human for food production, settlement and deriving income through agriculture, mining minerals, pastoralism activities, housing and recreational activities.

Land cover on the other hand refers to all physical materials located on the earth's surface. These materials can either be natural made or manmade. Land cover includes physical materials such as vegetation, buildings, roads, grass and water (Di Gregorio & Jansen, 1998). Gregrio & Jansen, (2000) goes ahead to clarify that land cover is strictly vegetation and manmade features and that areas covered in bare rock or bare soil are land rather than land cover.

2.2 Land use and land cover change (LULCC)

Land use land cover change is a process that involves modifications of the earth's surface features by activities and operations of human beings on land in the process of obtaining benefits from it (Hassan et al, 2016). Historically, modifications on land have been in existence as mankind used to get his essentials from land through hunting and gathering, but the rate of modification has increased of late majorly due to man having access to technologies which can cause change of land cover and land use at a greater scale (FAO, 2016).

Land use land cover change was initially concerned with the physical aspect of change, but then it gathered momentum when researchers realized that it has got vast impact on a global scale such as in influencing climate. Studies have shown that land cover change has some relationship with the carbon cycle process, which in turn influences the climate (Otterman, 1974). Marland et al, (2003) highlights the link between environmental disturbance and the global concentration of carbon dioxide that causes a greenhouse effect leading to climate change.

According to FAO, (2016) modifications on land and land resources have implications on agriculture, forestry, ecology, hydrology and environment. The impacts of the modifications have seen the global forest area reduce by 6.5 million hectares per year from 2010 to 2015 as a result of human activities. The land under forest was reduced as it was taken over by cultivation among other human activities.

The environmental and ecological impacts of land use land cover change is characterised by environmental degradation through depletion of resources such as water, soil, air, nutrients and habitat destruction. The conversion of forest lands to farmlands itself alters the ecological set up of a place and sometimes causes wildlife extinction. Intensive farming on the other hand depletes the soil of nutrients leading to increased soil erosion, siltation and water pollution. Therefore, there needs to be a balance in exploiting of natural resources to prevent environmental degradation (Wu, 2008).

The hydrology and quality of water resources of a place is also affected by changes in land use land cover. Patra, et al (2018) noted that land use land cover change as a result of urbanization affects the quality of ground water resources by changing pattern and rate of recharge. The growing urbanization reduces the rate of ground permeability leading to decreased ground water recharge. They also find a direct relationship between urbanization and increase in temperature as well as decrease in the amount of rainfall. The increased temperature and decreased rainfall is caused by the increase in impermeable surfaces and decrease in evapotranspiration respectively.

Land use land cover changes also have some socio-economic impacts. Land being a major factor of production is essential for housing and food production. There needs to be a balance between competing demand for land for settlement and farming. Urbanization brings more opportunities to farmers as it increases demand for food by increasing the customer base and favorable prices for farmers. However, it comes with more challenges that don't favor agricultural practices. Urbanization increases demand for land for settlement thus reducing land available for food and other agricultural productions. Urbanization also intensifies some non-agricultural practices that are more economical thus leading to abandonment of agriculture in seeking better enterprises (Wu, 2008).

2.3 The causes of Land use and Land cover Change

Natural and human factors are the main causes of modifications on the earth's surface. Natural factors involve events such as weather, fire, flooding, climatic variation and ecosystem changes (Meyer, 1995).

The human factors on the other hand, involves activities such as increased urbanization, increasing population, deforestation, agricultural expansion, government policies, land tenure systems and river damming among others. These human activities and operations directly affect the environment. The rate of change has however increased lately with increase in population and invention of technologies by man that can accelerate the harvest of environmental resources (Meyer & Turner, 1992).

The accelerated rate of land use land cover change caused by increased human population and urbanization among other human factors has attracted so many studies related to land use. Most of these studies have discovered that the major human causes of land use land cover change include; increasing human population, urbanization, land tenure and government policies.

A study by Mzuza et al, (2019) on land use land cover change in Nkula dam discovered that the increasing human population aided by refugees fleeing civil war in Mozambique resulted in increased demand for land for cultivation as the demand for food increased. The continued increase in population resulted in the degradation of land and environmental resources as it resulted in encroachment to marginal lands as well as protected forests and parks. The eventual outcome of the degradation and clearing of forest cover resulted in soil erosion and siltation in Nkula dam. The dam is used for irrigation and domestic and therefore continued siltation would harm food production.

A research also by Hague & Basak (2017) in the Bangladesh region supports the argument that anthropogenic activities caused land use land cover changes. The increase in the human population in the region has increased demand for land resulting to insufficient land available for settlement and cultivation. Their analysis shows that forested areas and water bodies are continually shrinking. Activities such as rice cultivation are becoming more popular than initial activities such as fishing, thus accelerating land degradation.

Urbanization also causes land use land cover change. Hassan et al, (2016) on a case study of Pakistan town noted that urban population had expanded into forest lands and low lying areas. The cause being that there had been rural to urban migration which increased pressure on the limited resources available, and that the absence of proper town plans would result to further changes in land use and land cover.

Land tenure systems influences management of land resources all over the world. In Kenya, for instance, land tenure systems are divided into; customary and statutory land tenure systems. In customary systems, rights to use or control a property are vested in the community. Land use in this situation is characterised by activities such as; exclusion of outsiders and little variations to land. Statutory on the other hand could either be freehold, leasehold or public tenure. Land use in statutory tenure is flexible. In some cases, individuals have rights to sell, lease or use property as collateral to seek loans. Whereas it enables easy access and utilization of resources, it is prone to unsustainable land uses. Owners are at liberty to subdivide land to smaller parcels and to use for whatever land use they deem so. Therefore, land tenure systems influences changes in land use/land cover of a place (Waiganjo & Ngugi, 2001).

Government policies and how it contributes to land use land cover change can be traced in Kenya to land distribution and resettlement policies in the twilight years of colonization and after independence. The issue started with the "one million acre scheme programme" that was meant to accommodate masses of landless families. The scheme would resettle more than 35000 landless smallholder families on one million acres of land. The objective was to purchase land from the European settlers using loans acquired from the World Bank and settle landless masses on the land. The outcome of the programme resulted to the subdivision of large farms initially used for agriculture to fragmented holdings. An observation made showed that those areas under cultivation reduced by more than 10% between years 1980 to 1982 and further drop of 3% between years 2000 to 2005 (Kanyinga, 2017). Land use policies have now been set up with the intention to ensure proper management of land resources and categorization of land uses in the country among others. However, enforcement of the set up policies has continued to be the problem (GoK, 2017).

In addition, impacts of government policies on land use can be seen according to Degife et al, (2018) on a study of the Gambella region in Ethiopia. The study states that 800000 people were relocated in the mid 1980 to the Gambella region and surrounding areas because of drought. As a result of this, it resulted in the modification of the landscape and deforestation due to demand for land for resettlement.

Finally, other countries such as China have come up with various policies meant to solve challenges faced as a result of LULC. The policies were set up to counter the complex changes in LULC as a result of rapid economic and social development. The policies implemented during various phases in time since 1965 resulted to various changed in land use land cover. For example, at some point grassland decreased then increased. Cultivation increased, then decreased and increased again. The changes in land use land cover were as a result of the various policies implemented at different phases of time. Therefore, the impacts of government policies on land use land cover cannot be underestimated (Li et al, 2017).

2.4 The implications of LULCC on Agriculture and Agricultural land.

During the start of the agrarian revolution, land use land cover change resulted to agricultural land expansion at the expense of forested areas resulting to the increased food production in response to the demand for food from the growing population (Pellikka et al, 2013). In support of this, FAO, (2016) report noted that there was a net forest loss of 7 million hectares per year and net gain of 6 million hectares per year in agricultural land between the year 2000 and 2010. Most of the gain was experienced in low income countries which were experiencing growth in population.

However, food production has started dwindling in recent years due to the continued increase in population. The land that had long been used for agriculture is now in demand for settlement of the population hence resulting in subdivision to smaller units. The land is now being used for construction of houses and used for other non-food activities resulting in reduced supply of food (FAO,2016).

Otterman, (1974) noted the relationship between land cover modifications and the carbon cycle, which affects the climate of a place. The conversion of forest lands to agriculture will eventually cause a drop in production due to low rainfall and high temperatures experienced in due time because of climate change. Lambin et al, (2003) also raises concerns to the fact that land use land cover change affects the climate of a place; hence it is critical to address issues of desertification and deforestation. After all temperature and precipitation are direct inputs in farming and any change would have enormous ramifications on agriculture (Hassan et al, 2016).

The implications of land use land cover change on agriculture is highlighted in Kenya where by arable agricultural land has continually decreased due to fragmentations as a result of urbanization, population growth and population influx. Large state owned farms in Trans Nzoia County initially used for seed production and agricultural promotions have been subdivided and tenure changed from state to private and used for settlement (GoK, 2009). The extreme impacts of these changes are that it has led to decline in agricultural production. A report for FAO by Kang'ethe, (2011) on situation study of food safety in Kenya noted that maize production has been on a decline in recent years. The decline he says could be attributed to unpredictable rainfall and increased urbanization. Limo, (2016) attributes the decline in maize production to land subdivision and land use change that have reduced the size of land under an activity. The shortfall of maize production has forced the government to import from neighboring countries to cover up for the deficit.

The indirect impact of land use land cover change on agriculture can be traced to Nkuku dam region in Malawi. Mzuza et al (2019) noted that the increasing population in the region caused by the influx of displaced persons fleeing civil war in Mozambique resulted to increased demand for more land for cultivation to feed the population. However, the demand for more land resulted to encroachment into marginal and protected forests leading to land degradation. The dam which is used for irrigation and domestic use has started experiencing siltation as a result of soil erosion. If the siltation on the dam continues, it will eventually reduce the volume of water the dam can hold thus indirectly affecting agriculture.

The fragmentation of large parcels into smaller units in the Kenyan rangelands diminishes available land for livestock farming and nomadic pastoralism. A case study by Kebaso, (2017) of Kaputiei, Kajiado North shows a change of LULC from agricultural to residential land use. Rangelands or lands available for livestock grazing have drastically reduced as settlements have increased due to urbanization. The reduction in lands available for grazing has directly affected livestock keeping as the study reveals beef production has also decreased.

It should be noted therefore, that land use land cover change reduces the size of land under agriculture which directly results to reduced agricultural productions leaving livelihoods food insecure. This threat to food security accelerated by increasing populations and urbanization has attracted local and international interventions which believe agriculture has a big role to play in alleviating many upcoming societal problems. Kenya's vision 2030 which is a documented plan highlighting strategies to the sustainable economic development in Kenya recommends interventions that intends to increase the size of land under agriculture by utilizing uncultivated lands and new cultivation to newly-opened lands. Likewise, agriculture is a main focus when it comes to the 17 SDGs set up by the United Nations General Assembly that aims to achieve decent lives for all by 2030. Land use practices that will ensure increased agricultural land and agricultural production will have a positive influence towards sustainable development goal 1 on "no poverty" and goal 2 on "zero hunger" of the 17 SDGs.

2.5 GIS and remote sensing Application in Land use Land cover Mapping

Weng, (2010) defines remote sensing as a science and technology of capturing information from far away objects without being in contact with them using sensors. It is a technology that uses electromagnetic radiation to carry information from objects on the earth's surface to the sensor. GIS and remote sensing were initially developed for military use, but it is now being widely used by civilians in applications such as agriculture, geology, forestry, land use and land cover.

Geographic information system is a computer based technology that allows for data capture, input, storage, retrieval, analysis, modelling and visualization. The system works with information that is linked to spatial reference, and uses databases to store spatial information (Fazal, 2008).

GIS and remote sensing technologies have been integrated and used together to enhance their capabilities. Whereas remote sensing is used to gather data for use in GIS, GIS is used for modelling and analysis. The remotely sensed data such as images are analysed and classified to extract thematic information that provides descriptive information about the earth's surface features. Geographic information system layers can further be extracted from the thematic information and used to create various maps or models for decision making (Weng, 2010).

Remote sensing capabilities and use went beyond military use when it was realized that it could be used to solve various environmental problems such as pollution and land degradation. Since then, there have been various advances and resources invested to improve the technology. New sensors have been developed with more enhanced capabilities while also more missions have been launched. This has been done with the sole purpose of providing accurate, high resolution and timely spatial information (Aronoff, 2005). For example, the Landsat satellite have improved their sensors with subsequent missions from the earlier ones that used multispectral scanner (MS) and earth thematic mapper (ETM+) to the latest Landsat 8, which uses operational land imager (OLI) which has improved calibration and a higher radiometric resolution. In addition, the accuracy and precision of remote sensing data has improved after the invention of the satellite positioning technology and the Global Positioning system (Roy et al, 2016).

Land use land cover mapping is now possible due to the satellite images containing wide spectral information. The various features on the earth's surface respond to varying reflectance. Features on the earth's surface reflect different amounts of energies in different portions of the spectrum. This makes it possible to identify the various types of features by analysing their spectral signatures. For example, the spectral signature for vegetation is different from water and vice versa (Croft, et al 2020).

The other aspect that is important to put in consideration when performing LULCC of satellite images is temporal resolution. Temporal resolution is the amount of time a sensor takes to revisit the previous location. This property of the sensor is important because changes occur in various locations on the earth's surface and these changes are what we are concerned about. It is crucial to obtain satellite images acquired or obtained at different times so as to analyse for environmental changes. Some studies would prefer yearly, others a decade and so on (Weng, 2010).

2.6 Change detection techniques

Change detection refers to the process of identifying spatial changes occurring on the earth surface as a result of natural phenomena or human activities (Mishra et al, 2017). The process of change detection in remote sensing involves the detection of spatial changes of the same location from a multi temporal satellite images acquired at different times (Asokan & Aniitha, 2019). The objective of change detection process is to detect those areas on satellite images that depict change between two or more sets of images (Mishra et al, 2017). They should be detected in a timely manner to better understand the dynamics and interactions between the natural and humans.

Satellite imagery is the main source of data used in remote sensing change detection. To detect changes one can either compare two sets of satellite images or a satellite image to an existing land use base map (Mohamed & Mobarak 2016).

There are various change detection techniques commonly used in remote sensing. They include; post classification, image rationing, image differencing, principal component analysis and change vector analysis among many others.

Post classification is the most popular technique used in change detection analysis. It involves the classification of each of the satellite images independently followed by generation of thematic maps. The corresponding themes are then compared to detect and identify where changes have occurred (Al-doski et al, 2013). This technique is mostly used since data acquired from different dates are classified separately thus minimizing sensor, atmospheric and environmental differences. It then minimizes the problem of normalizing for atmospheric and sensor differences between two dates (Mishra et al, 2017).

Image differencing is a technique with which two spatially registered imageries are subtracted pixel by pixel. The pixels from the changed area are distributed in the two tails of the histogram of the resultant image while the unchanged area is grouped around zero. The advantage with this technique is that it easily interprets the resultant image. However it is crucial to define the thresholds to detect the change from non-changed areas (Al-doski et al, 2013).

Principal component analysis is a multivariate analysis technique used to reduce the spectral components to lesser number of principal components. Linear transformation is used for reduction of spectral components and is also performed on the multi-date images and then combined to obtain a single dataset (Mishra et al, 2017).

Image rationing technique is regarded as a rapid mean. Areas of change are detected by calculating the ratio of the DN values of corresponding pixels on the two registered images at different dates with one or more bands. The comparison between data is done on a pixel by pixel basis (Mishra et al, 2017). This technique has received criticism due to non-normal histogram distribution of resultant image (Al-doski et al, 2013).

Finally, the change vector analysis technique is where change is represented in spatial in the spectral space. When change occurs over time, the pixel is expected to change its position in the spectral change vector, a vector called spectral change vector. The advantage with this technique is that it provides detailed information about the change occurred (Mishra et al, 2017).

The process of choosing the technique to use for change detection depends on various constraints such as size of study area, quality of data, field of application and information required. The nature of the problem is also important since not a single technique can be applied to all the problems. These change detection techniques are important for many researchers and other users who use them in various applications such as monitoring environmental and land use change, forests, agriculture, wetland change and urban management.

CHAPTER 3: MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Geographic Location and Size

Kiminini Sub-county is one of the five sub-counties in Trans Nzoia County. The others being Kwanza, Endebess, Saboti and Cherangany. Trans-Nzoia is a county in the former Rift Valley Province, located on the western side of Kenya bordering the Republic of Uganda to the West, Kakamega and Bungoma counties to the South, West Pokot to the East, Elgeyo Marakwet and Uasin Gishu to the South East.

Kiminini Sub-county is located between latitudes 0° 48' 17'' and 01° 03' 33'' North of the Equator and between longitudes 34° 47' 48'' and 35° 07' 08'' East of the Meridian. It covers an area of approximately 366 km^2 which is 16% of the entire County area. Figure 3.1 shows the location of Kiminini Sub-county in relation to Kenya and Trans-Nzoia County.

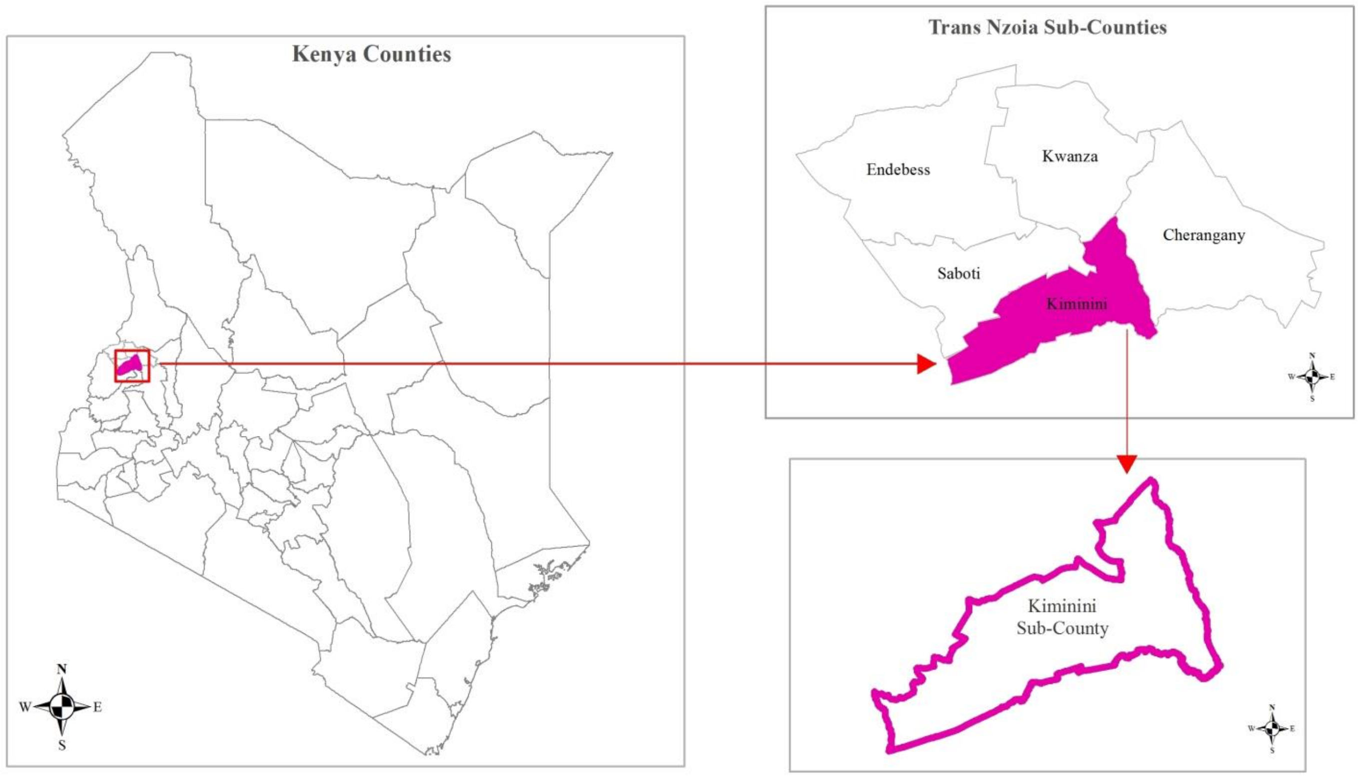


Figure 3.1: The Geographic Location of Kiminini Sub-county

Kiminini Sub-county comprises of 6 wards; Kiminini, Waitaluk, Sirende, Hospital, Sikhendu and Nabiswa. Figure 3.2 shows the wards in Kiminini Sub-county.

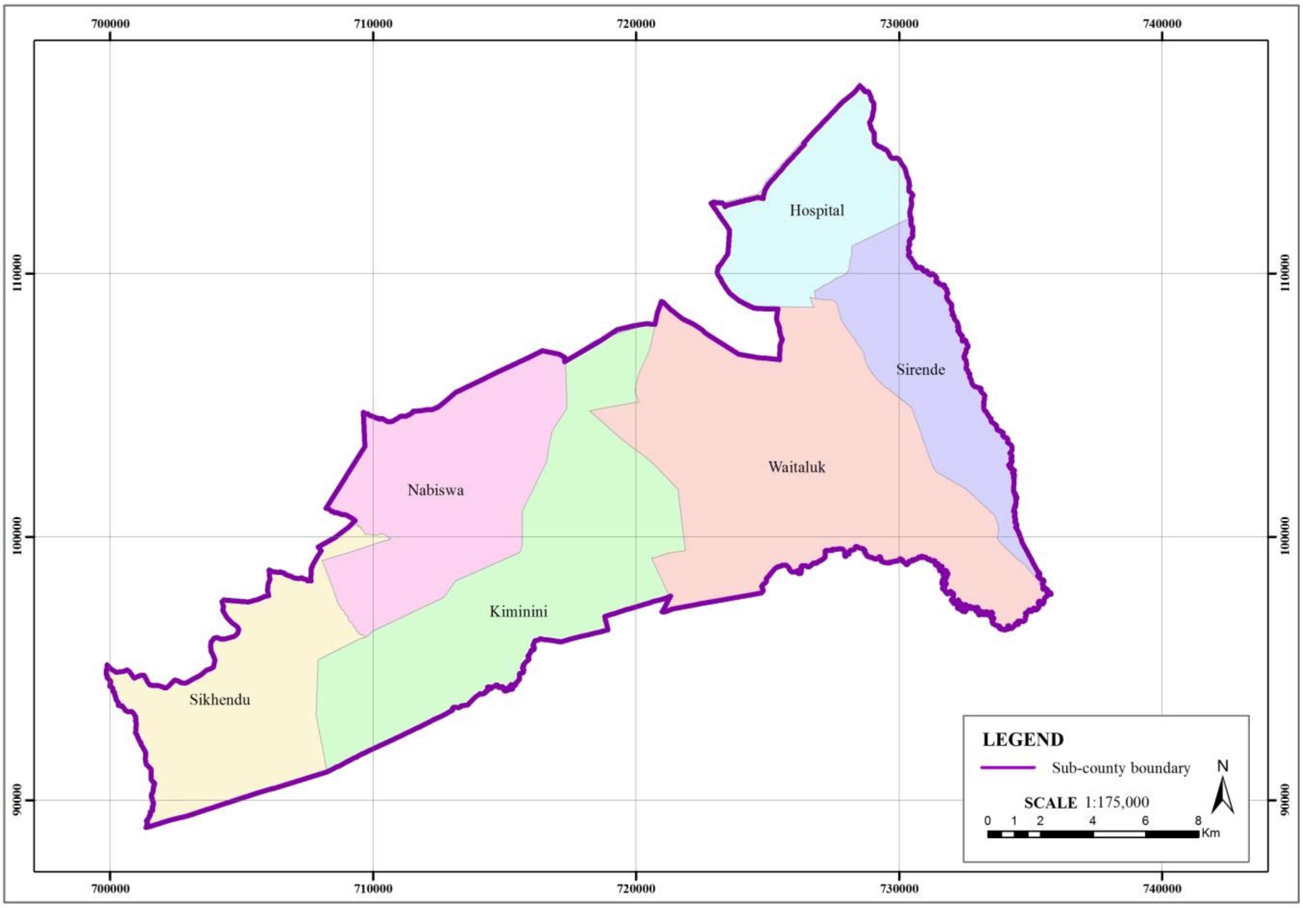


Figure 3.2: Kiminini Sub-county wards

3.1.2 Climate

The area receives a cool temperate climate with temperatures of between 23.4°C and 28.4°C and an annual rainfall ranges from 1,300 mm to 1,700 mm. The annual rainfall is distributed in three main seasons; March to May, June to August and October to December. Long rains are experienced between March and May while the shortest are between October and December (CIDP, 2018).

3.1.3 Topography

The area is generally flat with a few undulations covering an elevation of between 1650 - 1920 meters above sea level. The land slopes gently from the North towards the South and from the North East towards the South West. Figure 3.3 shows the digital elevation model of Kiminini Sub-county.

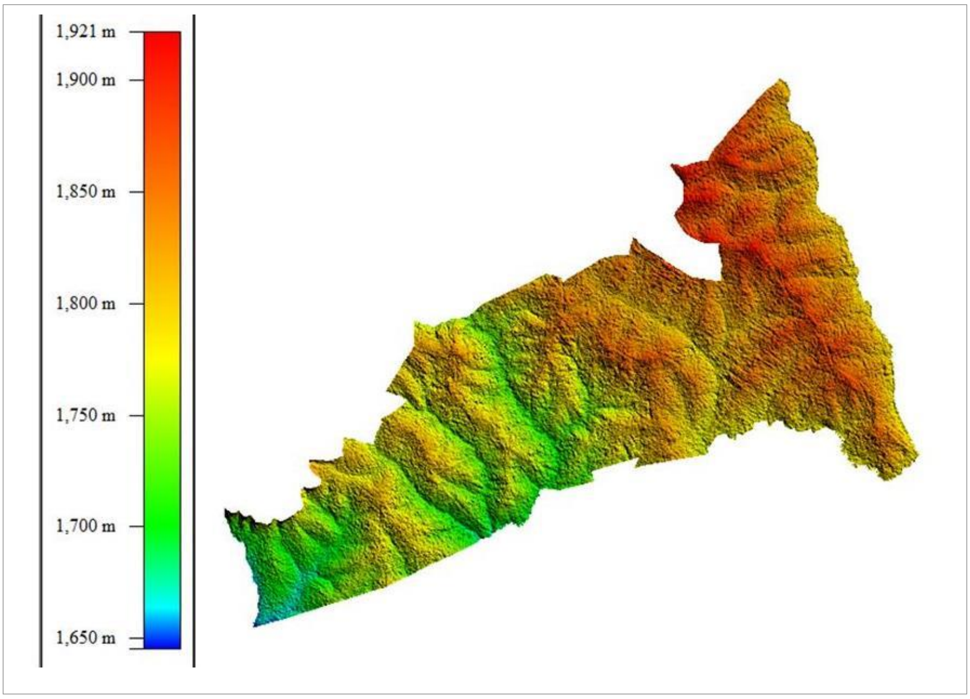


Figure 3.3: Digital Elevation Model of Kiminini Sub-county

3.1.4 Geology and Soil

Kiminini Sub-county sits on the mountain foot of Mt Elgon with a moderate to high fertility soils favourable for farming. The soils found here are dark brown with acidic humic topsoil, andosols and nitosols less rich with ash (NEMA, 2013).

3.1.5 Hydrology and Drainage systems

There are two main rivers in the area namely Nzoia River and Koitobos River. Koitobos River is located on the east side marking the boundary with neighbouring Cherangany Sub-county. Nzoia River on the other hand, is located to the south separating Kakamega and Trans Nzoia Counties. The other rivers located in the Sub-county are Tongareni and Kiminini Rivers.

3.1.6 Population

The Sub-county has a population of 288,659 and a population density of 788 persons per square kilometre as of the 2019 census by the Kenya National Bureau of Statistics. The population is being projected to grow to 308,245 persons by the year 2022 (CIDP, 2018).

3.1.7 Road network

There is an adequate connectivity of roads linking towns and centres in Kiminini Sub-county promoting economic development. The class A1 road connects Kitale Town, Kiungani, Kiminini and Sikhendu centres. The class B2 road connects Kitale Town and Maili Saba centre. The other high ranked roads available are class C44, C45, C48 and D 285among many other. Figure 3.4 shows the road network of Kiminini Sub-county.

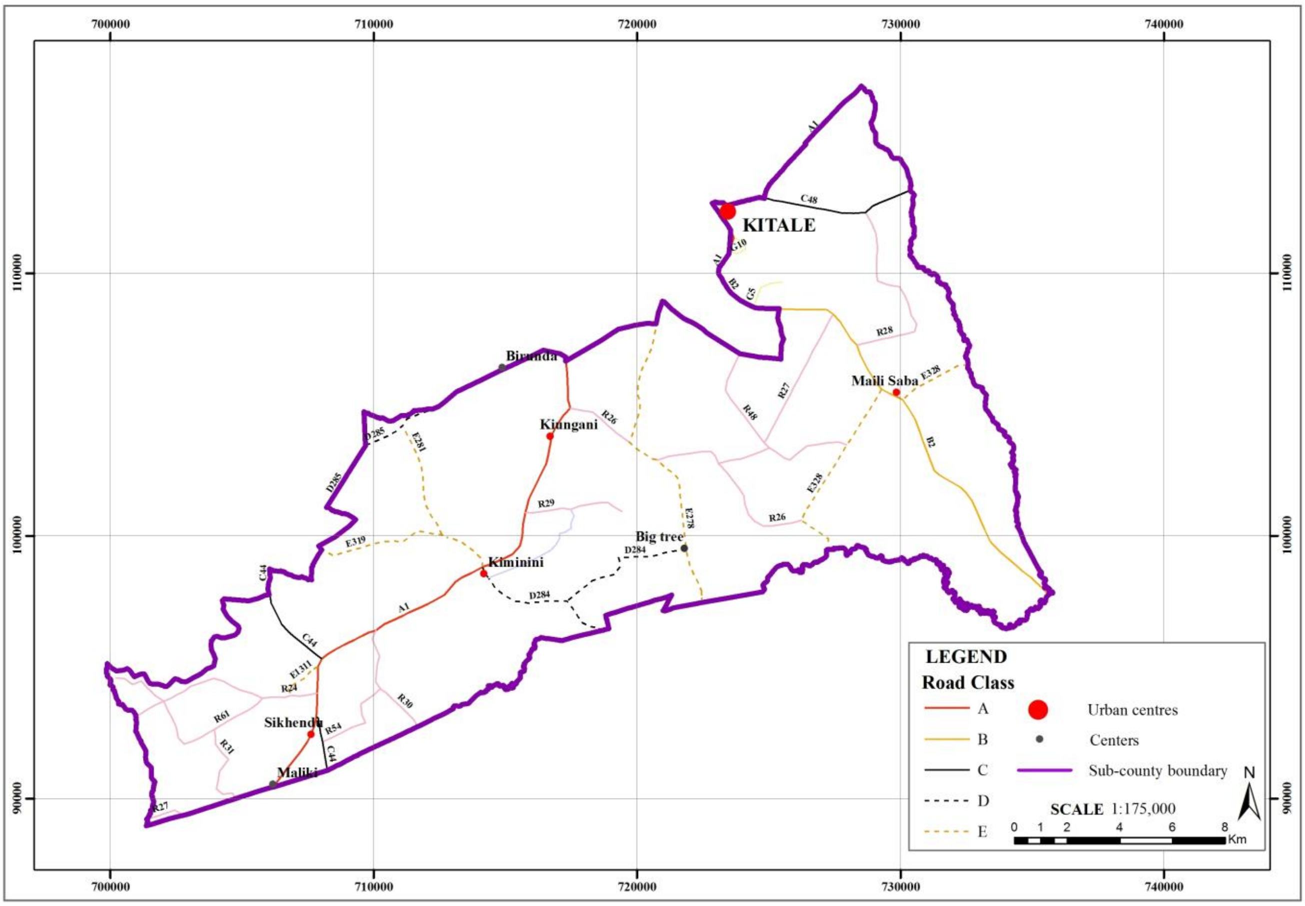


Figure 3.4: Kiminini Sub-county Road Network

3.2 Data Sources

In order to achieve the objectives of the study, 2 categories of datasets were collected; satellite and ancillary data.

3.2.1 Satellite Data

Landsat satellite data was acquired from the USGS earth explorer (https://earthexplorer.usgs.gov), a user interface for downloading Landsat data. Landsat satellite imagery for the years 2000, 2010 and 2020 were downloaded. Table 3.1 shows the various specifications of the Landsat data downloaded for the study.

Table 3.1: Landsat data and specifications

Satellite	**Sensor**	**Path/Row**	**Bands**	**Resolution**	**Year**
Landsat-7	ETM+ (Enhanced Thematic Mapper)	170/59	Bands (1 – 7) Band 8	30m 15m	2000
Landsat-5	TM (Thematic Mapper)	170/59	Bands (1 – 5 & 7) Bands 6	30m 120m	2010
Landsat-8	OLI (Operational Land Imager) & TIRS (Thermal Infrared Sensor)	170/59	Bands (1 – 7 & 9) Band 8	30m 15m	2020

3.2.2 Ancillary Data

Ancillary data are data from sources other than remote sensing that was used to assist in analysis and classification. Remote sensing data which in our study includes the satellite data cannot on their own conclusively perform analysis and classification, thus the need for ancillary data to assist in various functions. Ancillary data included the GPS field data which was used as ground truth data, sub-counties shapefile, aerial image and topographic data sheets that cover the area of study. Table 3.2 illustrates the specifications, data sources, descriptions and purpose for which the ancillary data was used for.

Table 3.2: Ancillary data sources and uses

Data type	Source	Description	Purpose
Topographic map (1:50000)	Survey of Kenya	88-2 (Kiminini) 89-1 (Mois Bridge) 75-3 (Kitale)	- Reference data - Base map
Sub-Counties shapefile	Kenya Data (Through RCMRD portal)	Shapefile of Kiminini Sub-County	- Delineating our area of study
Aerial Image	Survey of Kenya (Ministry of Lands, Trans-Nzoia County)	From the Archives of 2019	- Reference data - Preparing training sites
GPS Points	Field survey	Coordinates	- Sample points for Validation - Ground truth data

3.3 Methods of Data Analysis

The process of data analysis followed a series of stages in a step wise manner that included; pre-processing, classification, post-classification, validation process and land use land cover change detection. Figure 3.5 shows the methodology flow of data analysis.

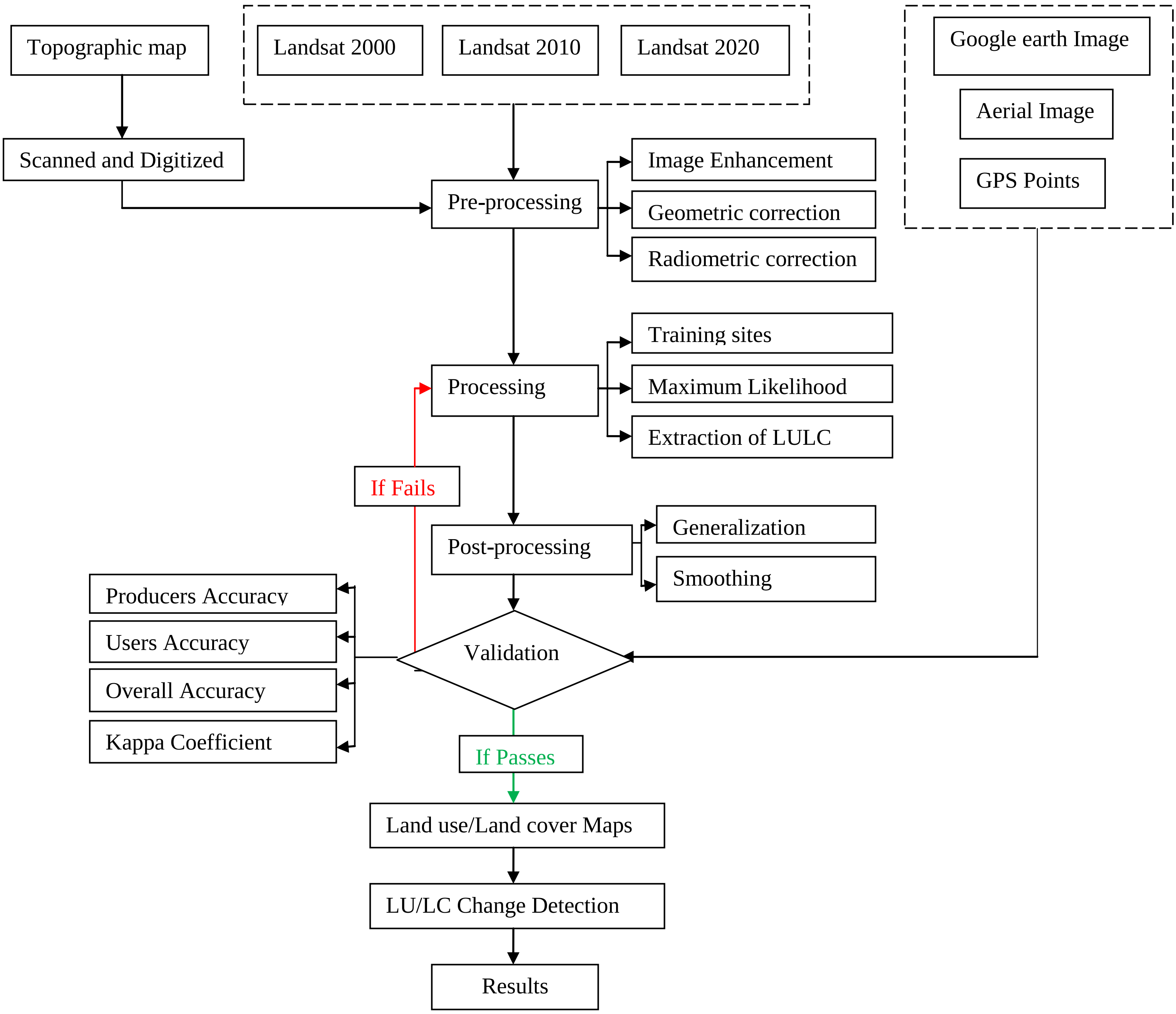


Figure 3.5: Methodology Work Flow

3.3.1 Data Pre-processing

Data pre-processing involved the extraction of data, geo-referencing and performing geometric and radiometric corrections. The Landsat satellite image was clipped to remove unnecessary parts and remain only with the area of interest. The process of clipping unnecessary parts was important, as it allowed for quicker processing of data.

Image enhancement was also done by combining bands to create a composite for better visualization. Finally, the pan-sharpening process was done at this stage to improve the composite resolution using the higher resolution panchromatic band. This was done for Landsat 7 Enhanced Thematic Mapper plus and Landsat 8 Operation Land Imager which have the 15 cm resolution panchromatic band 8.

3.3.2 Image Classification and Analysis

The study employed pixel based classification technique to carry out the analysis. Supervised and unsupervised classification tools of ArcGIS and QGIS software's were used concurrently. Supervised classification was employed for the satellite image year 2000 and 2010, while unsupervised for year 2020.

Supervised classification required the preparation of training sites with the help of the aerial image reference corresponding to the classes clustered. The study identified some land use land cover classes and their descriptions to be followed when preparing training sites. They included; built up areas, agriculture, forested areas, bare land and water bodies. Finally, maximum likelihood algorithms were used to carry out the classification. Table 3.3 shows the land use land cover classes identified and their descriptions.

Table 3.3: Land use land cover classes

Code	Land use types	Description
1	Forested Area	Forest, trees, shrubs and bushes
2	Built up Area	Buildings, settlements, temporary and permanent houses and villages
3	Agriculture	Farmlands, crops, cultivation.
4	Water bodies	Rivers, streams, water pans, snow or ice, lakes and dams
5	Bare land	Without buildings, crops and vegetation. Mostly grassland.

3.3.3 Post processing

This process was done after classification with the objective of improving the quality of the output. It involved filtering, smoothing and generalizing the classified output.

3.3.4 Validation of the results

When carrying out classification, sometimes pixels remain misclassified or misplaced. Therefore, there was need to perform validation to ensure that the land use land cover classes accurately represent what is on the ground. The validation process allows you to compare the output of analysis and a reference data that represents the real case on the ground.

The study utilized three types of reference data which included; the aerial image acquired in the year 2019, Google earth images and GPS points. Google earth image was deemed to be an effective reference because of the availability of images archives that cover our period of study on their website. Afterwards, the producers, users and overall accuracies were determined for analysed outputs for the years 2000, 2010 and 2020. The Kappa coefficient was then computed and used to measure the possibility of an agreement occurring by chance.

3.3.4.1 Producers Accuracy

The producers accuracy is the map accuracy from the map maker point of view. It refers to the total number of correctly identified pixels of a given category with respect to the total number of the correct pixel in a given category derived from the reference data. It is referred to as a measure of error of omission.

3.3.4.2 Users Accuracy

The users accuracy is the accuracy from the map user point of view. It refers to the total number of correctly classified pixel in a category with respect to the total number of samples interpreted as belonging to that class. It is referred to as a measure of error of commission.

3.3.4.3 Overall Accuracy

The overall accuracy is the proportion of the reference sites that were mapped out correctly giving the impression of how well the entire image has been interpreted. It refers to the total correctly interpreted samples with respect to the entire number of samples.

3.3.4.4 Kappa Coefficient

The Kappa coefficient is a measure used to determine how the classification results compare to the values assigned by chance. It is computed as shown;

$$Kappa = (Observed\ accuracy - chance\ agreement) / (1 - chance\ agreement) \qquad (3.1)$$

Table 3.4 shows the Kappa coefficient model adopted for the study with respect to values assigned by chance.

Table 3.4: Interpretation of Kappa Statistic

Kappa Coefficient	**Classification regarded as**
Below 0.4	Poor or no agreement
0.41 – 0.60	Slight agreement
0.61 – 0.75	Fair agreement
0.76 – 0.80	Substantial agreement
0.81 and above	Almost perfect agreement

3.4 Change detection

The final stage of the data analysis involved the change detection stage. It was done to help detect periodic changes occurring in the area.

3.4.1 Change detection technique

The study employed the post classification technique to carry out change detection. This technique was considered since satellite images for the year 2000, 2010 and 2020 were classified independently. Afterwards, thematic maps were generated from the classification for the year 2000, 2010 and 2020. Eventually, the comparison of the corresponding themes used to identify areas where change had occurred was carried out.

This technique was considered due to the advantages in minimizing sensor, atmospheric and environmental differences since data from two dates are separately classified. According to Mishra et al, (2017) this technique is best suited for land use land cover classification, urban sprawl measuring among other applications.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Land use land cover classification

The Landsat image analysis with support from the ancillary data; ground truth data and aerial image, helped inform five land use land cover classes. They included; agriculture, bare land, forest, built up area and water.

4.1.1 Agriculture

Agricultural land was identified for use in preparing training sites by the use of visual image interpretation elements such as pattern, tone and shape and their unique spectral reflectance. Vegetation, especially healthy vegetation have high reflectance in the near- infrared region that is between wavelengths 0.7 and 1.3 µm. Healthy vegetation is also a good absorber of energy in the visible region as chlorophyll absorbs light at wavelengths 0.45 to 0.67 µm. Therefore, it was important to download satellite images from months when crops at the region are all grown and also utilize band combinations that displayed agriculture clearly as shown in table 4.1.

Visual interpretation elements were used to identify areas with crops. The patterns, tone and shape clearly showed that an area is under crops. Thus the visual interpretation elements in combination with the unique spectral reflectance were used to develop training sites to be used for supervised classification.

4.1.2 Forest

Forested area described all the areas dominated with trees. The trees have spectral reflectance that is different from crops. Trees absorb more energy in the visible region and have a higher spectral reflectance in the near infrared region more than crops. Therefore, the false colour composite for forested areas showed a deep red colour in comparison to agriculture, which showed a lighter shade of red. The band combinations were used for development of training sites for the purpose of supervised classification. Table 4.1 shows band combinations used for identification of forested areas and other land uses.

4.1.3 Water bodies

Water bodies represented areas with rivers, streams, water pans, lakes and dams. Water bodies in the near infrared and mid infrared regions absorb light making it appear darker. The darker areas which represent water bodies were identified using band combinations as shown in table 4.1. Alternatively, training sites were developed using the true colour composites with water features appearing blue.

4.1.4 Built-up areas

Built-up LULC class represented areas covered by buildings and other forms of settlement. The identification of built up areas for the creation of training sites was done at areas closer to urban centres because of the dense settlement. Even though it was a bit challenging in the hinterland because of the mix up with other land use land cover types, some band combinations were used that clearly displayed built up areas as shown in table 4.1.

4.1.5 Bare land

Bare land represented open spaces not utilized for crop cultivation and lacks other vegetation. These are areas mostly covered in light grass or soil. Their spectral reflectance is different from vegetation which is also different from crop lands.

Table 4.1 shows the band combinations that were utilized in the analysis of the land use land cover classes identified by the study. Apart from some specific band combinations for each class type, false colour composites were useful for all the land use land cover identification.

Table 4.1: Landsat Satellite Band Combinations

Landsat **Land use/ Land cover**	Landsat 7 (2000)	Landsat 5 (2010)	Landsat 8 (2020)
Agriculture	4 3 2	5 4 1/ 4 3 2	6 5 2/ 5 4 3
Forest	7 4 2/ 4 3 2	7 4 2/ 4 3 2	5 6 2/ 5 4 3
Water bodies	4 5 1/ 4 3 2	7 5 3/ 4 3 2 /7 4 2	5 6 4/ 5 4 3
Built up areas	3 2 1/ 4 3 2	3 2 1/ 4 3 2	7 6 4/ 5 4 3
Bare land	4 5 1/ 4 3 2	4 5 1/ 4 3 2	5 6 4/ 5 4 3

4.2 Land uses land cover of Kiminini Sub-county in hectares

To achieve the objective of the study on quantifying the changes in land use land cover in Kiminini Sub-county, the study tabulated acreages for all identified land uses land cover from the analysis using the final land use land cover maps for the years 2000, 2010 and 2020. Table 4.2 shows the land use land cover areas in hectares and percentages compared to the total coverage of the Sub-county.

Table 4.2: Kiminini Sub-county area coverage land use land cover changes

Land uses land cover of Kiminini Sub-county						
LULC Classes/Year	**2000**		**2010**		**2020**	
	Area (Ha)	**Area (%)**	**Area (Ha)**	**Area (%)**	**Area (Ha)**	**Area (%)**
Agriculture	19729	53.91	32468	88.71	23542	64.32
Built up Area	576	1.57	1322	3.61	2586	7.07
Bare land	5048	13.79	1658	4.53	6851	18.72
Forest	11236	30.70	1143	3.13	3610	9.86
Water	11	0.03	9	0.02	11	0.03
TOTAL	**36600**	**100.00**	**36600**	**100.00**	**36600**	**100.00**

4.3 Land use land cover map of Kiminini Sub-county

The analysis of Landsat images generated the land use land cover maps for the years 2000, 2010 and 2020 as shown on figures 4.1, 4.2 and 4.3. The mapping process which was the objective of the study was achieved in the process. Table 4.2 shows areas and percentages covered by land use land cover in relation to the coverage of the Sub-county.

4.3.1 Land use land cover map for year 2000

Agricultural land in the year 2000 covered an area of 19729 Ha, which is 53.91% of the entire area of Kiminini Sub-county. Most of the land was covered by agriculture, followed by forested area which covered an area of 11236 Ha, 30.70% of the entire Sub-county. The remaining land, a percentage of 15.39 of the entire Sub-county area was covered in bare lands, built up and water in percentages of 13.79, 1.57 and 0.03 respectively as shown in table 4.2. The analysis shows that built-up areas were then mostly concentrated in the urban centres and small centres in the Sub-county. Agricultural land in the year 2000 spread all over the Sub-county separated by patches of forests and some bare lands. Figure 4.1 shows the land use land cover map for the year 2000.

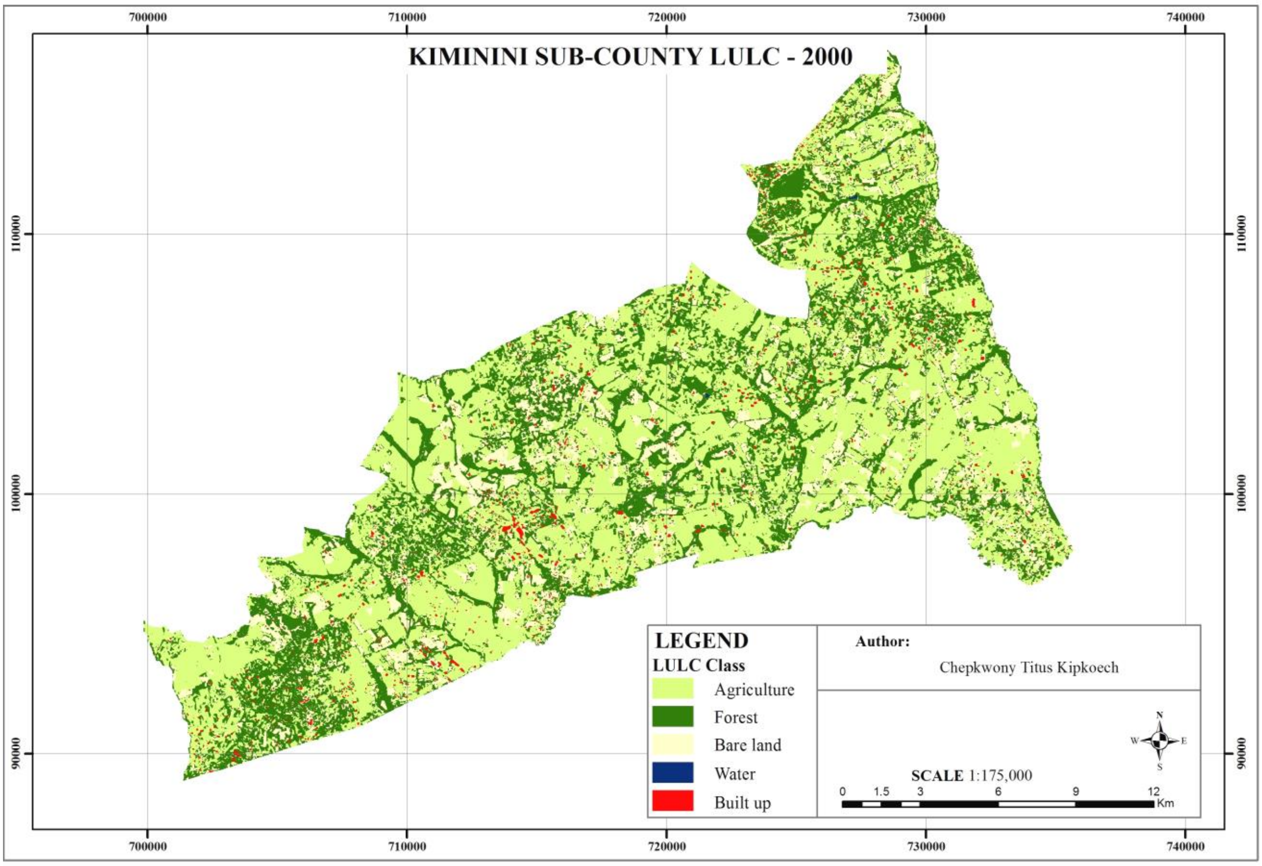


Figure 4.1: Land use land cover map for the year 2000

4.3.2 Land use land cover map for year 2010

Agricultural land in the year 2010 covered a majority of the Sub-county with an area of 32468 Ha, which is 88.71% of the entire Sub-county area as shown in table 4.2. The remaining land covering a percentage of 11.29 of the Sub-county was covered by water, built up area, forested and bare land in percentages of 0.02, 3.61, 3.13 and 4.53 respectively. The analysis shows that built up areas are not only still concentrated in urban centres and small centres, but have shifted to the other parts of the Sub-county. The patches of forests that spread all over the Sub-county in the year 2000 were cleared to pave way for agriculture. Figure 4.2 shows the land use land cover map for the year 2010.

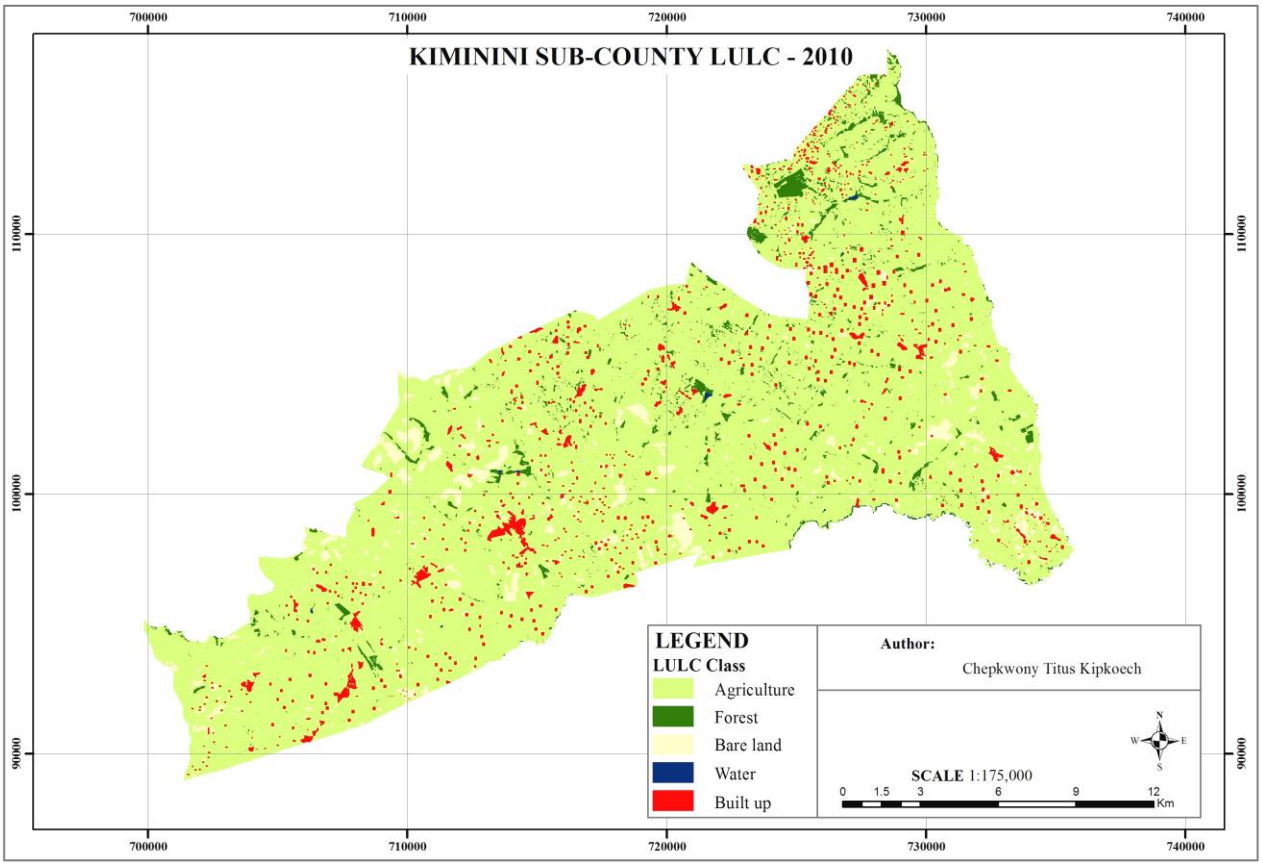


Figure 4.2: Land use land cover map for year 2010

4.3.3 Land use land cover map for year 2020

Agricultural land in the year 2020 covered an area of 23542 Ha, which translates to 64.32% of the entire Sub-county area as shown in table 4.2. Bare land came second in area size with a percentage of 18.72 while the remainder 16.96% of the Sub-county area was covered in forest, built up and water in percentages of 9.86, 7.07 and 0.03 respectively. The built up areas have intensively shifted everywhere in the Sub-county as compared to 20 years earlier which were only concentrated on the urban and small centres. The forested area and bare land have also expanded as evidenced by patches that spread all over unlike the previous year of analysis when they were very few. Figure 4.3 shows the land use land cover map for the year 2020.

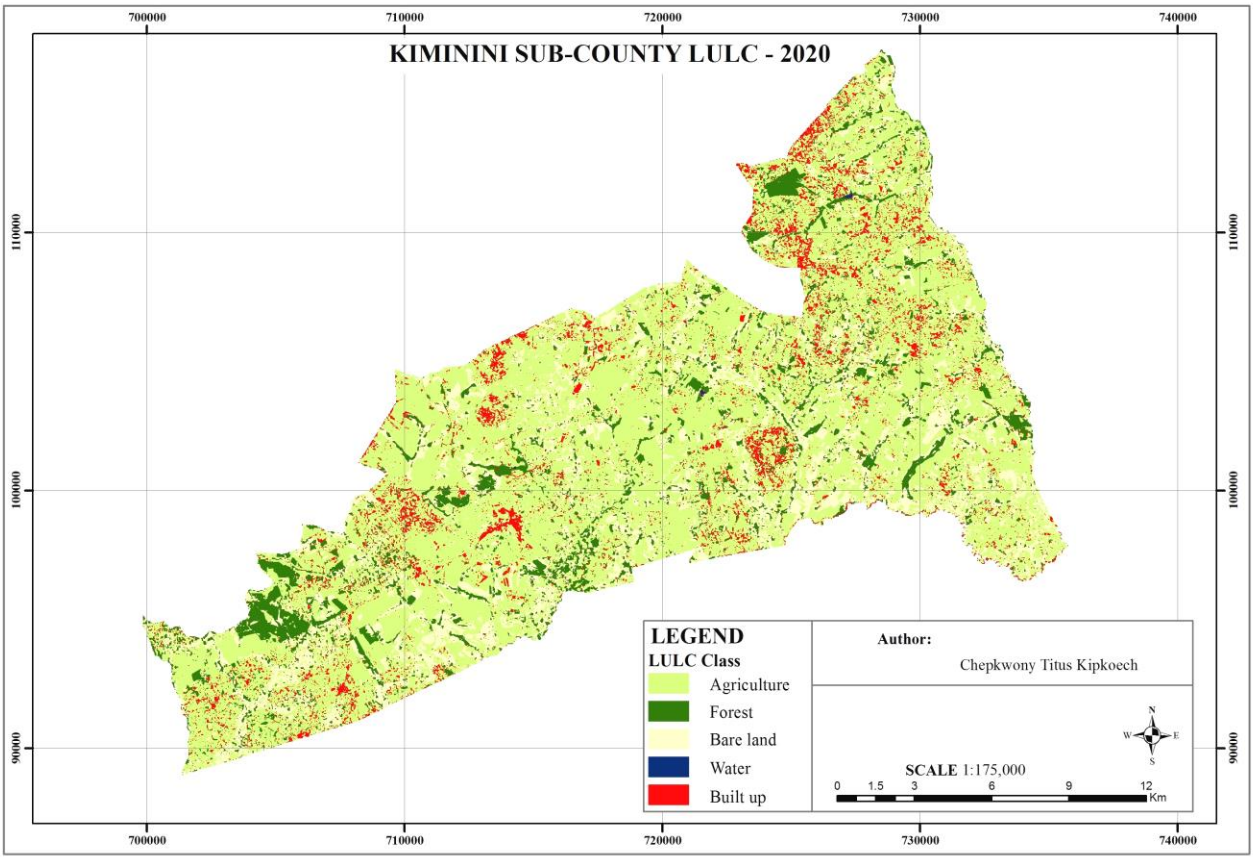


Figure 4.3: Land use land cover map for the year 2020

4.4 Accuracy Assessment

Accuracy assessment was performed to ensure that the output from classification is the same as to what is on the ground. This process was done with the help of reference data that accurately represent the situation on the ground. The study used three kinds of data which included; the ground truth GPS points collected randomly from the ground, aerial image acquired in the year 2019 and Google earth image which has an archive of images covering the period of study. The producers, users and overall accuracy were then determined for all the land use land cover types identified for the years under study. Finally, a Kappa coefficient was determined to measure the possibility of an agreement occurring between interpreted image and reference data. Table 4.3, 4.4 and 4.5 shows the producers and users accuracy for years 2000, 2010 and 2020 respectively.

Table 4.3: Accuracy assessment results for the year 2000

Class Name	Reference Totals	Classified Totals	Correct Number	Producers Accuracy (%)	Users Accuracy (%)
Agricultural land	22	23	19	86.36	82.60
Bare land	15	16	14	93.33	87.50
Built up areas	16	15	13	81.25	86.67
Water	6	6	6	100	100
Forested area	12	11	10	83.33	90.90

Table 4.3 shows the accuracy assessment results for the classification output for the year 2000. The accuracy assessment results are represented in terms of producers and users accuracies. The producers accuracy gives an indication of error of omission while the users accuracy gives an indication of error of commission.

Table 4.4: Accuracy assessment results for the year 2010

Class Name	Reference Totals	Classified Totals	Correct Number	Producers Accuracy (%)	Users Accuracy (%)
Agricultural land	22	24	20	90.90	83.33
Bare land	15	14	13	86.67	92.86
Built up areas	16	17	14	87.5	82.35
Water	6	6	6	100	100
Forested area	12	12	11	91.67	91.67

Table 4.4 shows the accuracy assessment results for the classification output of the year 2010 represented in terms of producers and users accuracies.

Table 4.5: Accuracy assessment results for the year 2020

Class Name	Reference Totals	Classified Totals	Correct Number	Producers Accuracy (%)	Users Accuracy (%)
Agricultural land	22	23	21	95.45	91.30
Bare land	15	15	14	93.33	93.33
Built up areas	16	17	14	87.50	82.35
Water	6	6	6	100	100
Forested area	12	12	10	83.33	83.33

Table 4.5 shows the accuracy assessment results for the classification output of the year 2020 represented in terms of producers and users accuracies

Table 4.6: Overall accuracies and Kappa coefficient

	2000	**2010**	**2020**
Overall Accuracy	87.32	87.67	89.04
Kappa Coefficient	**0.8701**	**0.8736**	**0.8880**

Table 4.6 shows the overall accuracies and kappa coefficient for the classification output for the year 2000, 2010 and 2020. The overall accuracies represents a measure of total correctly interpreted samples with respect to the entire number of samples while kappa coefficient is a measure of agreement between interpreted image and the reference data.

The kappa coefficient model adopted for the study as shown earlier in table 3.4 shows that the figures arrived at of 0.8701, 0.8736 and 0.8880 for years 2000, 2010 and 2020 respectively falls on the scale of 'almost perfect agreement' which is a high score as far as the computation of accuracies is concerned.

4.5 Change detection analysis

Change detection was performed to help detect periodic changes occurring between the previous and the following year of analysis. This was done to get a comparison of the size of area that a land use land cover had changed plus the percentage of change during the 10 year period under analysis. Change detection process was done to also understand the rate of change of each land use land cover.

4.5.1 Land use land cover change between the year 2000 and 2010

The Sub-county experienced several land use land cover changes between the year 2000 and 2010. Land under agriculture increased by 12739 Ha, a percentage increase of 64.57 while also built up area increased by 746 Ha, a percentage increase of 129.51. Whereas agriculture land and built up area increased during the 10 year period, bare land, water and forested area experienced a decline. Bare land, water and forested area declined by a percentage of 67.16, 18.18 and 89.83 respectively as shown in table 4.7.

In terms of largest area changed between the year 2000 and 2010, agricultural land leads with an increased area of 12739 Ha, followed by forested land with a decline of 10093 Ha and then bare land, built up area and water by an area change of 3390 Ha, 746 Ha and 2 Ha respectively.

The land use land cover change during the 10 year period shows a situation where forested lands were cleared to pave way for agriculture as evidenced by the increase in area covered by agriculture at the expense of forested lands. Bare lands also reduced as most of them were also taken over by agriculture.

Table 4.7 shows the percentage coverage of land use land cover in Kiminini Sub-county in the year 2000 and 2010 and change in area during the 10 year period.

Table 4.7: Land use land cover change between the year 2000 and 2010

LULC Classes/Year	2000		2010		Change in Area (2000 – 2010)	
	Area (Ha)	**Area (%)**	**Area (Ha)**	**Area (%)**	**Area (±Ha)**	**Area (±%)**
Agriculture	19729	53.91	32468	88.71	+12739	+64.57
Built up Area	576	1.57	1322	3.61	+746	+129.51
Bare land	5048	13.79	1658	4.53	-3390	-67.16
Forest	11236	30.70	1143	3.13	-10093	-89.83
Water	11	0.03	9	0.02	-2	-18.18
TOTAL	**36600**	**100**	**36600**	**100**		

Figure 4.4 shows a bar graph of land use land cover coverage for the year 2000 and 2010 and change in area during the 10 year period. Land under agriculture increased by the year 2010 at the expense of the other LULC classes; built up area, bare land, forest and water. The

change in area as illustrated in the figure shows an increase agriculture and built up area as they fall on the positive side of the graph while a decline in bare lands, forested area and water as they fall on the negative side of the graph.

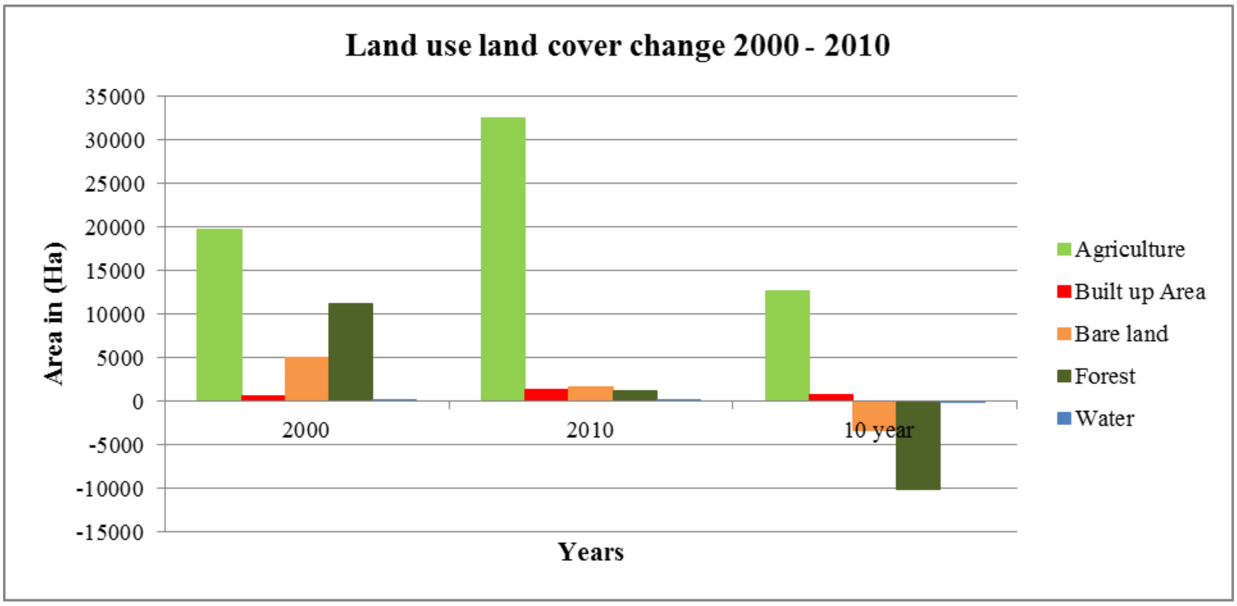


Figure 4.4: Bar graph for land use land cover change 2000 - 2010

4.5.2 Land use land cover change between the year 2010 and 2020

The Sub-county also experienced land use land cover changes between the year 2010 and 2020. Agriculture was the only LULC class that declined in size during the 10 year period. It decreased by an area of 8926 Ha, a percentage decline of 27.49. The rest of the land use land cover; bare land, forest, built up area and water increased by an area of 5193 Ha, 2467 Ha, 1264 Ha and 2 Ha respectively. This also translated to percentage increases of 313.20, 215.84, 95.61 and 22.22 respectively.

In terms of largest area changed during the 10 year period, agricultural land leads with a decline of 8926 Ha, followed by bare land, forested area, built up and water with increase in areas of 5193 Ha, 2467 Ha, 1264 Ha and 2 Ha respectively.

The changes in land use land cover between the year 2010 and 2020 depicts a situation where built up area, forested and bare land increased at the expense of agricultural land.

Table 4.8 shows the percentage coverage of land use land cover in Kiminini Sub-county in the year 2010 and 2020 and change in area during the 10 year period.

Table 4.8: Land use land cover change between 2010 and 2020

LULC Classes/Year	2010		2020		Change in Area (2010 -2020)	
	Area (Ha)	Area (%)	Area (Ha)	Area (%)	Area (±Ha)	Area (±%)
Agriculture	32468	88.71	23542	64.32	-8926	-27.49
Built up Area	1322	3.61	2586	7.07	+1264	+95.61
Bare land	1658	4.53	6851	18.72	+5193	+313.20
Forest	1143	3.13	3610	9.86	+2467	+215.84
Water	9	0.02	11	0.03	+2	+22.22
TOTAL	**36600**	**100**	**36600**	**100**		

Figure 4.5 shows a bar graph of land use land cover coverage for the year 2010 and 2020 and change in area during the 10 year period. Bare land, built up area and forested area increased at the expense of agricultural land. The change in area as illustrated in the figure shows a decline in land under agriculture as it falls on the negative side of the graph while an increase in built up area, bare land and forested area as they fall on the positive side of the graph.

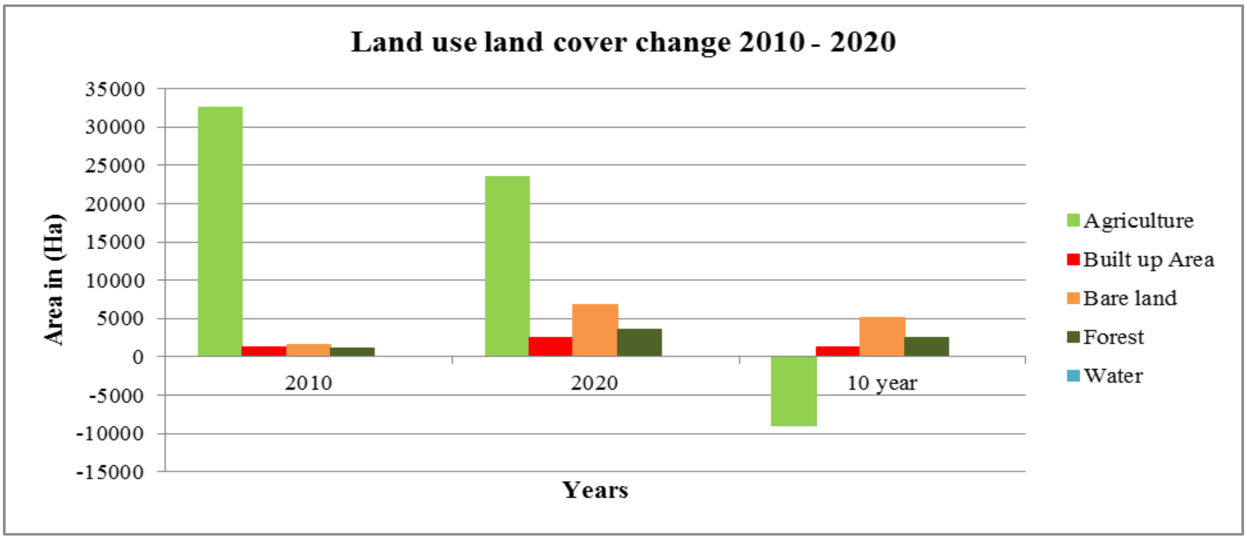


Figure 4.5: Bar graph for land use land cover change 2010 - 2020

Figure 4.6 line graph displays the trend of the 5 land use land cover classes during the 20 years of study.

Agriculture

Agriculture, the LULC class with the most acreage covering 19729 Ha in the year 2000 increased by an area of 12739 Ha to cover 32468 Ha in the year 2010, and then decreased by an area of 8926 Ha to covering 23542 Ha in the year 2020 as shown in figure 4.6.

Forests

Forested, the LULC class with the second most acreage in the year 2000 covering 11236 Ha decreased by an area of 10093 Ha to cover 1143 Ha in the year 2010. It then increased by an area of 2467 Ha to cover 3610 Ha in the year 2020 as shown in figure 4.6.

Bare land

Bare land which covered 5048 Ha in the year 2000 decreased by an area of 3390 Ha to covering 1658 Ha in the year 2010. It then increased by an area of 5193 Ha to covering 6851 Ha in the year 2020.

Built up area

Built up area is the only LULC class which increased in coverage continually for the 20 years. In the year 2000 it covered 576 Ha, and then increased by an area of 746 Ha to covering 1322 Ha in the year 2010. It then increased by an area of 1264 Ha to covering 2556 Ha in the year 2020 as shown in figure 4.6.

Water

Water covered a minimal area or remained almost the same in the 20 years of analysis. Water covered 11 Ha in the year 2000, and then decreased by an area of 2 Ha to covering 9 Ha in the year 2010. It then increased by an area of 2 Ha to covering 11 Ha in the year 2020. See figure 4.6 for the trend of all the 5 land use land cover classes for the past 20 years.

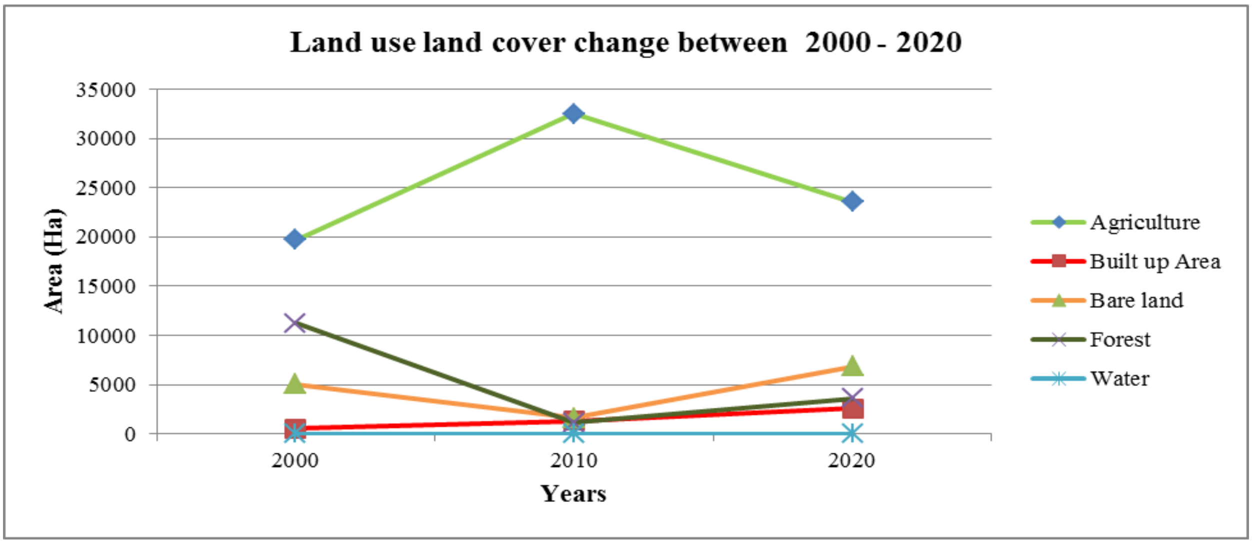
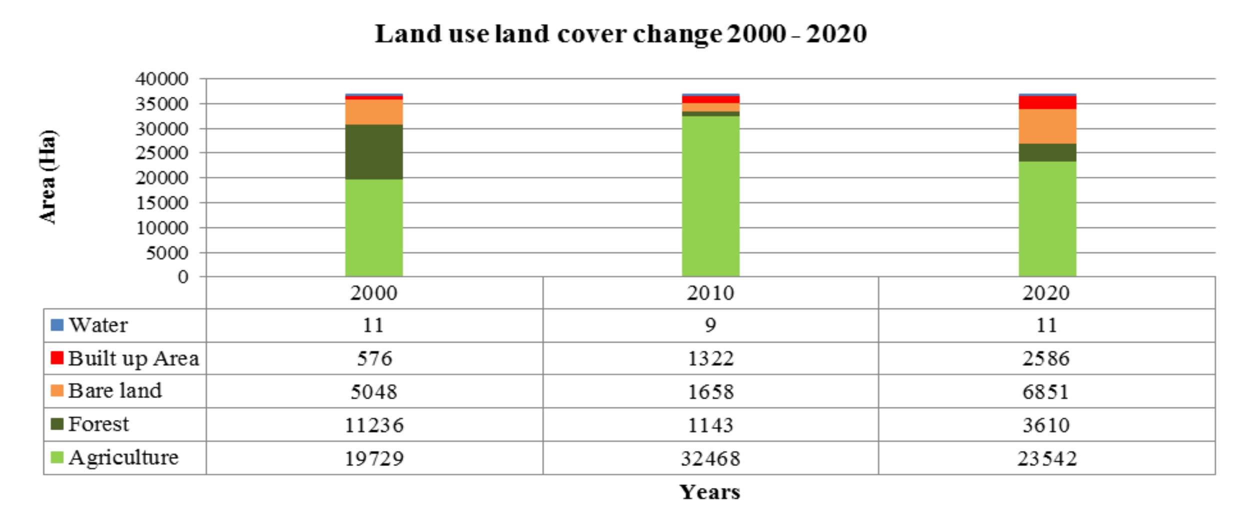


Figure 4.6: Land use land cover trend between the year 2000 and 2020

Figure 4.7 represents a stacked graph of the areas covered by land use land cover in Kiminini Sub-county in the year 2000, 2010 and 2020. The graph displays the area covered by each LULC class in respect to the whole Sub-county coverage in the years under analysis. In the year 2000, agriculture, forest and bare land covered the majority of the Sub-county with built up areas and water covering a very smaller area. Agricultural land expanded in the year 2010 to take over the lands that were occupied by forests and bare land. In the year 2020, bare land, forested area and built up area expanded into the agricultural land thus reducing the area covered by agriculture.



	2000	2010	2020
Water	11	9	11
Built up Area	576	1322	2586
Bare land	5048	1658	6851
Forest	11236	1143	3610
Agriculture	19729	32468	23542

Figure 4.7: Stacked graph for land use land cover change 2000 – 2020

4.6 The implications of Land use land cover change on agricultural land

The objective on investigating the implications of land use land cover change on agricultural land discovered two outcomes that affected the area of land under agriculture for the past 20 years. The agricultural land according to the analysis increased between the year 2000 and 2010 and then decreased between the year 2010 and 2020.

4.6.1 Agricultural land between the year 2000 and 2010

The investigation discovered that agricultural land increased from 19729 Ha in the year 2000 to 32468 Ha in the year 2010, an increase of 12739 Ha which is a percentage increase of 64.57. The increase of 12739 Ha out of the entire county area of 36600 Ha is a coverage of 34.80% which is quite a big size of land converted to agriculture during the 10 year period. The other notable activity in the same periods is that forested land declined by 89.83%, from 11236 Ha in the year 2000 to 1143 Ha in the year 2010. The other decline was that of bare land which reduced by 67.16% from an area of 5048 Ha to 1658 Ha. Therefore, forests were cleared and converted to agriculture as idle lands likewise were put to agriculture.

The conversion of more forested lands to agriculture and expansion of agriculture into idle lands between the year 2000 and 2010 is attributed to factors such as increased demand for food from the rising population. The Kenya population data showed that the population of Kiminini sub-county rose from 64685 in 1999 to 199386 in 2009 (KNBS, 2019). The increased population in Kiminini Sub-county ensured constant market for food, which encouraged more expansion of agriculture into forested land between the year 2000 and 2010**.** FAO, (2016) supports this argument by stating that there was a forest loss of 7 million hectares per year and a 6 million hectare gain of agricultural land per year between the year 2000 and 2010 in tropical countries. In addition, the availability of land for expansion as depicted by the analysis is another factor which encouraged more expansion of agriculture into forested area and bare lands. Other conditions that encouraged more farming included the reliable climatic conditions, stable prices, readily available fertilizers and extension services from government.

4.6.2 Agricultural land between the year 2010 and 2020

The study also revealed that between the year 2010 and 2020 land under agriculture declined from 32468 Ha to 23542 Ha, a decrease of 27.49%. The decline of land under agriculture of 8926 Ha out of the entire Sub-county area of 36600 Ha is a 24.38% of the Sub county land turned to other uses. The analysis reveals that the decrease in land under agriculture was as a result of an increased coverage of land under forests, bare land and built up areas. The increased percentage of forested area, bare land and built up area between the year 2010 and 2020 was 215.84%, 313.20% and 95.61% respectively. This means land that initially was under agriculture was converted to forests and built up while other land was left idle.

The built up areas increased from 1322 Ha to 2586 Ha, an increase of 1264 Ha converted from agriculture to settlements. In support of the increased settlements, CIDP, (2018) argues that there are more than 45 settlements schemes spread all over Trans Nzoia county set up by the government to resettle land less and displaced persons of the 1992 and 2007 clashes. This means subdivision of vast lands initially under agriculture to smaller pieces to set up new homes for the new owners. Urbanization in the Sub-county also contributed to establishment of more commercial and residential settlements to meet demand for rural urban migration. Kenya population data reveals that Kitale town population increased from 106187 in the year

2009 to 162174 in the year 2019 supporting the fact that there had been more urbanization in the Sub-county (KNBS, 2019). Kiminini town whose population was estimated to be 12000 in 2009 was projected to be more than 20000 in 2019 (CIDP, 2018). The document also reveals that the outskirts of Kiminini town is characterised by uncoordinated developed structures that keep growing into the agricultural lands.

The forested areas increased from 1143 Ha to 3610 Ha, an increase of 2467 Ha converted from agriculture to forested area. The conversion of agricultural land to forested area is because of the many government and international initiatives towards increasing forest cover to counter climate change that was more active around 2010. In Kenya, the Kenya vision 2030 document launched in the year 2008 intended to increase forest cover in Kenya from less that 3% to 4% (GoK, 2007). There have also been other calls by the government to plant 1.8 billion seedlings through to the year 2022 as highlighted by the ministry's website (http://www.environment.go.ke/?p=6738, accessed on 17th May 2021). In addition, there have been initiatives by the County Government of Trans Nzoia to increase county tree cover from the current 16.8% to at least 20% by the year 2022 as highlighted by the article on the county's website (https://www.transnzoia.go.ke/county-to-support-planting-of-a-million-trees accessed on 30th May 2021). All these initiatives are possibly the cause for the 2467 Ha conversion of agricultural land to forested area between the year 2010 and 2020.

Finally, bare land increased from 1658 Ha to 6851 Ha between the year 2010 and 2020, an increase of 5193 Ha of agriculture land turned idle. There are several reasons leading to abandonment of agriculture between the year 2010 and 2020. The division of land to smaller portions to cater for demand for settlement and other uses has led to abandonment of agriculture as the land is not economical. According to Nekesa, (2019) the average agricultural land sizes in Kiminini in 1963 was 30 acres but due to land subdivisions it has reduced to as low as 1.5 acres. Farmers are also lately abandoning growing maize, the main crop grown in the Sub-county because of the many challenges such as diseases, pests, erratic rains and low prices (http://www.xinhuanet.com/english/2018-03/10/c_137029963.htm, accessed on 15th May 2021)

Therefore, the implication of land use land cover change on agricultural land in Kiminini Sub-county is a two way scenario in the past 20 years, which led to increase and then a decrease in agricultural land. Between 2000 and 2010, it led to increase in agricultural land at the expense of forested land and other LULC and between 2010 and 2020 it led to increase in forested land and bare land at the expense of agricultural land. These kinds of scenarios of fluctuation in land use land cover are not healthy and there needs to be a balance in land use. FAO, (2016) noted that there was a net loss of 7 million hectares of forests per year between the year 2000 and 2010. And that such a loss led to land degradation, desertification, soil erosion and increase in greenhouse gas. The later years, between 2010 and 2020 lead to loss of agricultural land in favour of built up areas, forest and bare lands in Kiminini Sub-county. According to Gomiero, (2016) the drastic decline in agricultural land poses a serious threat to food production and food security for poor countries experiencing rise in population, thus there needs to be a balance in land use land cover.

4.7 Causes of land use land cover changes in Kiminini Sub-county

Finally, on the objective of reviewing the causes of land use land cover change, the study with the application of the final land use land cover maps and other reliable secondary sources of data reviewed the causes of LULCC to include; population increase, resettlement schemes, urbanization, low economic returns from agriculture and land owners subdividing and selling.

4.7.1 Population increase

Kenya National Bureau of Statistics data indicated that the population of Kiminini Sub-county has been constantly increasing as shown in table 4.9 for the past 3 official counts done. The population increase is a factor which directly affects the land use land cover change in the Sub-county since its increase, increased the demand for food and land for settlement. The KNBS data which shows that the population of Kiminini Sub-county kept increasing is supported with the land use land cover analysis which indicates that built up areas kept increasing from the year 2000 to 2020.

Agricultural land and built up areas increased between the year 2000 and 2010. Bare land and forested areas at the same period declined. The population increase in the same period increased the demand for food which led to conversion of more forested areas to agriculture. At the same time the idle lands were also converted to agriculture to produce more food to meet the demands for the population. The increase in built up areas between the same periods is due to development of settlements, commercial zones, educational, hospitals and other government utilities to meet the demands for the population. The built up areas are spread all over the Sub-county due to private ownerships of land allowing owners to set up homes on their lands.

Agricultural lands then declines between the year 2010 and 2020. Bare lands, built up areas and forested areas increased during the same period. Population increase is still an important factor affecting land use land cover change under this period. Population increased the demand of land for settlement leading to more private land subdivisions and sell to meet the demands. Unfortunately, the increased subdivisions led to division of agricultural lands to smaller parcels uneconomical for farming leading to eventual abandonment of agriculture. This is why there was an increase in bare lands during the same period. Built up areas is spread all over the Sub-county as shown in figure 4.3 because of the continued subdivision and setting up of homes by the new buyers. Table 4.9 shows the population census data for Kiminini Sub-county for the year 1999, 2009 and 2019.

Table 4.9: Population census data for Kiminini Sub-county

	1999	**2009**	**2019**
Population	64685	199386	288659
Population density	163	504	730.20

Source: Kenya National Bureau of Statistics

4.7.2 Resettlement Schemes

The large tracks of land in Trans Nzoia County and several other parts of Kenya were a white European settled area before independence. Immediately after independence, the land ownership changed to the government of Kenya under the "one million acre scheme" programme, which was meant to purchase land from European settlers using loans acquired from the World Bank to be used to resettle landless Kenyans (Kanyinga, 2017). Unfortunately, the process is still not yet complete 50 years after independence; landless Kenyans are still being resettled in government schemes by the National Lands Commission as highlighted in the article (https://www.pd.co.ke/news/national/nlc, accessed on 16th March 2021).

The large tracks of land in the County are being subdivided and allocated to landless Kenyans by the National Lands Commission. At the moment the County has 45 settlement schemes spread all over. A few examples of those schemes include; Ndalala, Kospirin, Matumbo, Nyasi, Botwa, Kapkarwa, Kimila, Karara etc. (CIDP, 2018).

Apart from settling landless Kenyans, displaced Kenyans after the 1992 and 2007 clashes have also been resettled in the County. A report from (https://reliefweb.int/report/kenya/8000-idps-set-be-resettled, accessed on 12th May 2021) indicated that 8000 Kenyans displaced after the 2007 post-election chaos were resettled and are still going to be resettled in the County because of availability of government owned lands.

Therefore, the resettlement of the displaced and landless population in the County is a cause of LULCC since large tracks of land that were under agriculture are subdivided and allocated to landless Kenyans for settlement use. The land use land cover analysis supports this argument as the built up areas in Kiminini Sub-county kept increasing continuously from the year 2000 to the year 2020. The increased settlement of landless and displaced Kenyans led to conversion of land use land cover from agricultural to built-up areas.

4.7.3 Urbanization

Urbanization in Kiminini Sub-county has led to conversion of the existing agricultural land to urbanized land uses such as commercial and high density settlements. The conversion to such kind of land uses is so as to cater for the rural to urban migration in the Sub-county. Kitale Town is one of the largest towns in western Kenya located at the border of Kiminini Sub-county. Its population has been continually increasing according to Kenya National Bureau of Statistics from a population of 106,187 in 2009 to 162,174 in 2019. It is even projected to increase more by the year 2022 according to statistics from the County Integrated Plan Development of 2018.

The areas shaded in dark grey in figure 4.8 illustrate the trend of growth of Kitale town and other urban centres such as Maili Saba, Kiungani, Sikhendu and Kiminini into the hinterland. Kiminini town is the second largest town in the county whose population was at 12,000 in 2009 and was projected to be more than 20,000 in 2019. The outskirts of the town is characterised by uncoordinated developed structures that have been growing into the agricultural lands. The relatively cheap standard of living in Kiminini has attracted people working in Kitale to live here and commute (CIDP, 2018). Therefore, urbanization is a factor that has been driving change in land use land cover in Kiminini Sub-county. Figure 4.8 shows a map of the trend of urbanization in Kiminini Sub-county.

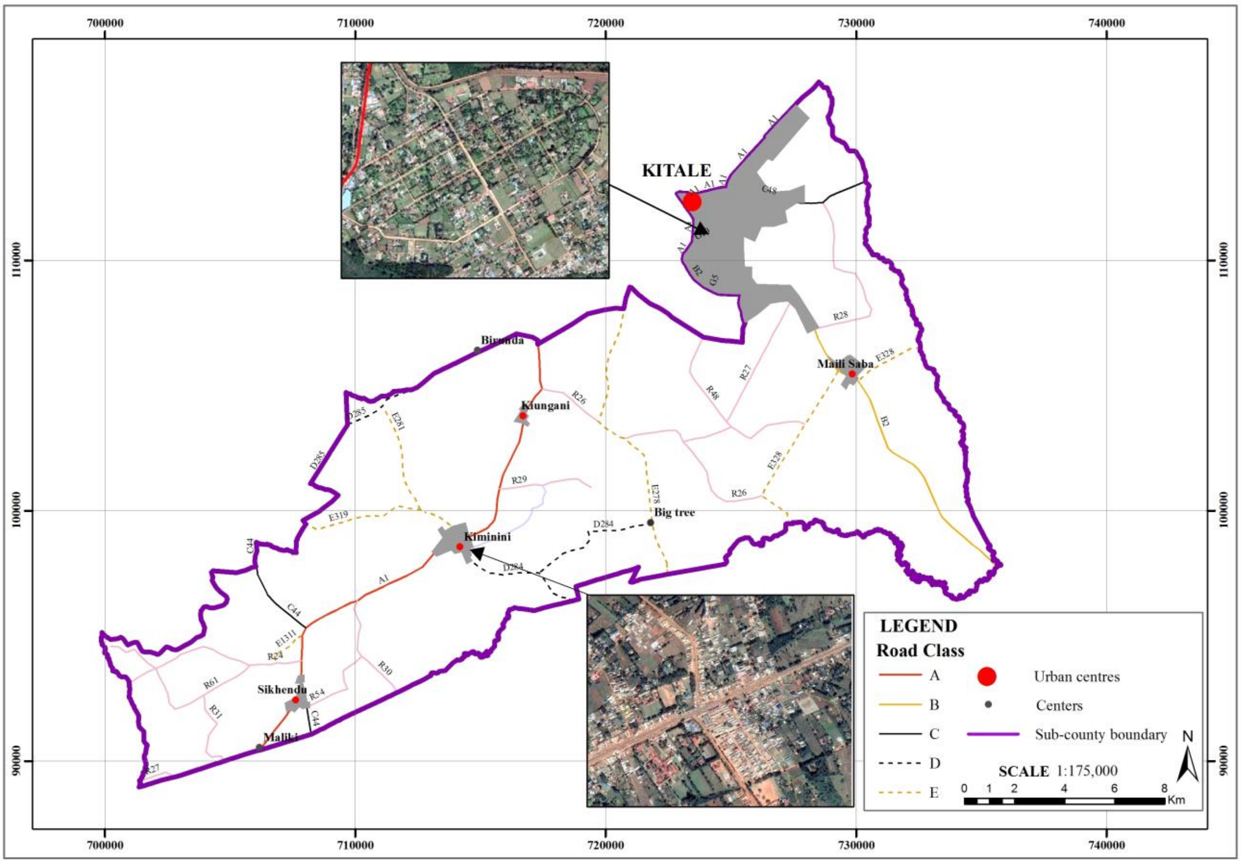


Figure 4.8: Urbanization in Kiminini Sub-county. (Imagery source: Google earth 2020)

4.7.4 Low economic returns from agriculture

The development and growth of urban centres in Kiminini Sub-county resulted to the conversion of agricultural land to commercial and residential uses. These are land uses that are mostly common in urban centres because of the nature of activities going on. Urbanization intensifies non-agricultural activities that are more economical leading to abandonment of agriculture in seeking better enterprises (Wu, 2008). The continually increasing population and urbanization in Kiminini Sub-county has increased the demand for residential and commercial houses, thus people abandon agriculture to develop residential and commercial units to meet the demand for houses for settlement and commercial businesses.

Farmers are also abandoning growing maize, main crop grown in Kiminini Sub-county because of many challenges such as diseases, pests, erratic rains and low prices. They are giving up growing maize and venturing in other economic activities as highlighted in the article (http://www.xinhuanet.com/english/2018-03/10/c_137029963.htm, accessed on 15th May 2021). The article highlights other challenges that affect agricultural development making it less attractive economically.

The subdivision of lands to smaller parcels is another factor contributing to low returns from agriculture. The demands for land for settlement from the increasing population lead to more subdivisions. The more the division of lands to smaller parcels, the less likely it will be feasible for agricultural production. The low returns from agriculture leads to abandonment of agriculture and venture into other non-agricultural activities that have better returns.

4.7.5 Land owners subdivide and sell

The majority of the lands in Trans Nzoia County were white European settled before independence. After independence, most of their lands were acquired by the state in a "one million acre scheme" programme with the aim of resettling landless Kenyans (Kanyinga, 2017). The initial land owners who received allocation from the government have further subdivided their lands to small portions and sold them to others. At the moment the average land holding size in the Sub-county is 0.607 hectares for small farm holders to 12.15 hectares for large farm holders (CIDP. 2018).

The mean land holding size in Kiminini is continually decreasing as subdivision of land is occasioned by population pressure. According to Nekesa, (2019) the average agricultural land sizes in Kiminini in 1963 was 30 acres but due to land subdivisions it has reduced to as low as 1.5 acres. And that the continued subdivision of lands to smaller uneconomic portions has caused many people to abandon agriculture while others sell their portions of land as it is not economical anymore to practise agriculture. This outcome is supported by the land use land cover analysis which shows that the bare lands sizes increased from the year 2010 to 2020 by 5193 hectares. This increase in bare lands could be as a result of abandonment of agriculture for other beneficial economic activities after lands have become so small. Figure 4.9 shows a map of cadastral samples of several parts of Kiminini Sub-county showing the extent of land subdivisions.

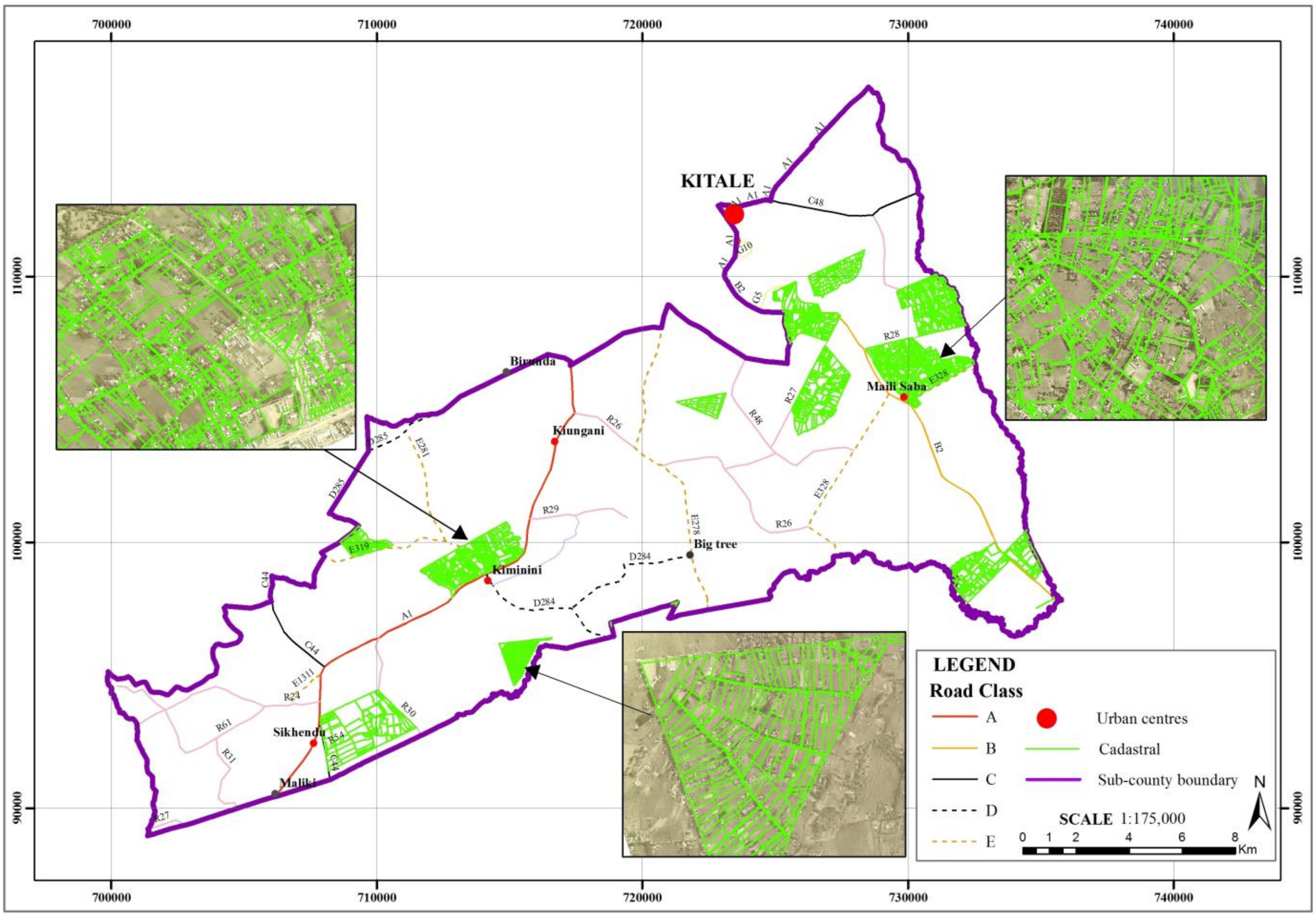


Figure 4.9: Cadastral samples for Kiminini Sub-county. (Imagery source: Aerial image 2019)

4.8 Discussion of Results

The study revealed five land use land cover types in Kiminini Sub-county, they include; agricultural land, forested area, bare land, built up and water. It also revealed various changes in the mentioned land use land cover between the years 2000 and 2020 which are attributed to various driving forces. Agriculture has been the most affected of the five LULC classes in terms of area change. The size of land under agriculture in Kiminini Sub-county covered 19729 Ha in the year 2000, then increased to 32468 Ha by the year 2010 and then dropped to 23542 Ha in the year 2020. The second most affected LULC class was forested land, which covered 11236 Ha in the year 2000, then dropped to 1143 Ha in 2010 and then increased slightly to 3610 Ha in the year 2020. Built-up areas increased continuously from covering 576 Ha to 1322 Ha and to 2586 Ha in the year 2000, 2010 and 2020 respectively. Bare land slightly increased by 1803 Ha in the year 2020 compared to the year 2000. Finally, land under water almost remained the same since the year 2000.

Agricultural land increased between the year 2000 and 2010 at the expense of forested areas and bare lands. The people cleared forests in the Sub-county to do more cultivation. In addition, it is evidenced that bare land reduced between the year 2000 and 2010 reason being more idle land was now cultivated. Agriculture then, was an attractive economic activity because there was enough land available for expansion into forested areas and also because of the increased demand for food from the increased population. The demand for food was necessitated by the continuously increasing population as evidenced by statistics from the Kenya National Bureau of Statistics and also urbanization in the Sub-county. FAO, (2016) supports the fact that forest cover went down around this time as it highlights that that global forest fell by 3% between 1990 and 2015 because of conversion to other land uses such as agriculture and mining.

Agricultural land change was again experienced between 2010 and 2020 as there was a drastic fall in the land under agriculture by 27.49%. Built up area, bare land and forested area increased at the expense of agricultural land. More land that was under agriculture was taken over by settlement and forest while other lands remained idle. CIDP, (2018) supports the increase in settlement by highlighting cases of resettlements in the County by the government. It also indicated that there were more than 45 settlement schemes in the County. The government also resettled most of the displaced persons from the 1992 and 2007 clashes in Trans Nzoia County as highlighted in the article (https://reliefweb.int/report/kenya/8000-idps-set-be-resettled, accessed on 12th May 2021). In addition, the increased urbanization in

Kiminini Sub-county as per the KNBS statistics that showed a continuous increase in population of Kitale and Kiminini Towns is a contributory factor to the take-over of agricultural land by other non-agricultural activities. Other towns in the Sub-county accelerating the takeover of agricultural land by urbanized settlement include Maili Saba, Kiungani and Sikhendu as shown in figure 4.8.

Bare land increased at the expense of agricultural land between the year 2010 and 2020. Bare land increase indicates the increased availability of idle land, which means a possibility that those who were practising agriculture abandoned the activity. The reason for abandoning agriculture is because of the many challenges such as the high cost of production, diseases, pests, erratic rains and low prices as highlighted in the article (http://www.xinhuanet.com/english/2018-03/10/c_137029963.htm, accessed on 15th May 2021). According to Nekesa, (2019) the average agricultural sizes in Kiminini Sub-county was 30 acres in 1963, but due to land subdivision it has reduced to as low as 1.5 acres. Many of those who were practising agriculture have abandoned the economic activity while others have sold their portions of land as it is not economically viable to farm on small portions of lands. Figure 4.9 showing cadastral samples from various parts of Kiminini Sub-county support the fact that there has been increased land subdivision. The division of lands to smaller portions has led to abandonment of agriculture as the smaller portions of land are not economical for agriculture, thus the reason for increased bare lands between the year 2010 and 2020.

Forested areas increased between the year 2010 and 2020 at the expense of agriculture. The reason for the increase in forest cover is because since the year 2010, there have been many government and international initiatives towards increasing forest cover to counter climate change. For instance, the Kenya vision 2030 document that was launched in the year 2008 aims to have a secure and clean environment by the year 2030. To do so, it intended to increase forest cover in Kenya from less than 3% to 4% (GoK, 2007). There have also been other calls and initiatives by the government through the cabinet secretary with intentions of increasing Kenya's forest cover by 10%. Under the initiative, Kenya needs to plant 1.8 billion seedlings through to the year 2022 as highlighted in the ministry's website (http://www.environment.go.ke/?p=6738, accessed on 17th May 2021). In addition, there have been initiatives by the County Government of Trans Nzoia to increase county tree cover from the current 16.8% to at least 20% by the year 2022. The leadership back then allocated funds that were meant to support such efforts as highlighted by the article on the county's website (https://www.transnzoia.go.ke/county-to-support-planting-of-a-million-trees accessed on 30th

May 2021). All of these initiatives could be the reason why forest cover increased in the Sub-county from the year 2010 to 2020 at the expense of agriculture.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main objective of the study entailed the mapping of land use land cover changes and their implications on agricultural land using GIS and remote sensing technologies in Kiminini Sub-county, Trans Nzoia County. The purpose of the study was to use GIS and remote sensing technology to graphically display changes in land use land cover over a period of 20 years and investigate the implications of the changes on agricultural land. This was achieved through a breakdown of the main objective to some detailed specific objectives.

On the objective of mapping of land use land cover changes in Kiminini Sub-county from the year 2000 to 2020, the mapping process with the support of GIS and remote sensing technology revealed the existence of 5 land use land cover classes; forested, bare land, agriculture, built up and water in the mapping area. The outputs of the mapping process are land use land cover maps for the year 2000, 2010 and 2020 as shown in figure 4.1, 4.2 and 4.3. The results from the mapping process revealed changes in land use land cover in the 20-year span that could be attributed to various factors such as urbanization, population increase, low economic returns from agriculture and land subdivision.

The objective on quantifying the changes in land use land cover in the mapping area was accomplished using the outputs of the mapping process. Change detection using GIS and remote sensing was done on the land use land cover maps for years 2000, 2010 and 2020. To carry out change detection, each land use land cover areas were determined and compared during the 10-year period. The study revealed that between the year 2000 and 2010 agriculture and built up area increased by 64.57% and 129.51% respectively. Bare land, water and forest declined during the same period by 67.16%, 18.18% and 89.83%. Again the study revealed some land use land cover changes between the year 2010 and 2020. Agriculture land decreased with a percentage of 27.49. The others classes increased by 95.61%, 313.20%, 215.84% and 22.22% for built up, bare land, forest and water respectively. Agriculture increased between the year 2000 and 2010 at the expense of forest and bare lands. Bare lands, forest and built up then increased between the year 2010 and 2020 at the expense of agricultural land.

The study identified increased population, urbanization, resettlements in the area, low economic returns from agriculture and increased land subdivision as the causes of land use land cover change. The population increase and population influx increased the pressure on agricultural land as a result of increased need of land for settlement. The study finds that urbanization in the Sub-county increased the demand of land for settlement, commercial ventures, industrial parks, education, public purpose and public utilities. Therefore, with the continued urbanization comes the development of urban kind economic activities, which the population finds it more attractive economically compared to agriculture leading to abandonment of agriculture. Finally, it was discovered that several policies by the government had resulted to the resettlement of displaced and landless population from other counties to the county. That was noted from the increasing settlement schemes that now stand at 45 in total that have led to the subdivision of agricultural land to small units which may not be feasible for farming.

Finally, on the objective of investigating the implications of land use land cover changes on agricultural land, the study revealed that agricultural land was the most affected by the changes. The land under agriculture increased by 64.57% between the year 2000 to 2010 and then decreased by 27.49% between the year 2010 and 2020. This change is very critical, especially that the study is informed by the fact that the Sub-county is commonly referred to as Kenya's food basket by the CIDP, (2018) which indicates that most of the staple food come from the Sub-county. Therefore, it is significant to note that the fluctuation in land under agriculture is a risk to food security to the county and country at large. Gomiero, (2016) supports that argument by stating that a drastic decline in agricultural land poses a serious threat to food production and food security. Policy makers need to be informed by the findings of the study so as to make better decisions concerning proper land use planning.

5.2 Recommendations

The study has proven that GIS and remote sensing is an effective technology for application in land use land cover change detection analysis. It therefore recommends the relevant authorities dealing with land use inquiries to adopt such technologies which are significant in analysing changing spatial patterns and relationships of land use land cover. These spatial patterns will provide them with insights of the trends of land use land cover change over time thus enabling them make informed decisions concerning land use issues.

Landsat satellite images are easily accessible, cheap and reliable for analysis of land use land cover change as shown by the findings of the study. However, with their spatial resolution of 30m it was a bit challenging to differentiate the signature for some land use land cover features such as bare land and livestock pasture. Hence it recommends that well-funded government institutions should acquire high resolution aerial images or satellite images which will improve the spatial accuracy for future analysis.

The study utilized satellite images for a 10 year span to arrive at the findings that there had been various land use land cover changes. The recommendation is that 10 years is a longer period of time to be used for monitoring environmental and land use land cover changes. Therefore, the government institutions should consider acquiring yearly high resolution aerial images or satellite images.

Agriculture remains to be a backbone of the Kenyan economy and its contribution to the GDP remains unmatched by other sectors. Therefore, more effort should be put to develop and improve the performance of the sector. There should be counter solutions to the problems caused by increased population and urbanization such as intensive land subdivision and land use change from agriculture to other uses. An example is the adoption of modern farming techniques that increases yields within a small piece of land.

Finally, in order to reduce the loss of agricultural land due to the increasing population and rapid urbanization in the Sub-county, there is a need for formulation and enforcement of land use policies that would protect against urban sprawl, excessive subdivision of land and the conversion of agricultural land to other uses.

5.3 Areas for Further Research

The study focussed on the investigation of the impacts of land use land cover change on agricultural land, after considering the assumption that the loss of agricultural land was an important factor to the decline in agricultural production. Therefore, future studies should focus on the impact of land use land cover on agricultural production by collecting agricultural production data over a longer period of time. This will proof whether the loss of agricultural land has any effect on agricultural production.

The physical aspect of land use land cover change was clearly illustrated in the study, but future research interests should be placed on the impact of land use land cover change on a global scale such as how it affects climatic conditions, hydrology and the ecosystem of a place. Data should be collected over a longer period of time, analysed and integrated with other factors to bring out the global impacts of land use land cover change.

REFERENCES

Al-doski, J., Mansor, S. B., & Shafri, H. Z. M. (2013). Change detection process and techniques. *Civil and Environmental Research*, 3(10).

Alexandratos, N. (n.d.). *WORLD FOOD AND AGRICULTURE TO 2030/50*. 32.

Aronoff, S. (2005). *Remote sensing for GIS managers* (1st ed). ESRI Press : Independent Publishers Group (IPG) [distributor].

Asokan, A., & Anitha, J. (2019). Change detection techniques for remote sensing applications: a survey. *Earth Science Informatics*, 12(2), 143-160.

CIDP, (2018). Trans Nzoia County Integrated Development Plan, 2018-2022

County Government of Trans Nzoia, (2021 June, 30) *county to support planting of a million trees.* *https://www.transnzoia.go.ke/county-to-support-planting-of-a-million-trees/*, [accessed on 30th May 2021].

Croft, H., Chen, J. M., Wang, R., Mo, G., Luo, S., Luo, X., & Bonal, D. (2020). The global distribution of leaf chlorophyll content. *Remote Sensing of Environment*, 236, 111479.

Daily Nation, (2013 April, 1) *8,000 IDPs set to be resettled.* https://reliefweb.int/report/kenya/8000-idps-set-be-resettled, [accessed on 12th May 2021].

Degife, A. W., Zabel, F., & Mauser, W. (2018). Assessing land use and land cover changes and agricultural farmland expansions in Gambella Region, Ethiopia, using Landsat 5 and Sentinel 2a multispectral data. *Heliyon, 4(11), e00919.*

Di Gregorio, A., & Jansen, L. J. (1998). A new concept for a land cover classification system. *The Land*, 2(1), 55-65.

Fazal, S. (2008). *GIS basics.* New Age International.

Food and Agriculture Organization of the United Nations (FAO). (1997). *AFRICOVER: land cover classification.* FAO.

Food and Agriculture Organization of the United Nations (FAO). (2011). The state of the world's land and water resources for food and agriculture (SOLAW)-Managing systems at risk. *Food and Agriculture Organization of the United Nations.*

Food and Agriculture Organization of the United Nations (FAO). (2014). Country Programming Framework for Kenya 2014–2017. FAO, *Rome, Italy*.

Food and Agriculture Organization of the United Nations (FAO). (2016). State of the World's Forests 2016: Forests and agriculture: Land-use challenges and opportunities. *FAO Report.*

Food and Agriculture Organization of the United Nations (FAO). (2021 June 23) *Kenya at a glance. http://www.fao.org/kenya/fao-in-kenya/kenya-at-a-glance/en/* [accessed on 21th July 2021].

Gomiero, T. (2016). Soil degradation, land scarcity and food security: Reviewing a complex challenge. *Sustainability*, 8(3), 281.

Government of Kenya (2007). *The Kenya Vision 2030.* Nairobi: Government Printers.

Government of Kenya. (2009). *The National Land Policy*. Nairobi: Government Printers.

Government of Kenya (2017). *The National Land Use Policy.* Nairobi. Government Printers.

Gregrio, A., & Jansen, J. (2000). Land Cover classification system (LCCS); Classification concepts and user manual for software version 2.

Haque, M. I., & Basak, R. (2017). Land cover change detection using GIS and remote sensing techniques: A spatio-temporal study on Tanguar Haor, Sunamganj, Bangladesh. *The Egyptian Journal of Remote Sensing and Space Science*, 20(2), 251-263.

Hassan, Z., Shabbir, R., Ahmad, S. S., Malik, A. H., Aziz, N., Butt, A., & Erum, S. (2016). Dynamics of land use and land cover change (LULCC) using geospatial techniques: A case study of Islamabad Pakistan. *SpringerPlus*, *5*(1), 812. https://doi.org/10.1186/s40064-016-2414-z

J, M., S, W., B, G., & Kkg, C. (2020). Assessment of Land Use and Land Cover Change Using GIS and Remote Sensing: A Case Study of Kieni, Central Kenya. *Journal of Remote Sensing & GIS*, *09*(01). https://doi.org/10.35248/2469-4134.20.9.270

Kang'ethe, E. (2011). Situation analysis: Improving food safety in the maize value chain in Kenya. *Report prepared for FAO. College of Agriculture and Veterinary Science, University of Nairobi, Nairobi.*

Kanianska, R. *(2016).* Agriculture and its impact on land-use, environment, and ecosystem services. *Landscape ecology-The influences of land use and anthropogenic impacts of landscape creation, 1-26.*

Kanyinga, K. (2017, May). Kenya experience in land reform: The million-acre settlement scheme. *In Workshop discussion paper, viewed* (Vol. 22, pp. 459596-1168010635604).

Kebaso, W. M. (2017). Effects of Land Subdivisions to Food Security *Case Study: Kaputiei North-Kajiado County* (Doctoral dissertation, University of Nairobi).

Kenya National Bureau of Statistics (Ed.). (2019). *2019 Kenya population and housing census*. Kenya National Bureau of Statistics.

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual review of environment and resources*, 28(1), 205-241.

Li, S., Wang, T., & Yan, C. (2017). Assessing the role of policies on land-use/cover change from 1965 to 2015 in the Mu Us Sandy Land, northern China. *Sustainability*, 9(7), 1164.

Limo, E. B. C. (2016). *Land Sub-division Effect on Agricultural Productivity in Trans-Nzoia West Sub-county, Kenya* (Doctoral dissertation, MOI UNIVERSITY).

Mallupattu, P. K., & Sreenivasula Reddy, J. R. (2013). Analysis of land use/land cover changes using remote sensing data and GIS at an Urban Area, Tirupati, India. *The Scientific World Journal*, 2013.

Marland, G., Pielke Sr, R. A., Apps, M., Avissar, R., Betts, R. A., Davis, K. J., & Xue, Y. (2003). The climatic impacts of land surface change and carbon management, and the implications for climate-change mitigation policy. *Climate policy*, 3(2), 149-157.

Meyer, W. B. (1995). Past and present land use and land cover in the USA. *Consequences*, 1(1), 25-33.

Meyer, W. B., & Turner, B. L. (1992). Human population growth and global land-use/cover change. *Annual review of ecology and systematics*, 23(1), 39-61.

Ministry of Environment and Forestry, (2021 May, 17) *Strategy to increase forest cover*. http://www.environment.go.ke/?p=6738, [accessed on 17th May 2021].

Mishra, S., Shrivastava, P., & Dhurvey, P. (2017). Change detection techniques in remote sensing: a review. *International Journal of Wireless and Mobile Communication for Industrial Systems*, 4(1), 1-8.

Mohamed, N., & Mobarak, B. (2016). Change detection techniques using optical remote sensing: a survey. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)*, 17(1), 42-51.

Mzuza, M. K., Zhang, W., Kapute, F., & Wei, X. (2019). The Impact of Land Use and Land Cover Changes on the Nkula Dam in the Middle Shire River Catchment, Malawi. *In Geospatial Analyses of Earth Observation (EO) data.* IntechOpen.

Nekesa, D. A. (2019). *Rural Land Subdivision And Its Impact On Household Maize Production* (Doctoral dissertation, University Of Nairobi).

NEMA, (2013). Trans-Nzoia District Environmental Action Plan 2009 – 2013 Nairobi: Government Printers.

Ogechi, B. A., & Hunja, W. E. (2012). *Land Use Land Cover Changes and Implications for Food Production: A Case Study of Keumbu Region Kisii County, Kenya*. *3*(10), 8.

Otterman J. (1974). Baring high-albedo soils by overgrazing: a hypothesised desertification mechanism. Science 86:531–33

Patra, S., Sahoo, S., Mishra, P., & Mahapatra, S. C. (2018). Impacts of urbanization on land use/cover changes and its probable implications on local climate and groundwater level. *Journal of Urban Management*, 7(2), 70-84.

Pellikka, P. K., Clark, B. J., Gosa, A. G., Himberg, N., Hurskainen, P., Maeda, E., ... & Siljander, M. (2013). Agricultural expansion and its consequences in the Taita Hills, Kenya. *In Developments in Earth surface processes* (Vol. 16, pp. 165-179). Elsevier.

People Daily Kenya, (2021 March, 16) *NLC officials put on notice over Chepchoina resettlement.* https://www.pd.co.ke/news/national/nlc, [accessed on 16th March 2021].

Poongothai, N. N. S. (2011). Identification of Land use and Land cover Changes using Remote Sensing and GIS. *International Journal of Engineering and Technology*, 3(5), 570.

Roy, D. P., Kovalskyy, V., Zhang, H. K., Vermote, E. F., Yan, L., Kumar, S. S., & Egorov, A. (2016). Characterization of Landsat-7 to Landsat-8 reflective wavelength and normalized difference vegetation index continuity. *Remote sensing of Environment*, 185, 57-70.

Waiganjo, C., & Ngugi, P. E. (2001). The effects of existing land tenure systems on land use in Kenya today. *In Proceedings International Conference on Spatial Information for Sustainable Development paper number TS6. 2, ISK/FIG/UN Nairobi Kenya Williamson IP, 2000, Best Practices for Land Administration Systems in Developing Countries, Proceedings International C*.

Weng, Q. (2010). *Remote sensing and GIS integration: Theories, methods, and applications*. McGraw-Hill.

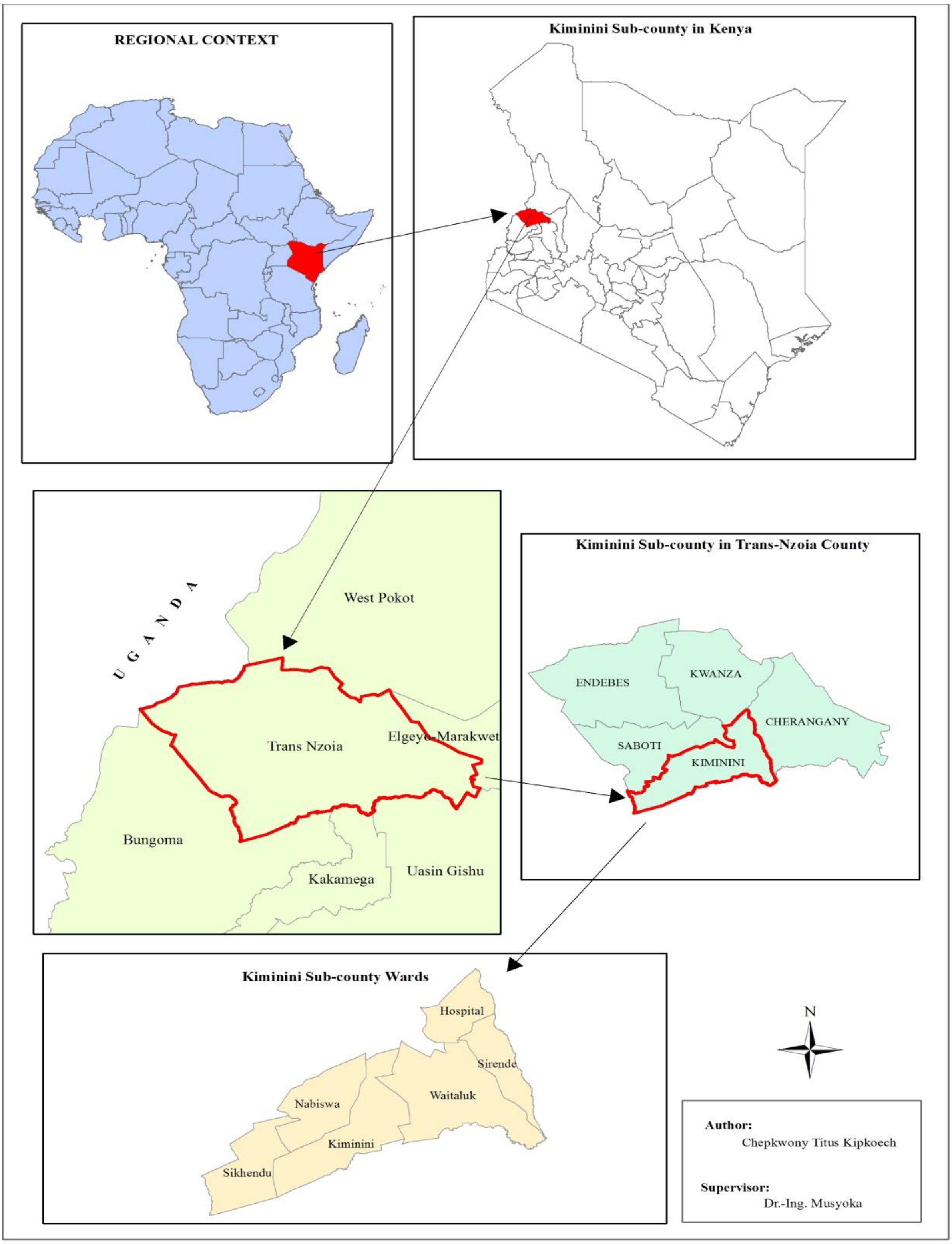
Wu, J. (2008). Land use changes: Economic, social, and environmental impacts. *Choices*, 23(316-2016-6225), 6-10.

Xinhua, (2018 March, 3) *Feature: Challenges push Kenyan farmers from maize to cane, horticulture.* http://www.xinhuanet.com/english/2018-03/10/c_137029963.htm, [accessed on 15th May 2021].

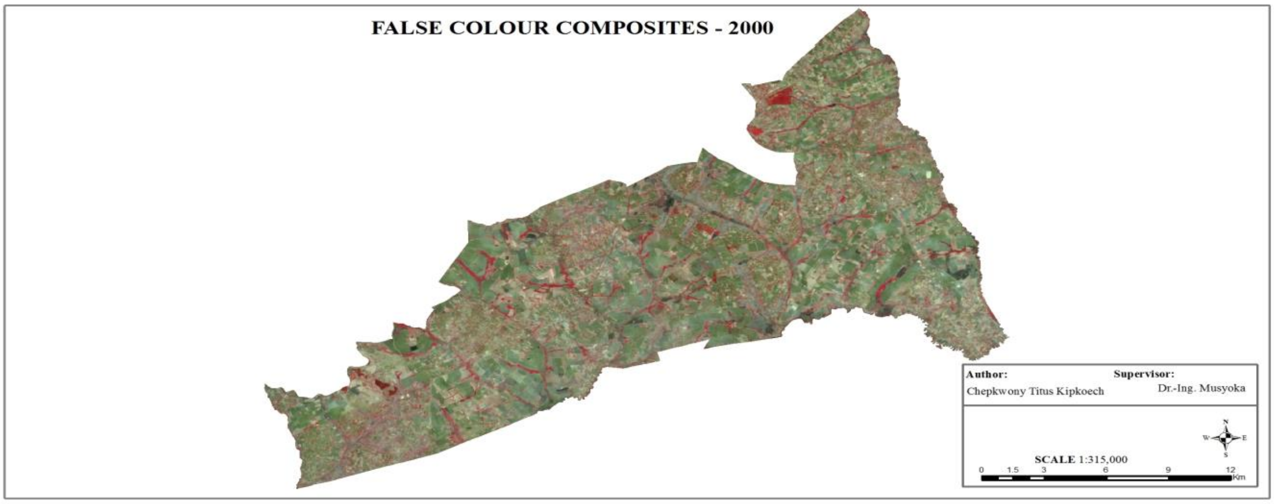
Zeleke, G., & Hurni, H. (2001). Implications of land use and land cover dynamics for mountain resource degradation in the Northwestern Ethiopian highlands. *Mountain research and development*, 21(2), 184-191.

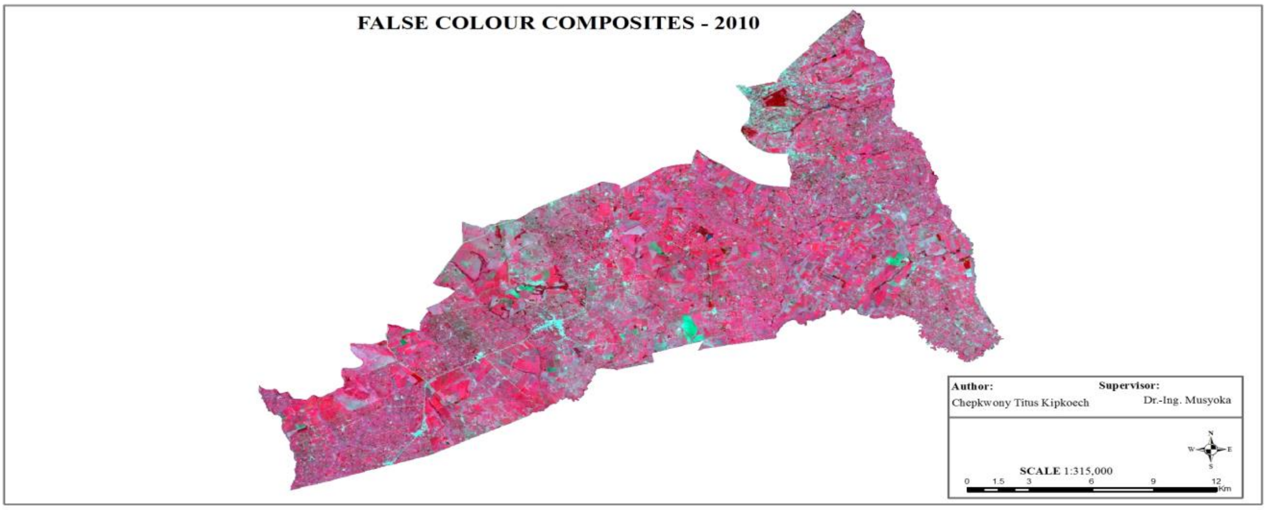
APPENDICES

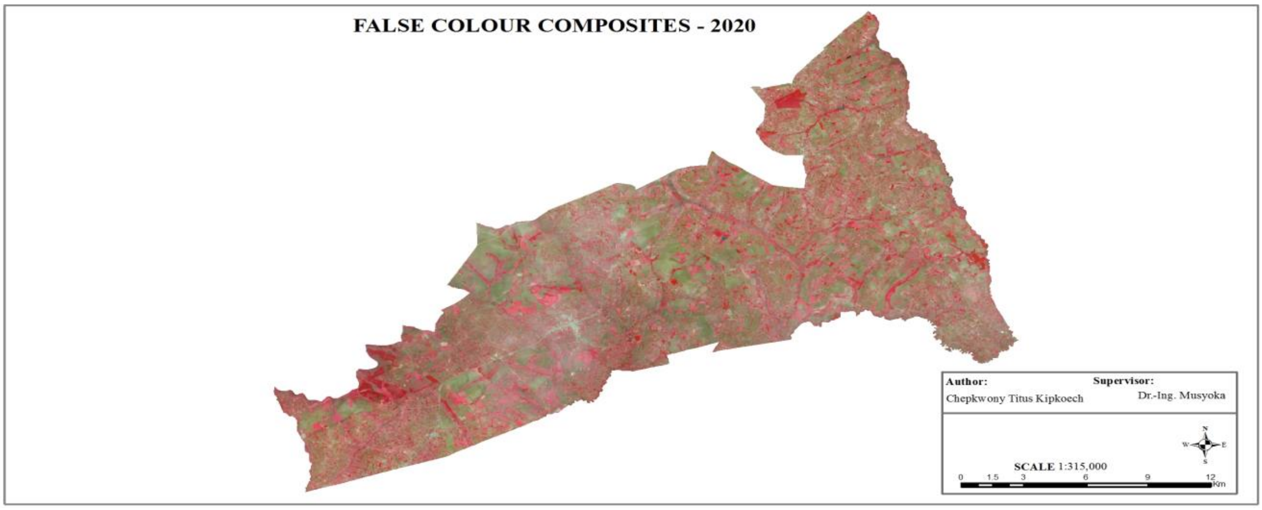
Appendix A: Kiminini Sub-county from Regional context



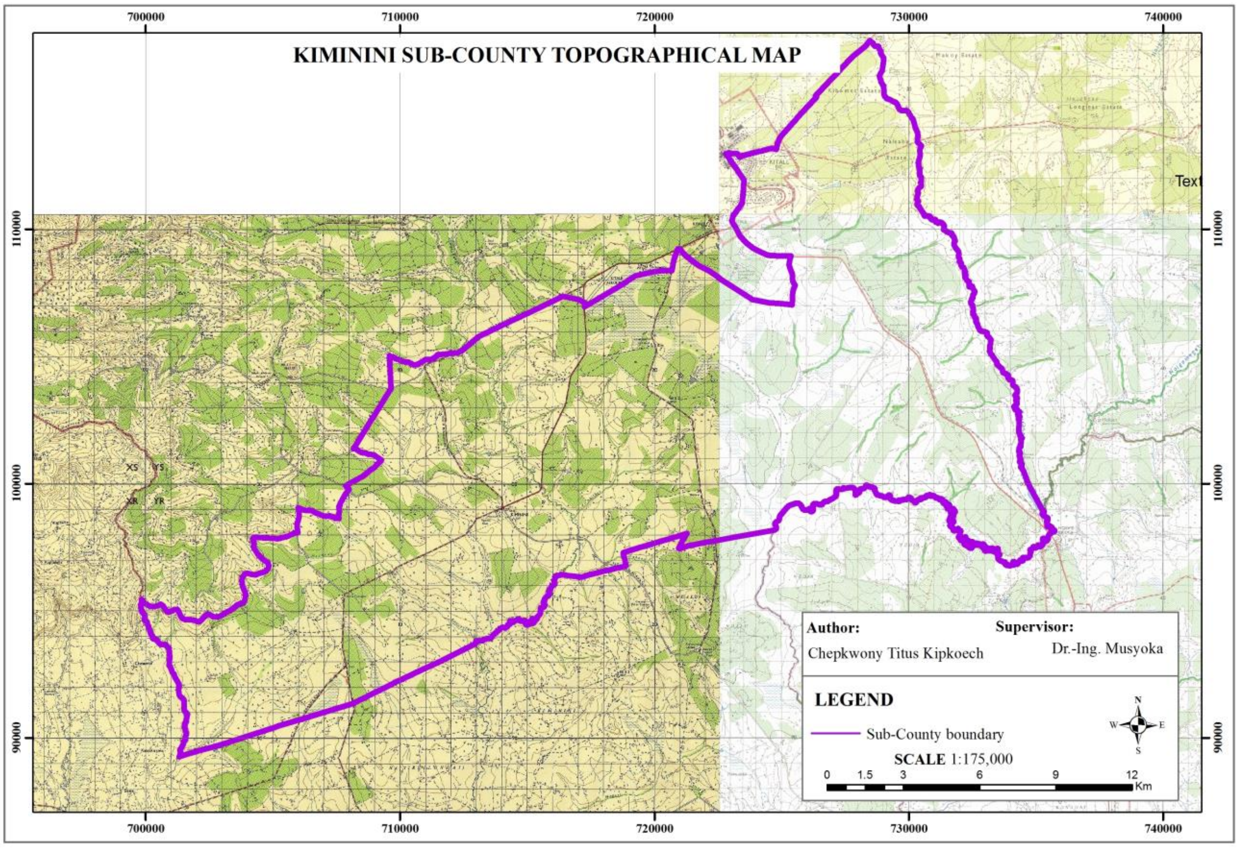
Appendix B: False Color Composites



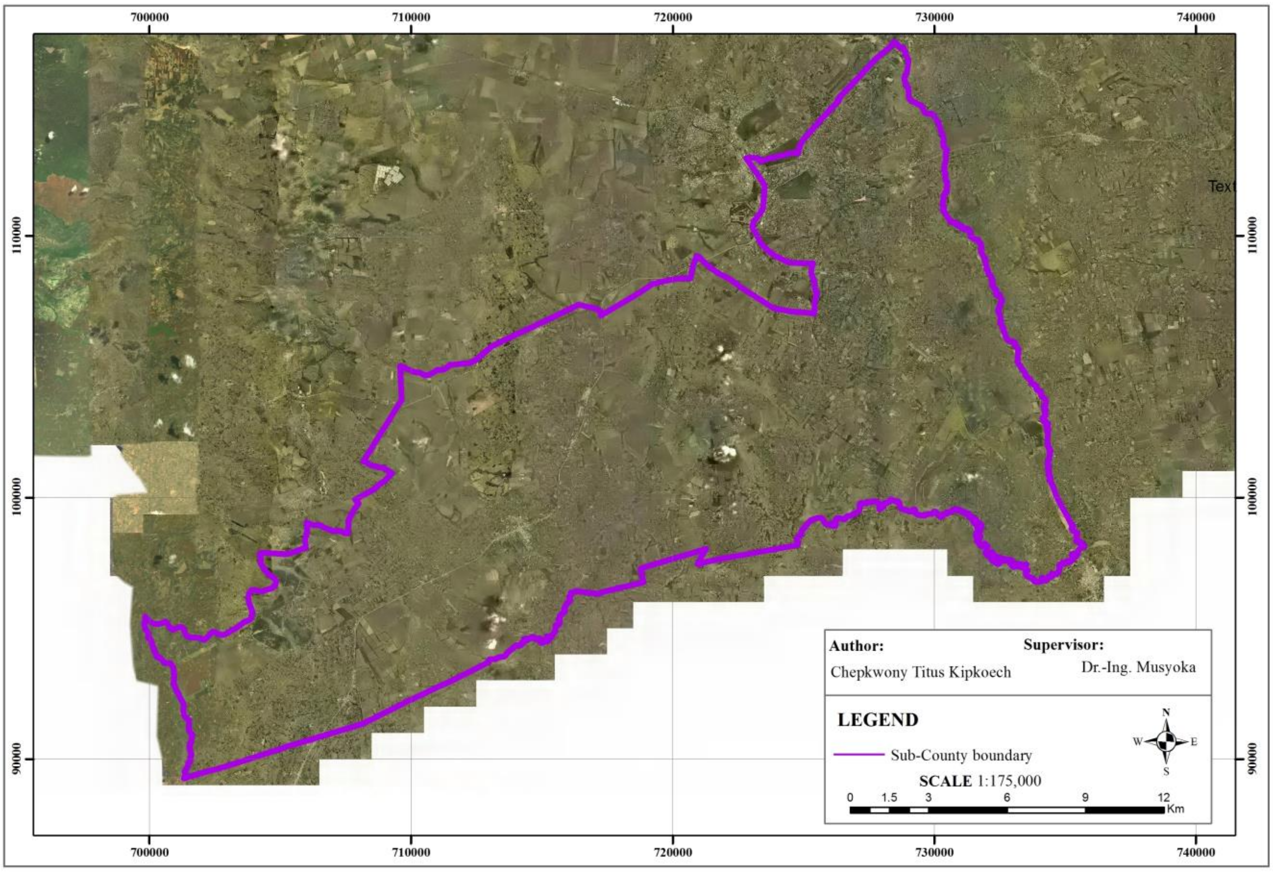




Appendix C: Kiminini Sub-county Topographical Map



Appendix D: Kiminini Sub-county Aerial Image



Appendix E: Similarity Report

ORIGINALITY REPORT

10%	9%	5%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	erepository.uonbi.ac.ke Internet Source	3%
2	Maureen Kapute Mzuza, Weiguo Zhang, Fanuel Kapute, Xiaodao Wei. "The Impact of Land Use and Land Cover Changes on the Nkula Dam in the Middle Shire River Catchment, Malawi", IntechOpen, 2019 Publication	1%
3	openprairie.sdstate.edu Internet Source	1%
4	dx.doi.org Internet Source	<1%
5	Marta Sapena Moll. "Development and analysis of land-use/land-cover spatio-temporal metrics in urban environments: Exploring urban growth patterns and linkages to socio-economic factors", Universitat Politecnica de Valencia, 2020 Publication	<1%
6	en.wikipedia.org Internet Source	<1%

7	edepot.wur.nl Internet Source	<1 %
8	cgspace.cgiar.org Internet Source	<1 %
9	ascelibrary.org Internet Source	<1 %
10	www.energycity2013.eu Internet Source	<1 %
11	203.158.6.22:8080 Internet Source	<1 %
12	Submitted to Kingston University Student Paper	<1 %
13	ri.ues.edu.sv Internet Source	<1 %
14	www.generationgenius.com Internet Source	<1 %
15	www.usgs.gov Internet Source	<1 %
16	Qihao Weng, C. P. Lo. "Spatial Analysis of Urban Growth Impacts on Vegetative Greenness with Landsat TM Data", Geocarto International, 2001 Publication	<1 %
17	athenaeum.libs.uga.edu Internet Source	

Turn it in report summary

STUDENT:

CHEPKWONY TITUS KIPKOECH: SIGNATURE............................DATE 26/08/2021

SUPERVISORS:

Dr.-Ing. S M Musyoka: SIGNATURE..................................DATE 26/08/2021

xxxxxxxxxxxxxxxxxxxxxxx: SIGNATURE..................................DATE...

Dean. FoE&.

01.09.21.

Chair, GST

1/7/2021

CHAIRMAN
DEPT. OF GEOSPATIAL & SPACE TECHNOLOGY
UNIVERSITY OF NAIROBI
P.O. Box 30197 NAIROBI