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Application of GIS and Remote Sensing Methods in Land Use and Land Cover Change Detection, a Case Study of Kisumu East.

BY

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June 2022

Declaration of Originality

I **Seth Olweny Obiero** 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.

... Seth Olweny Obiero.....	....	29TH JULY 2022.....
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This project has been submitted for examination with my approval as university supervisor

... Prof. G.C Mulaku......	....	29th July 2022
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Final Project Report

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Abstract

Global population is on a steady rise and this is manifested in the rate of urban growth worldwide. The effect cannot be ignored as it results in unplanned development. In order to plan for a rapidly growing population, there's need for timely and precise analysis of data to help in decision-making. This research has studied the application of GIS and remote sensing methods in land use and land cover change detection. The focus of the study was Kisumu East sub county in Kenya. The study is informed by inconsistency in data collection by planning authorities due to cost and accessibility factors. The objective of the study was to determine the Land Use and Land Cover changes that have occurred in Kisumu East between the year 2002 and 2022 in three epochs.

To achieve this, objective data collection was carried out in which satellite images for 2002,2013 and 2022 was obtained from the Regional Centre of Mapping of Resources for Development (RCMRD), population data from KNBS and training site data was collected in a field survey in the area of study. The satellite images were classified for land use and land cover classes (croplands, built-up areas, bare lands, water bodies and vegetation) and post-classification comparison was done for change detection. An analysis was done relating built-up areas to population changes for the environmental implications of the changes in built-up areas.

In conclusion, there was a general increase in land under built-up areas, bare lands and vegetation. Land under agricultural activities and water bodies reduced overall during the entire study period. In regards to environmental sustainability, the study found that Kisumu East is has a sprawling type of growth pattern which is not environmentally sustainable. The study recommended other data sources to improve on the rate of carrying out such studies in future. The study also recommends shorter time period between epochs to improve observation.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

Abbreviation	Meaning
GIS	Geographical Information Systems
CIDP	County Integrated Development Plan
ERDAS	Earth Resource Development Assessment System
ETM	Enhanced Thematic Mapper
FCC	False Color Composite
GDP	Gross Domestic Product
GPS	Global Positioning System
ICT	Information and Communication Technology
IEBC	Independent Electoral Boundaries Commission
IRENA	International Renewable Energy Agency
ISODATA	Iterative Self-Organizing Data Analysis Technique
ISP	Internet Service Provider
KNBS	Kenya National Bureau of Statistics
KODI	Kenya Open Data Infrastructure
LAC	Land Absorption Coefficient
LCR	Land Consumption Rate
LPG	Liquid Petroleum Gas
LULC	Land Use Land Cover
LULCC	Land Use Land Cover Change
MLC	Maximum Likelihood Classifier
NDVI	Normalized Difference Vegetation Index
OECD	Organization for Economic Corporation and Development
OLI	Operational Land Imager
OSM	Open Street Maps
RCMRD	Regional Centre for Mapping of Resources for Development
SDG	Sustainable Development Goals
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
UN	United Nations
USGS	United States Geological Survey

1 INTRODUCTION

1.1 Background

Urban areas are in a constant state of growth as population keeps growing worldwide. As a consequence, it is predicted that by the 2030 the population living in the urban areas of developing countries will be around 4.7 billion people(Bosco *et al*., 2011). This calls for planning for resources in urban areas. Land is the main resource and its utilization affects livelihoods. Land use and land cover change detection is a vital technology for urban management as a decision support system. This kind of analysis is applied in fields such as water resources management, land management and conservation, and sustainable development. Population growth, technological advancement (construction and healthcare), affects land use and land cover to a great extent (Tewabe & Fentahun, 2020).

This study applied remote sensing and GIS methods for Land use land cover change detection in Kisumu Town East. Land uses are the different arrangements, inputs and activities that people carry out in a given land cover. The land uses include farming or agricultural, settlements and even infrastructure. Land cover, is the physical land type which include water bodies, forests, grasslands, shrubs or even rock outcrops. Often times land use and land cover might be confused to mean the same thing. However, they are different as explained using three terms- grassland, rangeland and lawns. Grassland is a land cover while rangeland and lawns are land uses. The land use and land cover change of a given place are as a consequence of the socio-economic activity of the people and their operation in a given space for some period of time. Population dynamics, economic growth and physical factors such as topography, soil type, slope and climatic conditions contribute largely to land use land cover changes. Consequentially, availability of soils, vegetation and water is altered with effects on natural processes.

Considering global dynamics, LULC change detection is an important issue as it addresses the response to sustainable environmental and socio-economic drivers. LULC changes affect climatic conditions, natural phenomena and socio-economic environment locally and globally. For planning purposes, it is important to have LULC information for sustainable selection, planning and management of land as a resource. LULC change detection is valuable in measuring dynamics such as urbanization, agricultural expansion and landscape alterations. A deep understanding of these patterns is imperative for decision-making in regards to human interaction with natural phenomena.

1.2 Problem Statement

Cities are a complex part of an ecosystem. As they grow rapidly due to socio-economic activities, LULC changes occur depending on the growth rate and land management systems put in place by the authorities. These changes take place over time. The changes cannot be simply seen by the eye. Ideally, the management of cities should have an up-to-date record of the changes taking place in the cities to the lowest level. Unfortunately, that is not the case as the cost of collecting the data and updating it regularly is quite prohibitive. Coupled with the fact that the country does not have an integrated system for monitoring change in Kenya, this study will look into the changes (built environment, agricultural, bare lands, water and vegetation cover) that have taken place in the Kisumu East sub-county for the past two decades starting in the year 2002 to 2022 in three intervals of ten years each.

1.3 Objectives

1.3.1 Overall Objective

To determine the LULC changes that have occurred in Kisumu East between the year 2002 and 2022 in three epochs.

1.3.2 Specific Objectives

- To determine the changes in the built-up areas, agriculture and bare lands in Kisumu East between 2002 and 2022.
- To determine the changes that have occurred in coverage of water bodies and vegetation cover between 2002 and 2022 in Kisumu Town East Constituency.
- To find out the implications of the LULC changes to environmental sustainability in Kisumu East.

1.4 Justification for the Study

The study was necessitated by the need to monitor changes in the built environment, water bodies, agriculture, bare lands and vegetation cover over time for sustainability. This is as dictated by one of the Sustainable Development Goals (SDGs) which is to make cities and human settlements inclusive, safe, resilient and sustainable. Goal number 11.3 which emphasizes the need to enhance inclusive and sustainable urbanization and capacity for participatory integrated and sustainable human settlement planning and management by the year 2030, has the ratio of land consumption and population growth as an indicator for the progress made. This study went into the details of the changes employing GIS and remote sensing methods.

1.5 Scope of work

The coverage of the project was Kisumu East constituency in Kisumu County. This constituency doubles up as the county administrative unit and as such physical planning is done per sub-county and their respective wards. It has five wards namely Kajulu, Manyatta B, Nyalenda A, Kolwa East, and Kolwa central(Government of Kenya, 2018).

1.6 Organization of the Report

This report contains five chapters. The first chapter comprises short backgound of the study, problem statement, objectives of the study and gives justification for the study. The scope of the study is also outlined in this chapter. Chapter two is an outline of relevant literature on previous studies carried out on LULC and gaps that exist. The third chapter gives an account of the methodology and materials used in the study. Chapter 4 details the results and discussions. The final chapter, that is, chapter 5 is for the conclusions and recommendations. The last part of the document is references.

2 LITERATURE REVIEW

2.1 Introduction

A detailed review of relevant literature was done in this chapter with emphasis on remote sensing, the area of study (Kisumu East constituency in Kisumu County), land use and land cover change, population trends and how population affects LULCC and application of remote sensing and GIS in monitoring land use land cover change using a case study.

2.2 Remote Sensing

This is an art and science of collecting information about an object without getting into physical touch or contact with the object. Data of the earth’s characteristics is one of the pieces of information that can be acquired remotely using sensor. Traditional data acquisition methods for environmental information are wanning and more and more environmental experts are resorting to remote sensing and Geographical Information System (GIS) methods of data acquisition as the main sources of data on Earth Sciences. The proliferation of remote sensing and GIS technologies as the main data sources of environmental data has been greatly attributed to low cost of both computer hardware and software (Waghmare & Suryawanshi, 2017).

Remote sensing is used for data collection in inaccessible areas since one does not need to be in actual contact with the phenomena of interest. For that matter, it has been applied in a variety of ways for example forest cover monitoring in the amazon, consequences of climate change on glaciers in the Arctic and Antarctica, monitoring of volcanic activities and even measuring ocean depths using sonar technology. Other areas of application include military operations where enemy grounds can be located remotely. Ground survey as a result is only used on small scale operations and where it is safe to carry out survey(Ali, 2010).

There are different platforms for carrying out remote sensing and different data that is drawn from the different platforms. There is the airborne remote sensing where the sensor is mounted on an aeroplane and it is flown over the area of interest and images are captured. The product of this is aerial photographs which are used for infrastructure planning, land management operations and utility planning. Space-borne remote sensing on the other hand is where the sensors are sent up into space and they orbit the earth on satellites and they capture numerous scenes of the earth measuring different phenomena ranging from topography, temperature, surface heat, air moisture content, vegetation, wind and even water bodies. The main product of space-borne remote sensing is satellite images. The sensors have different spatial, temporal, and radiometric resolutions. As a result, the images produced by satellite imagery are used for different purposes(Waghmare & Suryawanshi, 2017).

Remote sensing application areas include planning, agriculture, military, civil engineering, marine engineering, disaster warning and preparedness, geodesy, hydrology, and even geology. LULC change detection is an application area in the physical planning discipline which encompasses land management, soil, and natural resource management, and water resource management(Ali, 2010).

2.3 Kisumu Town East Constituency

Kisumu town East is one of the two-hundred-and-ninety constituencies in the country. It is located in Kisumu County on the shores of Lake Victoria. Kisumu Town East is one of the seven sub-counties among Nyakach, Kisumu town West, Muhoroni, Nyando, Kisumu Central, and Seme. Kisumu Town East Sub- County or constituency has five wards, namely Kolwa Central, Kajulu, Manyatta B, Kolwa East, and Nyalenda A with a population of about 189,730 people all this on land of approximately 135.9 square kilometres. The population density of the Kisumu Town East sub-county is 1396 persons per square kilometre. The population density varies from ward to ward with Manyatta B leading at 14,130 people per square kilometre and the ward with the least population density is Kolwa East with 465 people per square kilometre (Government of Kenya, 2018). The national population density is at 90 people per square kilometre which makes Kisumu town East population density to be way higher than the country average

The population growth rate of Kisumu Town East Sub-county is considerably higher than the national population growth rate at 2.7 % compared to the National rate of 2.3%(Government of Kenya, 2018). At the current population density and growth rate, Kisumu East is largely urban as Kisumu city covers most of the Kisumu East sub-county. Of the population of Kisumu, 60%, live in peri-urban unplanned areas around the Central Business District (Apsan Frediani & Monson, 2016). Housing is a critical sector in any economy and as such Kisumu town, Kisumu East faces a steep challenge in the housing sector as most of the housing needs are taken care of by the local private developers who double up as landowners. Most housing in the Kisumu Town East sub-county is informal. This is attributed to the rapid population growth with little policy intervention in regard to the housing sector. It is the most populous sub-county in Kisumu County according to the 2019 population census.

Table 1: Kisumu County Population Distribution According to Political Units. Source:(KNBS,2019)

County	Sex			Total
	Male	Female	Intersex	
Kisumu	**560,942**	**594,609**	**23**	**1,155,574**
Kisumu East	108,304	112,689	4	220,997
Kisumu Central	84,155	89,985	5	174,145
Kisumu West	85,697	87,121	3	172,821
Seme	57,658	64,007	2	121,667
Muhoroni	76,770	77,345	1	154,116
Nyando	77,121	84,380	7	161,508
Nyakach	71,237	79,082	1	150,320

2.4 Land Use Land Cover Change

Land use is the physical, biological or chemical changes that occur to the physical and biological land features which are as a result of management. Land cover is the physical or biological features that conceal the earth’s surface and includes artificial structures, water bodies, bare land or soil and vegetation. The LULC changes are an ongoing global concern as far as the environment is concerned as it has a very significant impact on the anthropogenic and physical environment. It is now clear that LULCC has immense effect on fundamental environmental processes including biogeochemical cycles like the carbon cycle and nitrogen cycle which heavily impact on global warming(James Maina *et al.*, 2020).

LULCC has been greatly contributed to by human activity as human population has been increasing over the years. With increasing populations there comes a need for settlement and food production (farms, food markets or food processing factories) and several other developments including transportation infrastructure (roads, railways, bus termini, pipelines for water, sewerage or gas). These all require space and as a result land is utilized. Sometimes these developments are done on virgin lands or previously developed lands. In case of the former, land cover changes with regard to the land use it is assigned. The net effect results into changes in the availability of water, soil, vegetation and even clean air(Cheruto *et al*., 2016).

According to (Tewabe & Fentahun, 2020), LULCC in a particular area are usually a direct result of human activities in the given location. Population changes in the said locations is caused by the socio-economic and physical characteristics of the place. In their study of the Lake Tana basin in Ethiopia, population growth resulted in the need for more agricultural production which necessitated more agricultural activities and residential land use. Factors that influenced the population increment in the basin were the availability of water for agricultural production and a favourable topography.

With time the global population has been on a steady rise and thus there was more need for agricultural production. By the year 2017, agriculture was a means of support for about 40% global population. In emergent nations agriculture accounts for 30% of GDPs (Ramankutty *et al*., 2018). In Kenya for instance, 75 % of the people rely on agriculture as an economic activity and the pressure on land is immense as only 20% of the country's land is arable(Cheruto *et al*., 2016). The resultant effect is that more land will be hived off for agricultural expansion and as such wetlands and other rangelands will be affected by agricultural production.

As much as LULCC can be caused by natural phenomena such as prolonged droughts, floods or forest fires, in most instances anthropological activities are the biggest contributors to the changes. The extent of global LULCC has not been clearly set out due to methodological and semantic reasons. Methodologically, there is no single method that has been capable of measuring or assessing LULCC to global scale, however, case studies have been used as empirical studies to better understand LULCC confirming or verifying theoretical models under specific conditions. Land cover changes can directly be observed from remote sensing data or through secondary census data(Lutzenberger *et al*., 2014).

2.5 Population

The most important planning tool worldwide is population statistics and as such it affects LULC immensely. By 2017, the global population stood at 7.6 billion people, this represents 1 billion more people compared to 2005. The world population growth rate currently at 1.1% per year, has dropped considerably from 1.24% in the past ten years. With the current growth rate of 83 million people per year, which is expected to drop, global projections predict a 8.6 billion people by 2030(UN, 2019).

Of the 7.6 billion people around the world, 55.3% live in urban or peri-urban areas. The proportion is predicted to rise to 60% by the year 2030(UN, 2018). In the year 2000 urban population stood at 47 % of global population. The trend shows that there is continued increase of urban population globally. It is approximated that by 2030, 33% of the World will be reside in urban areas with populations as large as 500,000 people. Urban population in developed countries has increased significantly from 77% in 2000 and it is expected to get to 84% in 2030. With these statistics, it is clear that most people in developed nations live in urban areas. The growth rate in middle income countries on the other hand is expected to grow from 42% to 59% between the year 2000 and 2030 and developing countries' urban population to grow from 26% to 38%. In a nutshell, urban population is bound to grow globally(UN, 2020).

To get the required data for planning in every country, governments carry out population census at given time intervals. In Kenya the first population census was carried out in 1948, the second one was conducted in 1962, third in 1969 and from then it has been done after every 10 years. The results of the 1948 census showed that the population of Kenya stood at 5,407,599 people. The 1962 population census yielded 8,636,263 people a considerable increase from the 1948 census. In 1969 the population stood at 10,956,501 people. The 1979 census which was the second census after independence resulted in 15,327,061 people, in 1989- 21,448,774 people and 28,686,607 people in 1999. The population growth rate from 1948 up to 1999 was not stable but it was high and unsettling(Kenya, 1999). As such it is important to estimate how population growth affects urbanization and its net effect on the environment and any opportunities it presents in the planning fraternity.

Table 2: Kenya Population Census 1948 to 1999

Census	Population	Percentage	Rate of Growth
1948	5,497,599		
		57.1	3.2
1962	8,636,263		
		26.9	3.4
1969	10,956,501		
		39.9	3.4
1979	15,327,061		
		39.9	3.4
1989	21,448,774		
		33.6	2.9
1999	28,660,534		

Moving forward from 1999, it was evident that population would continue to increase. This was mainly pinned on a higher birth rate compared to the death rate. Migration at that time was not a big contributor to the population growth. With the two indicators of lower fertility and rising mortality, the prediction was that by 2035 population would peak at 40 million people.

At this time, urban areas were classified on the basis of population exceeding 2000 people. In 1999, the national urban population was at 19%. Tharaka Nithi and Marakwet Districts had purely rural populations. The province with the leading urban population was Coast province at 36.6%, followed by North Eastern, Rift Valley, Nyanza, Central, Western and Eastern with 15.2 %, 13.7%, 9.7%, 9.6%, 8.1% and 5.8% respectively(Kenya, 1999).

The 2009 census indicated an increase in population from the previous 28,686,607 people in 1999 to 38,610,097 people. This was an increase of 9,923,490 people, a 2.9% growth rate per annum from the previous census. With this population 32% was urban population(Government of Kenya, 2010). The results of the 2019 national census came at 47,564,296 people. This was distributed across 12,143,900 households. The population growth rate was 2.2% per year between this census and the 2009 census, a decline in population growth rate by 0.7 %(KNBS, 2019).

2.6 Linking LULCC to Sustainable Development Goals

The 2015 United Nations General assembly sitting in New York embraced the Sustainable development goals (SDGs) and all member countries signed each and every of the 17 goals. The goals with a total of 169 targets aim at relinquishing poverty, environmental stewardship and ensuring global peace and social justice by the year 2030. While at it, the SDGs must ensure a balance with nature's processes and provision. To ensure continuity of life for species on the planet, there is one guiding factor that is important. That is land management. Everything from nutrient supplies (carbon and nitrogen cycles), biodiversity (plants and animals), hydrological cycle and natural systems that support life depend on how land is managed. As such LULCC is a very vital part of any form of urban governance(Munroe *et al.*, 2020).

Cities, according to (Nicolau *et al.*, 2019) have been growing in an expansive way instead of compact manner, which eats into the arable lands and natural ecosystems. The growth of cities is as a result of migratory population growth. As a result, there is conversion of most of the arable and natural ecosystems into impervious surfaces denying the earth the natural ability to work as sinks for environmental wastes such as greenhouse gases and surface run-off water, the impacts of which vary from place to place. (Munroe *et al.*, 2020) also discussed the challenges faced by cities across the divide ranging from biodiversity loss, ecosystem degradation, land conversions and modifications and climate catastrophes, all with livelihood altering impacts to the people.

Land use science according to (Munroe *et al.*, 2020) is an important facet towards achieving not only one but a number of targets of the sustainable development goals. The number of goals that are directly intertwined with land use are goal number 1,7, 11, 13 and 15. These goals focus on poverty, affordable and clean energy, sustainable cities and communities, climate action and life on land respectively.

2.6.1 Goal number 11

According to (IRENA & OECD, 2021), sustainable goal number 11 is to make cities and human settlements inclusive, safe, resilient and sustainable. The goal's focus is on the wellbeing of humans and other bio diversities in cities. It takes account of the fact that cities are growing bigger with about 50% of the World residing in cities, a figure that is bound to go up especially in emerging economies of Asia and Africa. To make life in cities sustainable there is need to provide for affordable housing, good and affordable public transport, do upgrades to slums, create green spaces and protect arable lands from encroachment by city hardscapes(Johnston, 2016).

Target 11.3 which intends to enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement and planning and management in all countries. Land Consumption Rate is indicator 11.3.1 which aims at monitoring LULC change versus population growth. Land consumption according to (IRENA & OECD, 2021) is the net transformation of land from rural to urban functions.

2.6.2 Land Consumption Rate (LCR) and Land Absorption Coefficient (LAC)

Land consumption Rate (LCR) is the rate of conversion of an urban area during a given time frame. It is depicted as a proportion of land occupied by built up areas of an urban area at the start of the period. Built up areas are areas occupied by building. The unit of measuring LCR is a percentage value. The data for achieving this measurement is area data for built environment in any urban area with defined boundary and population data for the area over a period of time(IRENA & OECD, 2021).

Land Absorption Coefficient is the estimate of change in the consumption of land by a given land use, in this study's instance built-up areas. the significance of LCR and LAC is their importance in monitoring the effects of greenhouse gases per capita and also help in climate change watch (Oyugi *et al.*, 2017).

2.7 Case Study: Monitoring Urban Growth and Land Use Change Detection with GIS and Remote Sensing Techniques in Daqahlia Governorate Egypt

This study was carried out in Mansoura and Talkha cities of Daqahlia Governorate in Egypt. These cities were experiencing rapid urbanisation at varying rates and patterns at the time of the study. This informed the investigation into the urban growth beginning from 1985 to 2010. The study was carried out in three epochs of 1985, 2000 and 2010. The major concern that informed the study is the uncontrolled way in which urban areas sprawl into the periphery. The research noted that urbanization is a positive development if it is done sustainably. However, the situation in Egypt at the time was unplanned development characterized by lack of basic infrastructure. This kind of development was as a result of unprecedented population growth. The increased population has also resulted in a strained resource base in the region.

The pattern of development according to the research is either linear along major highways, in country sides or radially around well-developed cities. This phenomenon is referred to as sprawl which is usually as a result of population growth, closeness to resources and basic amenities. The resultant loss of biodiversity and agricultural lands is dire. According to the Egyptian Ministry of Agriculture, the annual loss of agricultural lands for the period between the year 1980 and 2000 stood at 26,250 acres per year(Hegazy & Kaloop, 2015). Daqahlia governorate, whose agricultural lands covered about 670km² is estimated to have lost a quarter of her agricultural lands during the period between 1980-2000 to urban growth.

The anthropogenic changes on land were monitored in the research using GIS and remote sensing methods which Egypt had adopted as early as these technologies were invented. The area of study located within the Nile basin is considered one of the most fertile lands and urbanization poses a threat to the agricultural area. This called for the study to ensure a balanced LULC for sustainable development. Data used included topographic maps from the Survey of Egypt, satellite images downloaded via the USGS Earth Explorer website (dates not specified). Analysis was done using the ERDAS imagine software to detect changes in urban sprawl. The research involved both unsupervised and supervised classification method. For unsupervised classification, the ISODATA clustering algorithm was used in accordance to the number of class clusters and pixel signature. For supervised classification, the Maximum Classification

Algorithm was used. The image obtained from unsupervised classification was used as a reference and as a way of understanding the distribution of pixels(Hegazy & Kaloop, 2015). The classification resulted in four land uses/ land covers namely agricultural, barren, water bodies and built-up areas. Subsequently, the classification was done for the 2 other epochs of 2000 and 1985. Accuracy assessment to ensure that the land use and land cover classification is accurate was also carried out. Change detection was afterwards done to determine the extent of change.

The results of the analysis were as shown in Table 3(Hegazy & Kaloop, 2015)

Table 3: Land Use Land Cover for Daqahlia(Hegazy & Kaloop, 2015)

Map Unit	Area 1985		Area 2000		Area 2010	
	Km^2	%	Km^2	%	Km^2	%
Agriculture	610	91.04	588	87.76	382	57.01
Built-up	28	4.18	47	6.98	243	36.26
Barren Land	3	0.48	6	0.96	19	2.83
Water	29	4.3	29	4.3	26	3.9
Total Area	**670**	**100**	**670**	**100**	**670**	**100**

From the analysis, the area under built-up environment in 1985 covered $28km^2$ out of the total $670km^2$, barren land $3km^2$. In 2000, $47km^2$ was covered by built-up areas while barren land had also increased to $6km^2$ and agricultural land reduced to $588km^2$. In the year 2010 there was dramatic increase in built-up area to $243km^2$ which was more than five-fold the previous area covered. Agricultural lands shrunk to $382km^2$, barren lands increased to $19km^2$ and water bodies shrunk to a further $23km^2$ from $29km^2$ in the year 2000.

Using the transitional probabilistic matrix to determine future land use land covers, the Markov chain template predicted that by 2035 built up area would rise by 16.1% from the $243km^2$, agricultural land would decrease by a further 20.1 %, barren lands would increase by 6.31% and water bodies decrease by 2.3%. The cities of Mansoura and Talkha in Daqahlia had therefore experience massive sprawl. Their agricultural lands shrunk significantly and built-up area and barren lands increased(Hegazy & Kaloop, 2015). In conclusion, it is observed that the cities' growth consumed much of agricultural land and therefore multi-disciplinary studies should be done to advise on curbing the uncontrolled urban growth.

3 MATERIALS AND METHODS

3.1 Description of the Area of Study

3.1.1 Location and Size

Kisumu East is located on the North Eastern part of Kisumu County. Kisumu East borders Nandi County's Aldai Sub-county to the North, Muhoroni Sub-county Eastwards, Nyando Southwards, Kisumu Central to the West and Kisumu West to the North-western side. The South-Western side of Kisumu East is covered by Fresh water Lake Victoria. Kisumu East covers an area of approximately 135.9 square kilometers(Government of Kenya, 2018). Kisumu East lies between latitudes 0°11' S and 0°01'N and longitudes 34°40' E and 34°53'.

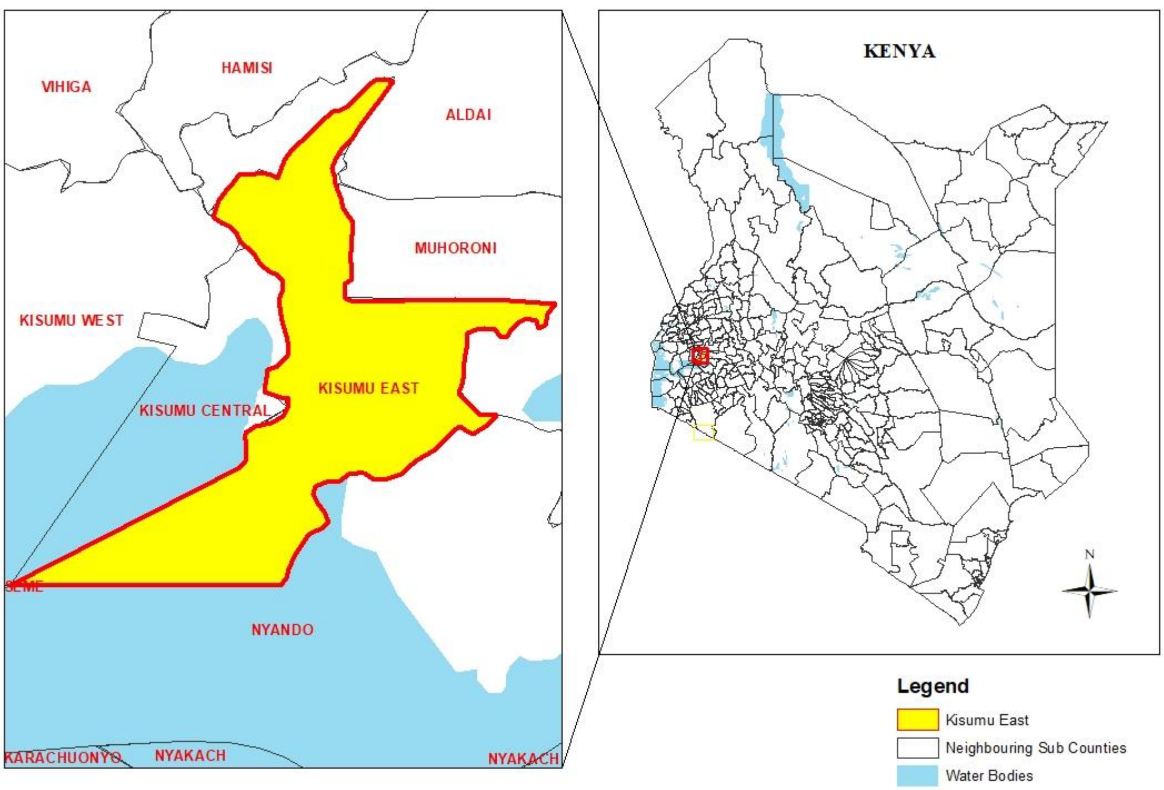

Figure 1: Map of Area of Study

3.1.2 Physical and Topographic Features

Kisumu East's topography is generally undulating. The areas on the Northern side covering Kajulu ward are characterized by gently sloping hill. The hills are characterized by granitic rocks. The granitic rocks are not uniform throughout the study area as they are only exposed in few areas like Got Nyabondo, Riat hills and Mamboleo hills. The gradient of the slopes ranges from 3 to 16 percent. On the Southern parts of the area of study is a system of rivers flowing through an almost flat plain which forms part of the larger Kano plains. The area includes Kibos, Chiga, Orongo, Mowlem and Bouye areas which are characterised by black cotton soil and sand in some areas(Josh, 2004).

The area of study is served by a network of rivers such as river Kibos, River Nyamasaria, River Auji and river Awach. These rivers all drain into Lake Victoria.

3.1.3 Forestry and Vegetation Cover

Kisumu East has no lands gazetted as forest. However, this does not imply that there are no trees or vegetation cover throughout the area of study. The hilly sides of Kisumu East bordering Nandi County and Kisumu West have a relatively medium to high planted tree cover. The most popular trees planted in the area are Eucalyptus, blue-gum, grevilia and pine trees. The most common indigenous tree species in the area of study include *Cassia siamea* (Obino), *Acacia spp* (Ali/Laktar/Kudho), *Euphorbia triculli* (Ojuok), *Markhamia lutea* (Siala) and *Albizia zyiyia* (Otur-bam). Other categories of plants include shrubs and grasses. The most common shrubs include *Aloe kedongensis Reynolds* (Aloe vera), *Rhus natalensis Bernh* (local name Sagla), *Carissa edulis Vahl* (local name Ochuoga) among others. The distribution of trees and other vegetation covers like shrubs and herbs across the area of study is uniform but can still be subject of study(Okach & Amuka, 2014).

3.1.4 Infrastructure, Transport and Communication

Kisumu East is served with a well-developed road network of all-weather roads and murram roads. The major roads that are part of the Kisumu East network include the Kisumu-Kakamega highway(A1), Kisumu-Nairobi highway(A1) and Mamboleo-Miwani highway(C34). These roads provide a convenient means of transport and as such improve the business environment of Kisumu East. Other major infrastructure which are in neighbouring sub counties that are vital to the trade and development of Kisumu East subcounty include the Port of Kisumu, the Kisumu international airport and the oil jetty. (Government of Kenya, 2018)The port has for instance increased trade with neighbouring countries where local products are transported via the Lake to Uganda and Tanzania. The oil jetty also allows for trade in oil and the Kisumu international airport is open for transport of fresh agricultural produce across the globe.

In terms of energy, there's a well-developed network of power distribution lines throughout the area of study. The main source of power is hydroelectric power. Solar energy has not been well tapped as a source of clean energy. Reliance on wood for cooking is still high as the cost of Liquid Petroleum Gas(LPG) is high and unattainable for most households(Government of Kenya, 2018).

Information and Communication Technology (ICT) is the backbone of most business processes across all sectors in Kisumu East. In that light, there's a robust network of telecommunication network throughout Kisumu East. The main Internet Service Provider (ISP) in the area is Safaricom. However, other players like Zuku and Kalanet are also competing fairly in the area.

3.1.5 Socio-economic Activities

Kisumu East is an area of diverse socio-economic activities ranging from trade, tourism, agriculture, industries. In trade, there are markets spread across the sub-county namely Mamboleo markets, Chiga market, Wathorego market and Kibos market. For industries, there is a sugar factory in Kibos and a steel milling plant also in Kibos. In agriculture, there are small scale agriculture farms littered across the area with crops such as vegetables, bananas, beans, maize, sorghum and fruits such as avocados and mangoes. Towards the North-Eastern side of the sub-county in the areas covering Wathorego, Got Nyabondo and Guba, there's small scale banana, maize, vegetables and fruit farming. Maize and beans farming is done for subsistence while the other crops are both for subsistence and commercial (Government of Kenya, 2018).

3.2 Datasets

The data used for the study comprised of satellite imagery, population data, and GPS field survey data for verification. The satellite imagery used in the study was acquired from Regional Centre for Mapping of Resources for Development (RCMRD) downloaded from the USGS website. The other datasets used are as shown in Table 4.

Table 4: Datasets used in the study

No.	DATA TYPE	SOURCE OF DATA	DESCRIPTION OF DATA
1	Multispectral Satellite Images	RCMRD (USGS - https://glovis.usgs.gov/)	LANDSAT 7 ETM: 2002 Image (2002-09-04)
			LANDSAT 8 OLI TIRS: 2013 Image (2013-11-13)
			LANDSAT 9 OLI TIRS: 2022 Image (2022-01-14)
2	Kenya Population	Population Census Through KNBS	1999, 2009 and 2019 and their Projections
3	Kenya Constituencies	Through IEBC	Constituencies Shapefiles
4	Training Sites	GPS Data	Field survey points

3.3 Methods

LULC classification of the area of study was done for change detection and to establish the modifications of vegetation, water bodies, bare lands, croplands and the built environment. Examination of the LULC changes was done using the ArcGIS pro software because it enables the comparison of a range of raster, and expansively identifies the magnitude and type of change using tools available with the Image Analyst extension. The methodology incorporated various datasets which included satellite data (Landsat 7,8&9), shapefile of Kisumu Town East and population data.

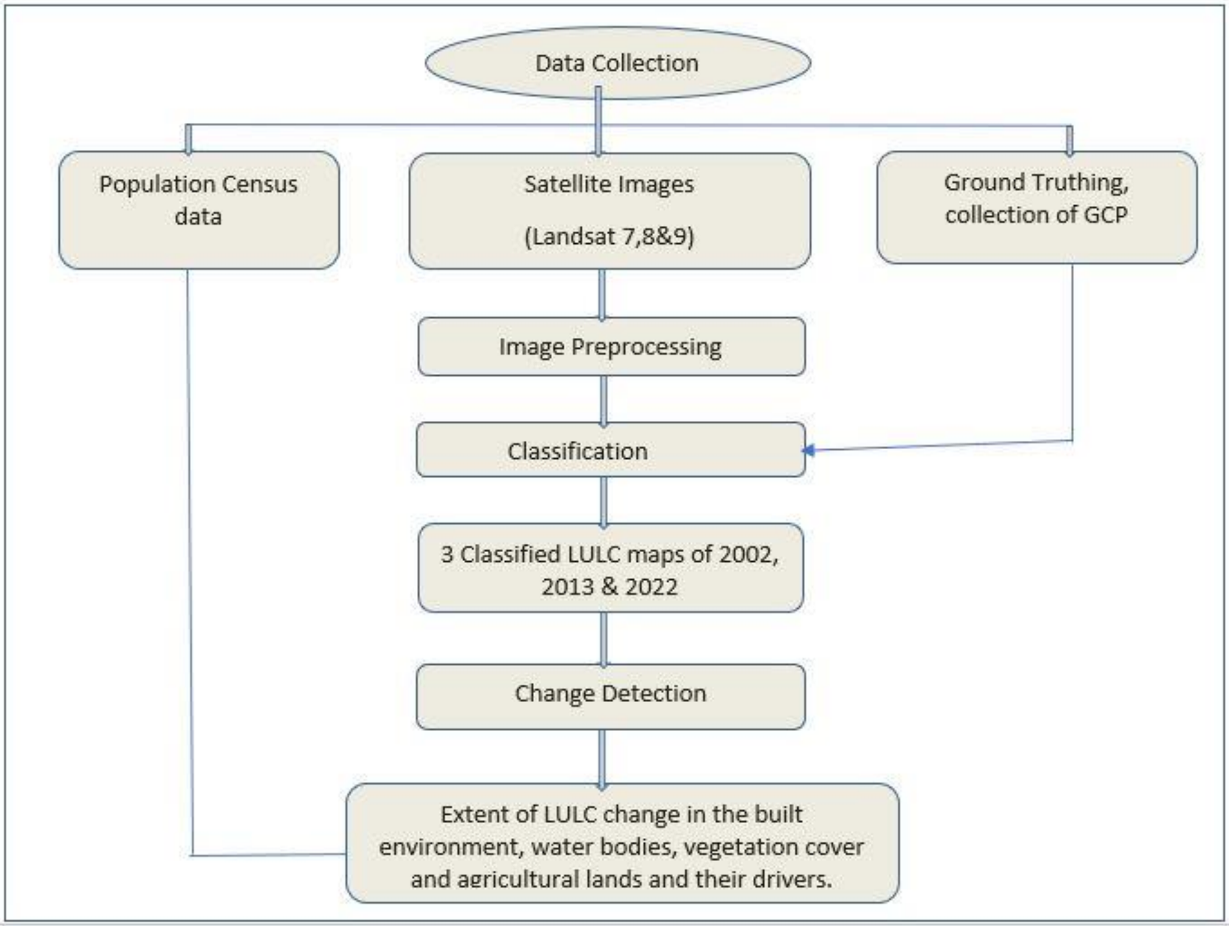

Figure 2: Methodology of Study

3.3.1 Image Preparation

For data clarity to enable visualization of the data's biophysical phenomena, data pre-processing was done (Liu & Mason, 2013). As much as the Landsat imagery had been subjected to radiometric and geometric correction by the USGS, different atmospheric conditions might cause complications when carrying out the polygon-based mosaic. Preprocessing included atmospheric correction, image enhancement, windowing and band stacking.

3.3.2 Atmospheric Correction.

Removal of the effects of the atmosphere from a satellite image's reflectance value constitutes atmospheric correction. This was done to correct for sun angle and cloud coverage during the time the sensors captured the image. The atmospheric correction was performed on individual bands in ArcMap.

3.3.3 Image Enhancement.

To improve image interpretation by the user, the image was altered in a way that amplified the information content.

3.3.4 Band Stacking

Band composite is important to combine the bands together since the Landsat image bands are downloaded separately. In this process, thermal bands were removed from all the images because of its properties (Liu & Mason, 2013). The bands were combined to form False Color Composites (FCC) which made it easy for analysis. For this study the following combination of satellite bands were utilized. For TM Bands (Landsat-7) 2, 3, 4, and 3,4,5 for Landsat 8.

3.3.5 Windowing

Windowing is the term given to reformatting of the satellite image to narrow-in on the area of interest. The satellite data was clipped to a subset of the case study area in order to focus on the relevant data of the area of study, and it was done band by band.

3.4 Development of Classification Scheme

A classification scheme based on ground features was developed for the study area. Classes in this study were modified to meet the requirement of this study. The different LULC classes were grouped into five broad types based on the visual interpretation of the image and verified from field inspection for simpler analysis and calculation of change detection. These are built-up areas (residential, commercial), croplands (agricultural areas), water (rivers and lakes), vegetation (scrubs, bushes, forest) and bare lands (transitional zones, bare soils, open lots and rock outcrops).

Table 5: Land Use and Land Cover Classification Scheme

Code	**Land Use /Land Cover Categories**
1	Built-up land (Residential, Commercial and services, Industrial, Transportation, communication and utilities, Industrial and commercial complexes and other built-up land.
2	Agricultural Farmland,
3	vegetation (scrubs, bushes, forest).
4	Waterbodies (Rivers, ponds, lakes)
5	Bare lands (transitional zones, open lots, bare soils and rock outcrops)

3.5 Classification

Image classification has one sole objective- creation of cluster classes from multispectral satellite imagery. The importance of classification is to make the right interpretation of the many colors and shapes in an image. This study employed the maximum likelihood algorithm using the supervised classification technique. The choice of algorithm is informed by the complexity of urban forms owing to the different landscape dynamics and structures. The algorithm, Maximum Likelihood Classifier (MLC), is a per pixel classifier making it suitable for the complex environment (Adepoju *et al*., 2006). To get training sites, spectral attributes like hue, tone, texture and patterns which relate to ground feature are used. As a per-pixel classifier, MLC was able to highlight and depict the spatial distribution of LULC types in urban areas. In areas with heterogeneity of pixels signifying different LULCs, there might arise errors caused by very low spectral separation. This might result in some wrong classifications (Mohamed *et al*., 2020). To solve the issue, training sites sizes and numbers in those areas would be extended in order to provide a better constraint for MLC. This will result to creation of LULC maps for the three epochs.

3.6 Change Detection

In this case, change was assessed between epochs 1, 2 &3 from the three land cover maps. Transitional changes of one LULC to another was noted. Change detection was done by running post-classification comparison of the three independently classified images. The post-classification process indicates the nature and amount of change. This is done via pixel-by-pixel comparison. The analysis here, covers the occurrent change, the characteristics of the changes and its extent in regards to area and spatial pattern.

3.7 Field survey and accuracy assessment

For ground truthing of the data, a hand-held GPS device was used to carry out field verification survey in areas with doubtful data. The NDVI will be utilized to get ground reference points, especially when detecting how built environment has led to decrease in agricultural and forested lands. This was then interlaced together for measurements of areas of change and their extents.

3.8 Population for the Study Periods and Calculation of LCR and LAC for Built Environment

The study analysed the population of Kisumu East using the 1999, 2009 and 2019 populations as base populations to project the populations for the study periods. The population growth rate was used to project the population based on the number of years. The formula used for the population projection is as follows:

$$Pn = Po(1 + r)^t$$

Where:

Pn= Estimated population at a given year

Po= Base year population

r = Population growth rate

t= number of years projecting for.

To calculate the land consumption rate (LCR) of the built environment, the formula below was used:

Land Consumption Rate (LCR) Calculations:

$$LCR = A/P$$

Where:

A= Area of Study under specific land use

P= Population of Area of study at a given time

Land Absorption Coefficient (LAC) Calculations

$$LAC = \frac{(A_2 - A_1)}{(P_2 \ - P_1)} \ldots$$

Where:

$$A_2 \, and \, A_1 = Are \, areas \, of \, Built - Up \, areas \, for \, different \, epochs$$

$$P_2 \, and \, P_1 = Populations \, of \, area \, of \, study \, during \, the \, different \, epochs$$

4 RESULTS AND DISCUSSIONS

Chapter 4 reports on the findings of the study with figures and tables showing the results of the study and discussions on the same.

4.1 Land Use Land Cover Map of Kisumu East in 2002

The primary land use in Kisumu East for the year 2002 was Agriculture with croplands covering an estimated area of 6,060.06 hectares which is 37.89 % of the total area of Kisumu East. Bare lands came second covering 24.92 % of the total area at 3,986.01 hectares. Water covered an area of 2,932.83 translating to 18.34% of the total area. The area under vegetation built up areas was 1,508.13 hectares standing for 9.43% and was closely followed by vegetation at 9.41% covering an estimated area of 1,505.52 hectares. Figure 3 shows the distribution of the land uses.

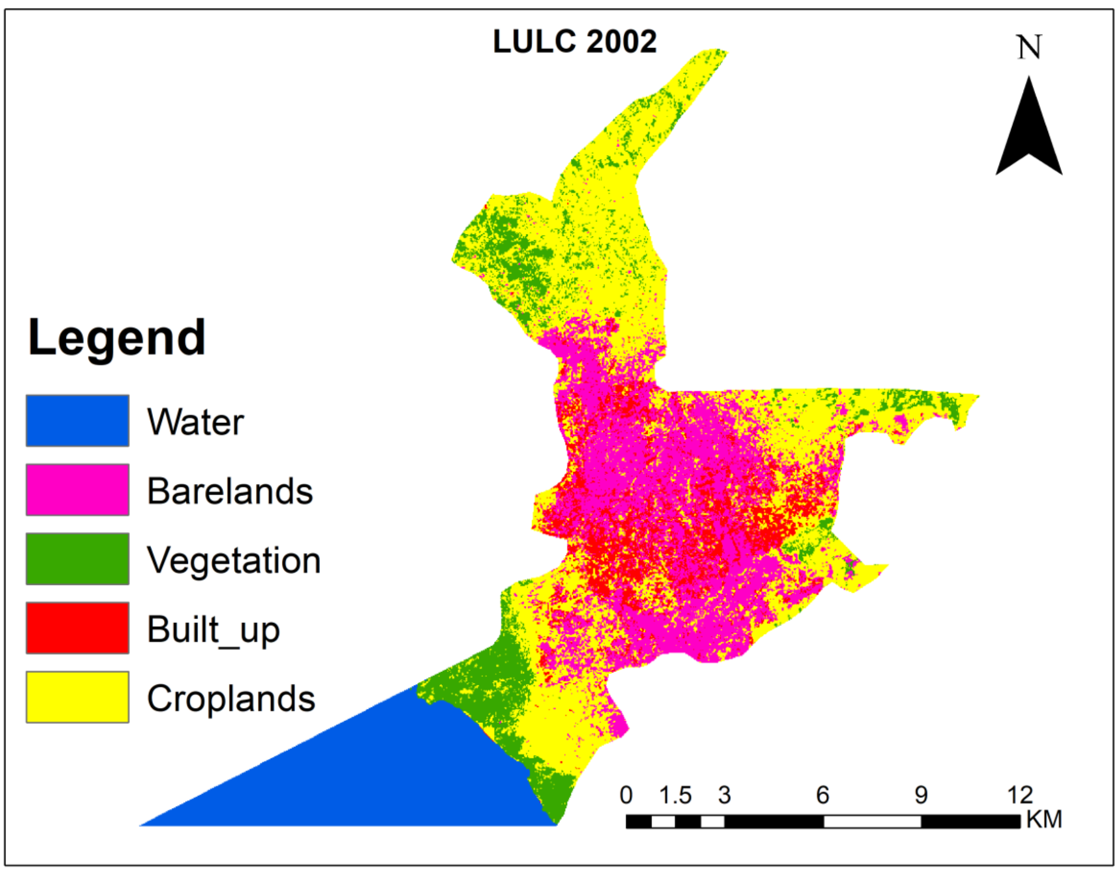

Figure 3: Land Use Land Cover Map of Kisumu East for Year 2002

4.2 Land Use Land Cover Map of Kisumu East in 2013

The results of classification for the 2013 epoch as shown in Figure 4. The primary land use in this period is Croplands(agricultural) covering a total of 5,620.23 hectares which translates to 34.99% of the total land coverage of Kisumu East. This was followed closely by built up areas which covered 3,663 Hectares translating to 22.8% of the total area of the study area. The area covered by water was third at 2,725.83 hectares loosely translating to 16.97% of the area of study. Vegetation cover and bare lands came in fourth and fifth at 2,323.71 and 1,730.88 hectares respectively covering 14.47% and 10.78% of the area of study.

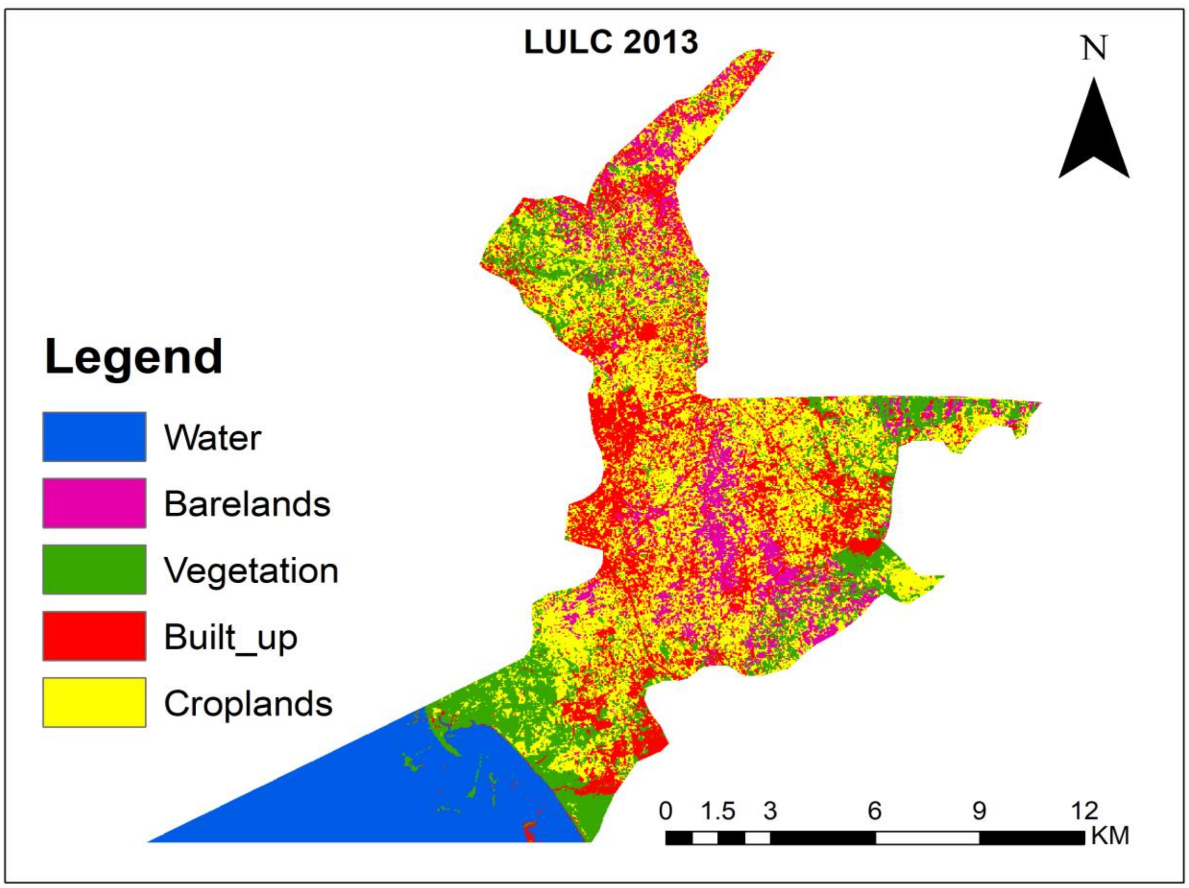

Figure 4: Land Use and Land Cover Map of Kisumu East for Year 2013

4.3 Land Use Land Cover Map of Kisumu East in 2022

Vegetation cover was the primary land use for the year 2022 covering an estimated area of 4,380.57 hectares translating to 27.36% of the area of Kisumu East, followed by bare lands covering an estimated 4,055.76 hectares translating to 25.33 % of the total area. Water came in third covering an area of 2,849.4 hectares, that is, 17.8% of the total area. Built areas follow with 2,566.98 hectares and croplands at 2,157.84 hectares both covering 16.03 and 13.48% respectively. Figure 5 is a map showing the coverages. Table 6 highlights the overall areas of the LULCs and their percentage coverage.

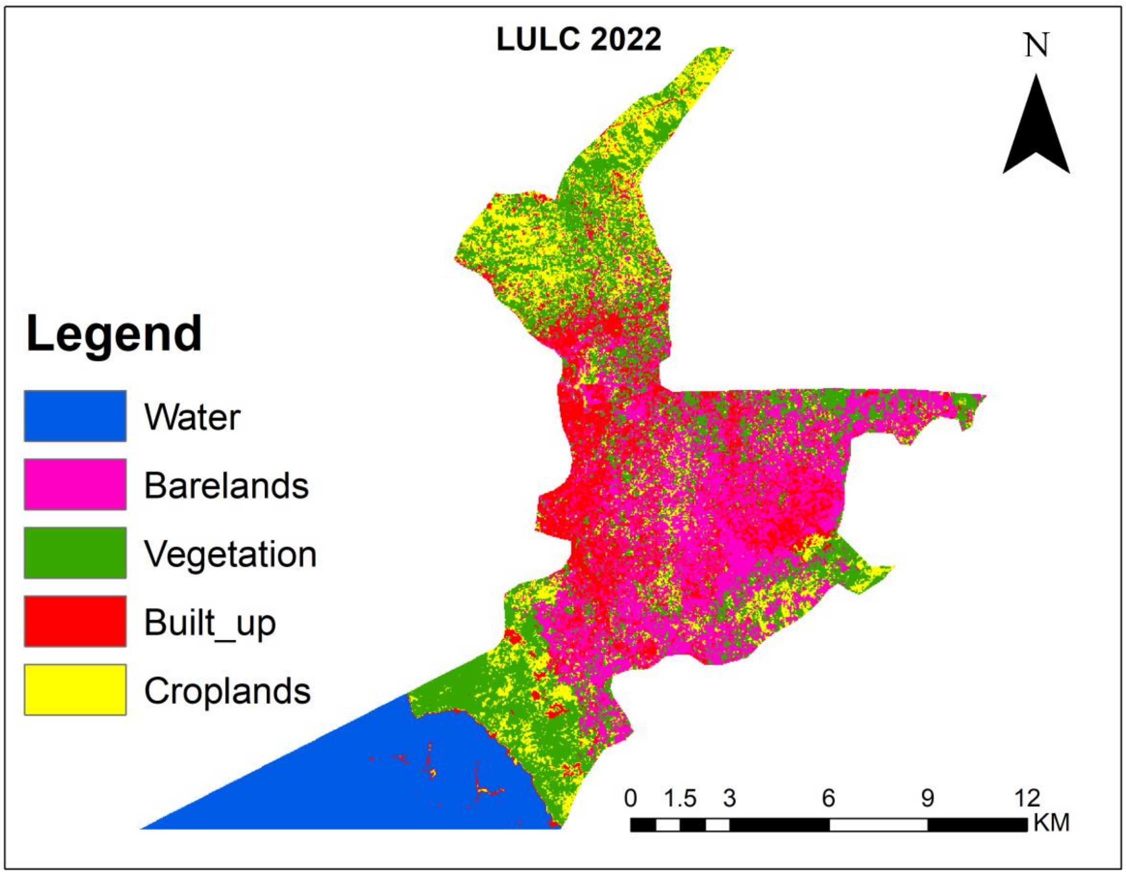

Figure 5: Land Use and Land Cover Map of Kisumu East for Year 2022

Table 6: Land Use and Land Cover Coverage in Hectares and Subsequent Percentages

YEAR	2002		2013		2022	
LULC	**Ha.**	**% Coverage**	**Ha.**	**% Coverage**	**Ha.**	**% Coverage**
Water	2,932.83	18.34	2,725.83	16.97	2,849.4	17.80
Bare land	3,986.01	24.92	1,730.88	10.78	4,055.76	25.33
Vegetation	1,505.52	9.41	2,323.71	14.47	4,380.57	27.36
Built-Up	1,508.13	9.43	3,663	22.80	2,566.98	16.03
Croplands	6,060.06	37.89	5,620.23	34.99	2,157.84	13.48
	15,992.55	**100**	**16,063.65**	**100**	**16,010.55**	**100**

4.4 Change Detection

The study revealed a lot of changes from the initial study year 2002 to the year 2022. The biggest overall gainer is vegetation cover which increased from 1,505.52 Hectares in 2002 to 4,380. 57 hectares in 2022. This is an increment of 2875.05 hectares translating to about 190% increase. This can be considered good for the environment as vegetation cover provides the much-needed sinks for carbon and other greenhouse gases. The increment as seen in Figure 5 occurred mostly on the North-Eastern horn of the area of study, an area covering Kajulu hills, *Got Nyabondo,* Mamboleo and Wathorego *areas*. The vegetation cover on that side of the area of study is mainly planted trees comprising blue gum trees, eucalyptus, pine, grevilia and indigenous trees like *Ober, Obino* and other bushes and shrubs.

Table 7: Overall Change 2002 to 2022

YEAR	2002		2022		Change
LULC	Ha.	% Coverage	Ha.	% Coverage	
Water	2,932.83	18.34	2,849.4	17.80	-83.43
Bare land	3,986.01	24.92	4,055.76	25.33	69.75
Vegetation	1,505.52	9.41	4,380.57	27.36	2,875.05
Built-Up	1,508.13	9.43	2,566.98	16.03	1,058.85
Croplands	6,060.06	37.89	2,157.84	13.48	-3,902.22

Agricultural land experienced the most downward turn recording a drop of 3,902.22 hectares, approximately a 69.39% drop in coverage. From Table 5, indicating the data sources, the date of the 2022 imagery is 2022-01-14. In January there's little or no crops in farms in Kisumu East. Most of the lands are fallow/ bare awaiting cultivation. This explains the increase in bare lands from 1,730.88 hectares in 2013 to 4,055.76 hectares in 2022. Figure 6 which shows the trend of LULC over the years shows a gradual decline in agriculture from the year 2002 to 2013 followed by a sharp decline in 2022. The general trend in reduced agricultural activities can be attributed to the high cost of farm inputs and low returns on investments in the agricultural sector.

Built- up areas saw an overall increase in area from the year 2002 to 2022 from 1508.13 hectares in 2002 to 2566.98 hectares in 2022. The initial percentage coverage was 9.43 percent and the latter percentage was 16.03 percent. This was a growth of almost 7 percent with 1058.85 hectares. The growth in built environment is attributed to the increased population in Kisumu County in general and Kisumu East specifically following a lot of changes ranging from the fact that Kisumu is a semi-autonomous region with resources allocated at the grassroots level following devolution after the promulgation of the 2010 constitution that brought about devolved units.

The general outlook from Table 6, shows that there was a tremendous increase of built-up areas from 1508.13 hectares in 2002 to 3663 hectares in 2013 and then a sudden drop in 2022 to 2566.98 hectares. The growth in 2013 was partly as a result of new wave of migration into the city of Kisumu following devolution and more opportunities at county levels, one being Kisumu County. Kisumu East was one of the beneficiaries of the new population owing to the low average cost of housing in the suburban area that consist of both formal and informal housing. However, by 2022 the numbers dropped following a series of demolitions in the county as seen by Kisumu County government in concerted efforts on Urban Renewal Programme and The National Railway Corporation together with the Ministry of Interior(Trust, 2021). The demolitions left as many as 3000 people homeless and led to one fatality.

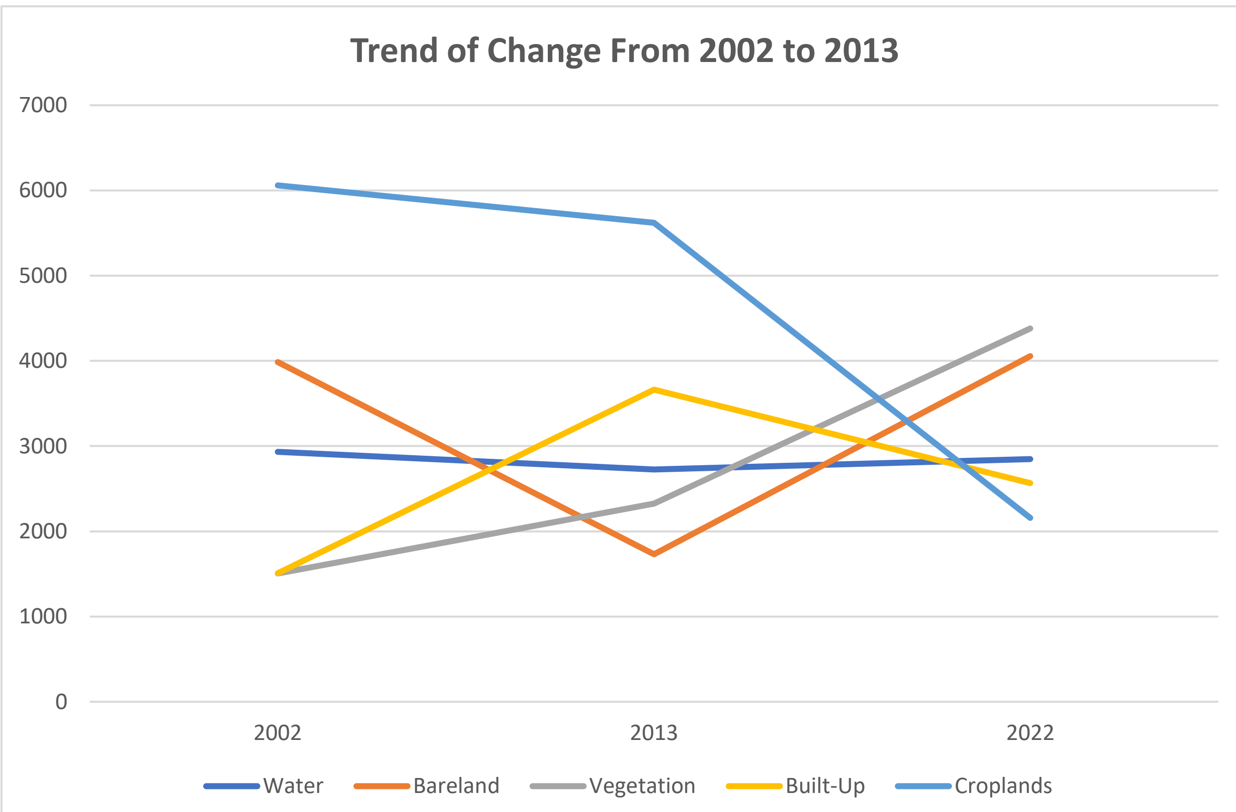

Figure 6: LULC Trend for Kisumu East 2002-2022

4.4.1 LULC Change Between the 2002 and 2013 Epochs

Table 8: LULC Changes Between 2002 and 2013 Epochs

YEAR	**2002**		**2013**		**Change**	
LULC	**Ha.**	**% Coverage**	**Ha.**	**% Coverage**	**Ha.**	**% Coverage**
Water	2,932.83	18.34	2,725.83	16.97	-207	(1.37)
Bare land	3,986.01	24.92	1,730.88	10.78	- 2,255.13	(14.15)
Vegetation	1,505.52	9.41	2,323.71	14.47	818.19	5.05
Built-Up	1,508.13	9.43	3,663	22.80	2,154.87	13.37
Croplands	6,060.06	37.89	5,620.23	34.99	-439.83	(2.91)
	15,992.55	**100**	**16,063.65**	**100**		

In the period between 2002 and 2013 there was significant changes in the different LULCs. The area covered by water reduced by 207 hectares from 2932.83 hectares in 2002 to 2725.83 hectares in 2013. The area occupied by bare lands also reduced greatly from 3986.01 hectares in 2002 to 1730.88 hectares in 2013, a reduction of 2255.13 hectares. Vegetation gained 818.19 hectares to 2323.71 hectares in 2013 from 1505.52 hectares in 2002. There was a significant increase in built-up areas from 1508.13 hectares in 2002 to 3663 hectares in 2013. Croplands also lost 439.83 hectares as shown in Table 8. The graphical depiction of the statistics is in Figure 7.

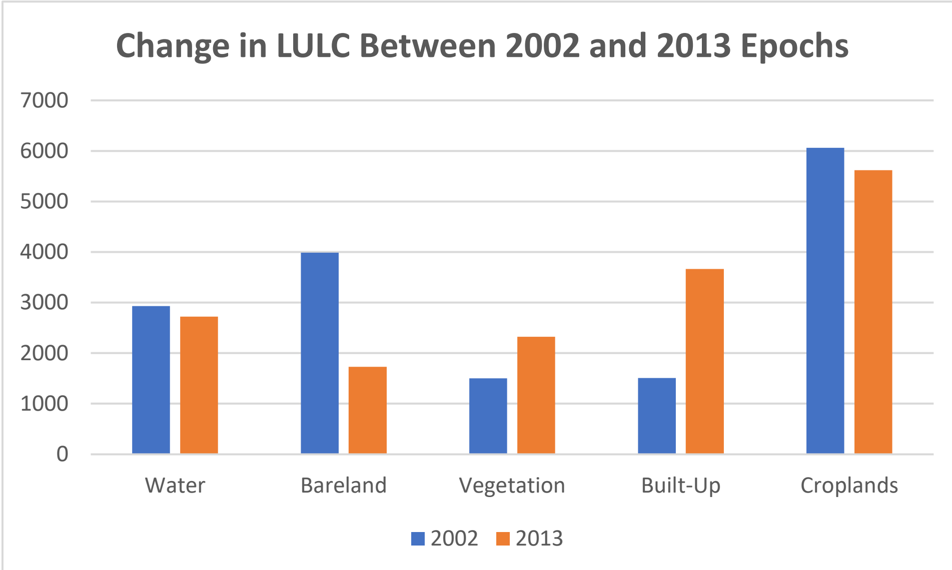

Figure 7: Graphical Illustration of LULC Changes Between the 2002 and 2013 Epochs

4.4.2 LULC Change Between the 2013 and 2022 Epochs

In the period between the 2013 and 2022 epoch, croplands and built-up areas lost a lot of space. The total loss for croplands was 3462.39 hectares while that of built-up areas was 1096.02 hectares. The rest of the LULCs gained ground with bare lands being the biggest gainer at 2324.44 hectares, followed by vegetation at 2056.86 hectares and water gaining 123.57 hectares.

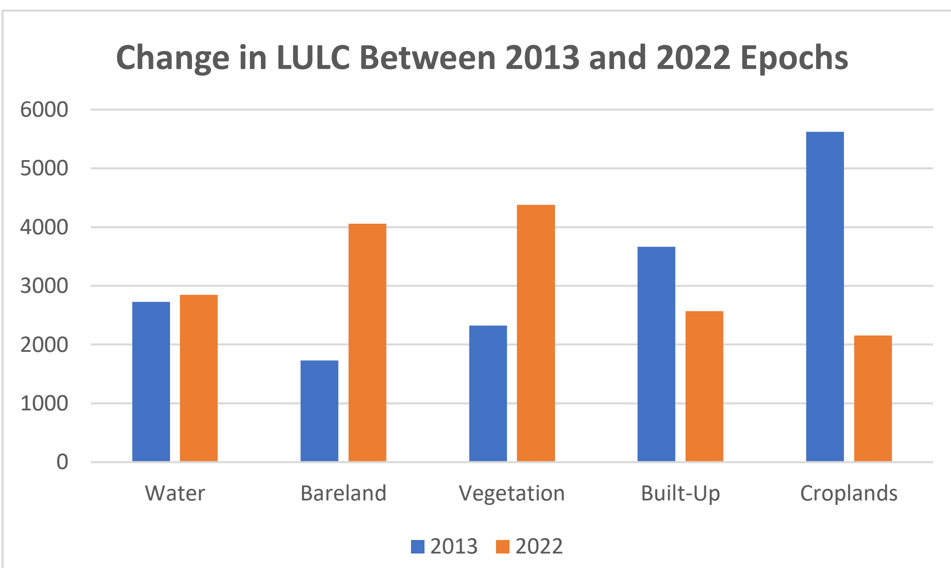

Figure 8: Graphical Illustration of LULC Changes Between the 2013 and 2022 Epochs

The graphical illustration is as shown in Figure 9 while the actual figures of the changes and percentages are shown in Table 9.

Table 9: LULC Changes Between 2013and 2022 Epochs

YEAR	**2013**		**2022**		**Change**	
LULC	**Ha.**	**% Coverage**	**Ha.**	**% Coverage**	**Ha.**	**% Coverage**
Water	2,725.83	16.97	2,849.4	17.80	123.57	0.83
Bare land	1,730.88	10.78	4,055.76	25.33	2,324.88	14.56
Vegetation	2,323.71	14.47	4,380.57	27.36	2,056.86	12.89
Built-Up	3,663	22.80	2,566.98	16.03	-1,096.02	(6.77)
Croplands	5,620.23	34.99	2,157.84	13.48	-3,462.39	(21.51)
	16,063.65	**100**	**16,010.55**	**100**		

4.5 Land Use Land Cover Conversions

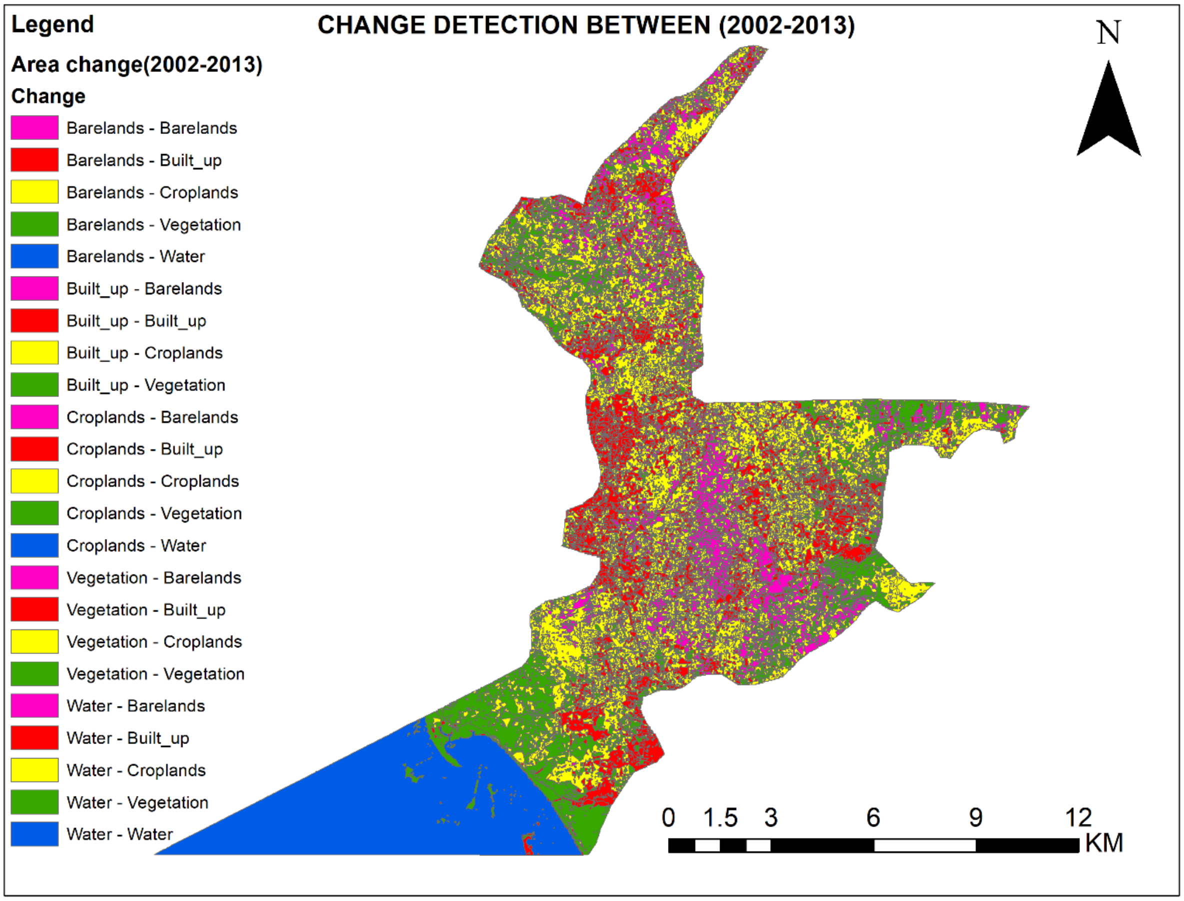

Figure 9: Change Detection Map Between 2002 and 2013

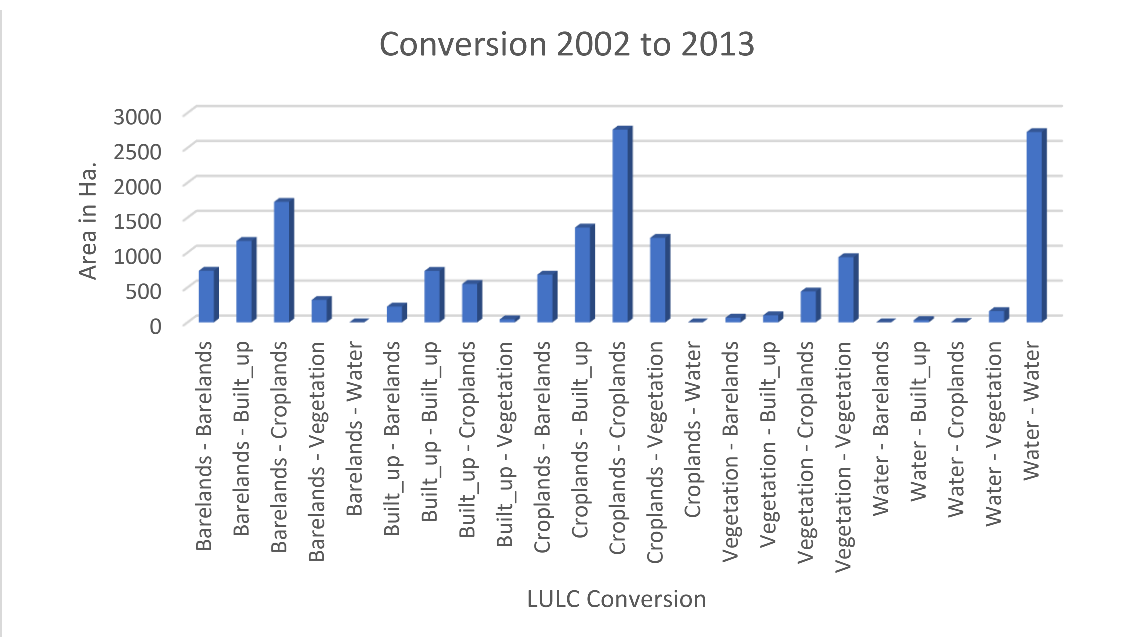

Figure 10: Graphical Illustration of the Conversions Between 2002 and 2013

Figure 9 and Figure 10 both show conversions that took place between the 2002 and 2013 epochs. From Figure 9, the changes that took place in specific LULC was illustrated in the thematic colours. Graphically, in Figure 10 it shows that bare lands were greatly converted to croplands between the two epochs. From Table 10, the actual value of the conversion was 1725.56 Ha. This was followed closely by croplands conversion to built-up areas at 1357.69 Ha and finally bare lands to built-up areas as the third largest gainer at 1166.15 Ha.

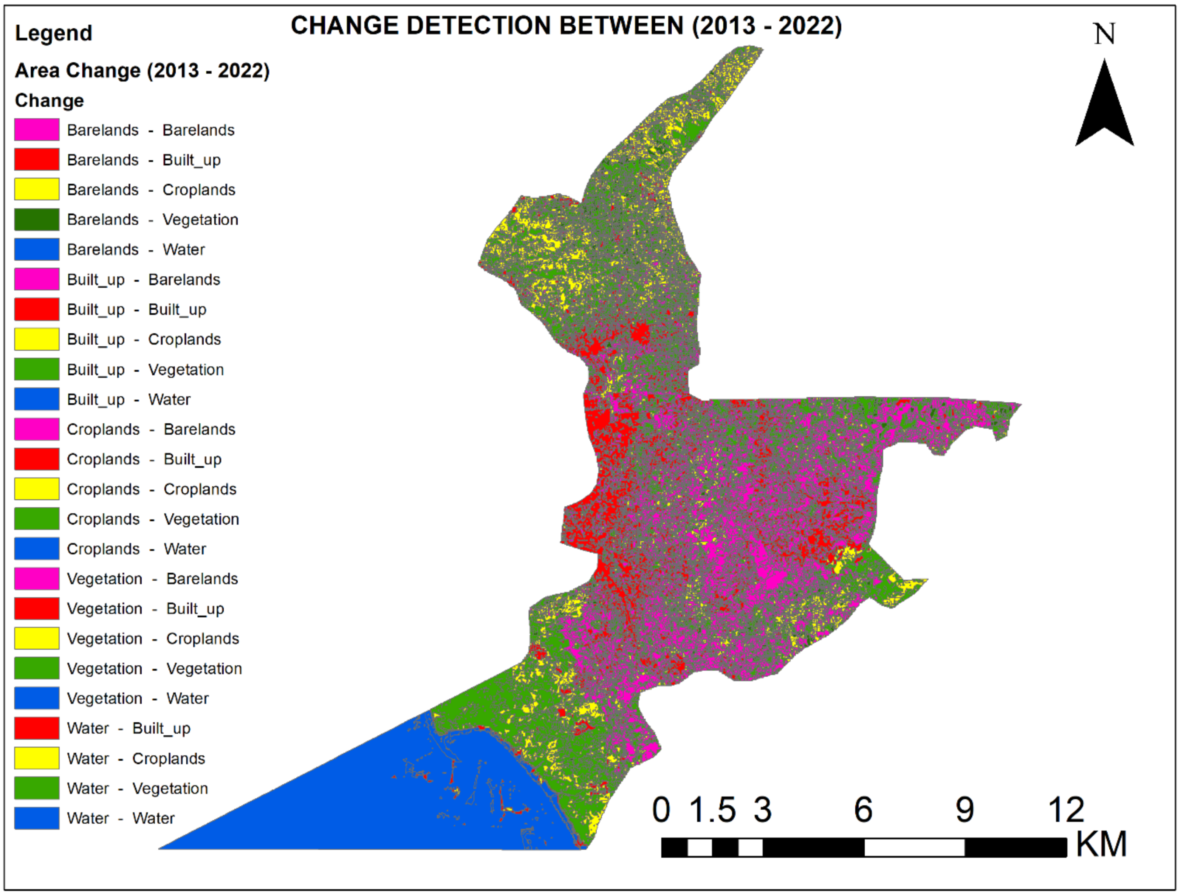

Figure 11: Change Detection Map Between 2013-2022

Figure 11 shows the conversions that took place in thematic colours between the 2013 and 2022 epochs. The graphical illustration of the conversions is depicted in Figure 12 where croplands to vegetation was the highest conversion at 1872.3 hectares according to Table 10. This was followed closely by croplands conversion to bare lands at 1821.25 hectares. The third largest conversion was built-up areas to bare lands at 1053.89 hectares. The lowest conversion was bare lands to water at 0.06 hectares, followed by water to vegetation and water to croplands at 1.77 and 4.13 hectares respectively.

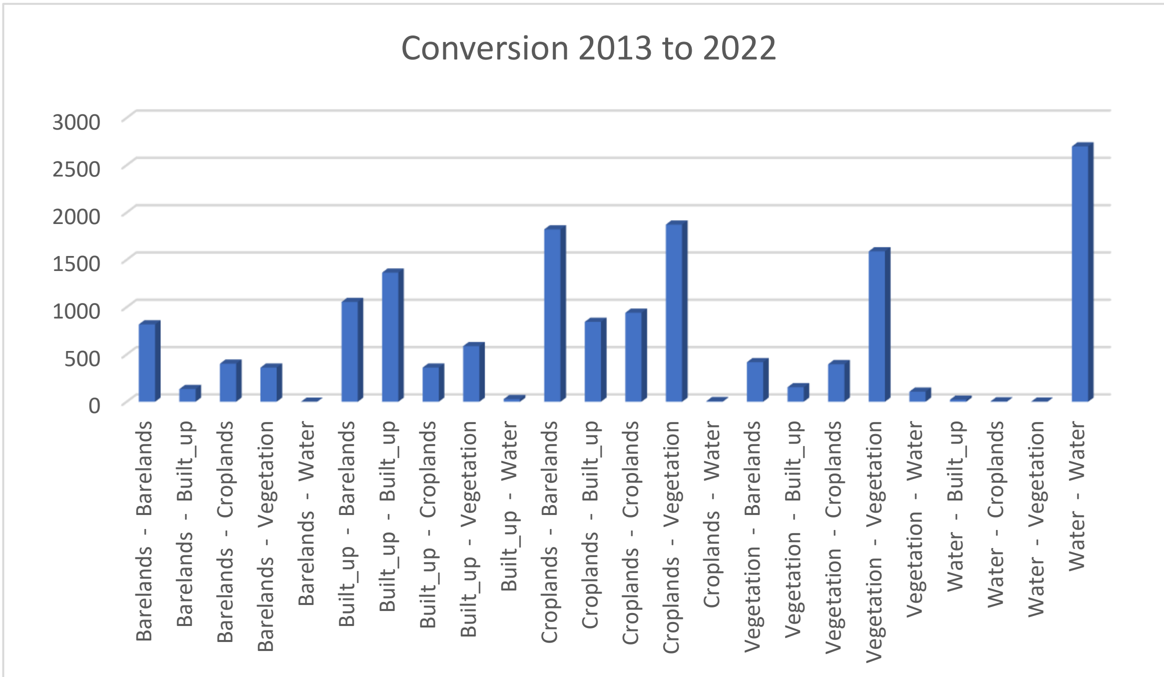

Figure 12: Graphical Illustration of Conversions Between 2013 and 2022

Table 10: Table Showing Land Use and Land Cover Conversions Between the Different Epochs

Change	**Area Change (2013-2022)**	**Area change (2002-2013)**
Bare lands - Bare lands	817.23	738.33
Bare lands - Built-up	134.17	1,166.15
Bare lands - Croplands	402.42	1,725.56
Bare lands - Vegetation	361.01	320.88
Bare lands - Water	0.06	0.00
Built-up - Bare lands	1,053.89	225.72
Built-up - Built-up	1,364.60	736.41
Built-up - Croplands	361.11	550.17
Built-up - Vegetation	587.58	43.88
Built-up - Water	28.25	
Croplands - Bare lands	1,821.25	683.09
Croplands - Built-up	844.69	1,357.69
Croplands - Croplands	940.64	2,760.19
Croplands - Vegetation	1,872.30	1,210.00
Croplands - Water	6.13	0.17
Vegetation - Bare lands	417.84	67.05
Vegetation - Built-up	153.71	101.30
Vegetation - Croplands	397.07	441.80
Vegetation - Vegetation	1,589.76	933.14
Vegetation - Water	111.51	0.06
Water - Built-up	21.58	32.52
Water - Croplands	4.13	5.87
Water - Vegetation	1.77	160.84
Water - Water	2,697.75	2,725.15

4.6 Population trends in Kisumu East Over the Years

Table 11: Kisumu East Population Trend

Kisumu East Population Trend								
1999 Population	**Growth Rate (p.a)**	**2002 Projection**	**2009 Population**	**Growth Rate (p.a)**	**2013 Projection**	**2019 Population**	**Growth Rate (p.a)**	**2022 Projection**
54,753	2.9	59,656	150,124	2.6	166,356	220,997	2.6	238,687

Kisumu East population has been on an upward trend. In 1999, the population was 54,753 people in the whole of Kisumu East. At a population growth rate of 2.9% per annum, the population in the year 2002 was at 59,656 people. This increased to 150,124 people in the 2009 National population and socio-economic census. The trend was still upward as the rate of growth was still at 2.6% per annum as shown in Table 11. In 2013, the population of Kisumu East had increased to 166,356 people projected at 2.6% per annum from the year 2009. In the 2019 census, Kisumu East population had grown to 220,997 people maintaining the 2.6 % growth rate. This brought the population in 2022 to 238,687 people. With this trend, it is evident that the population of the area of study is on a constant rise. This calls for more efforts in planning for resources in the area of study and environs for sustainability.

4.7 Built-Up Areas Maps Over the Years

Figure 13 shows the population distribution in Kisumu East in the year 2002. The central areas of the area of study contained most of the population. the area around Mowlem was the most populated area. Population in this area is due to the fact that it is a transition zone from Kisumu city's central business District and there was some semblance of good transport networks around this area. Population is distributed along the roads in a linear manner and the markets also provide for clustering of population and nodes for urban growth. Chiga market for instance sits on the junction of the road from Kibos to Miwani town in Nyando sub-county and Rabuor town also in Nyando sub-county. Figure 14 still indicates that Mamboleo and Gita markets were the least populated areas in the year 2002 despite their closeness to the Mamboleo junction-Miwani road which is a class C34 road.

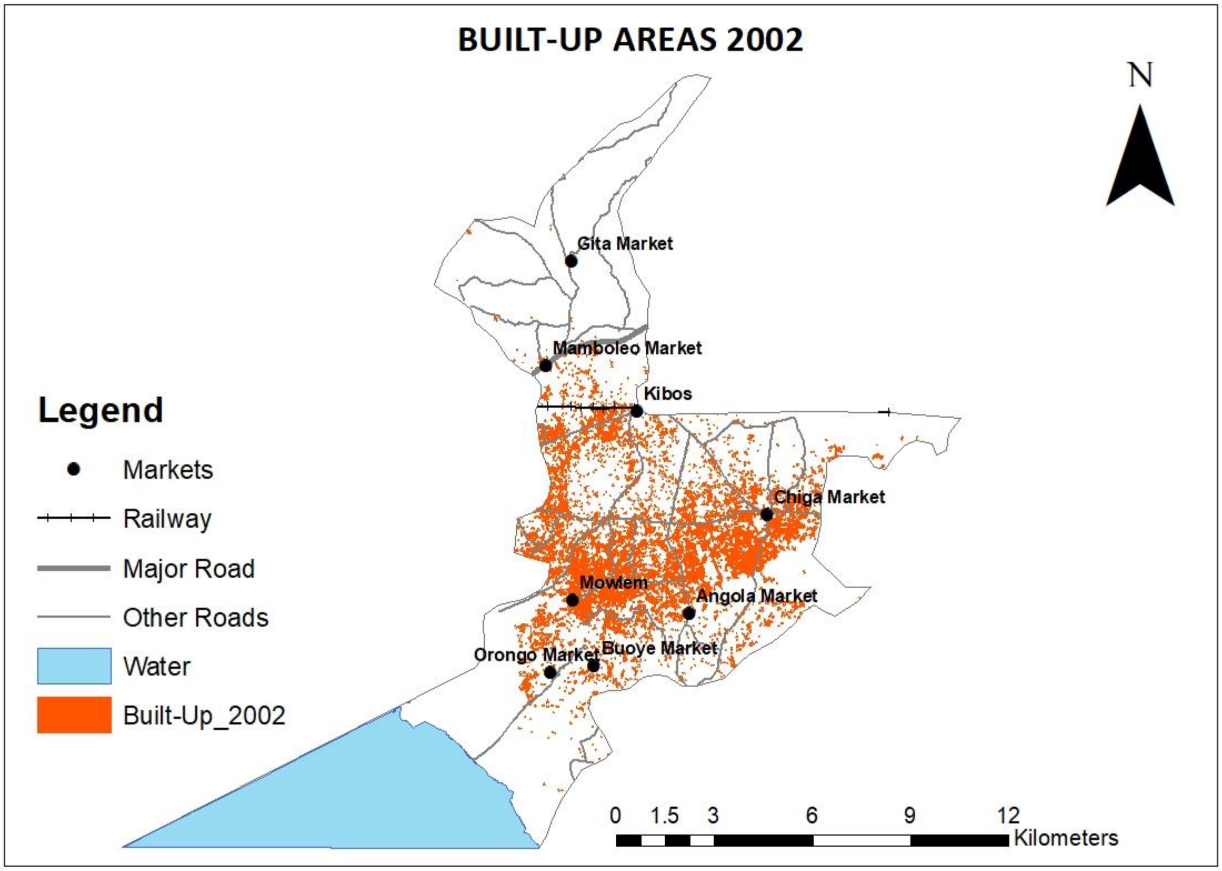

Figure 13: Built-up Areas for the Year 2002

This is attributed to the lack of urban amenities on that side of the study area. Population across the railway towards the north was scanty at this point in time. Areas around Buoye, Orongo and Angola market had medium population density, thanks to their closeness to the lake with good land for vegetable farming and fishing grounds. However, the drainage on this side of the study area is poor and the areas experience perennial flooding.

Figure 14 is the built-up areas for the year 2013. This figure shows a decline in population in the central area of the area of study particularly the area between Kibos and Mowlem. There is, however a population spike towards the Nothern sides of Gita and Mamboleo and on the Southern side towards Buoye and Orongo areas. Buoye and Orongo are along the Kisumu-Nairobi highway which is a class A1 Road. The expansion of this road attracted more population in this direction. The population around Chiga and Angola markets also dwindled significantly as more people opted for the hilly sides of Mamboleo and Gita areas. The movement can be attributed to the flooding of the areas during the rainy seasons making Mamboleo and Gita better alternatives for settlements (Laji *et al.*, 2017).

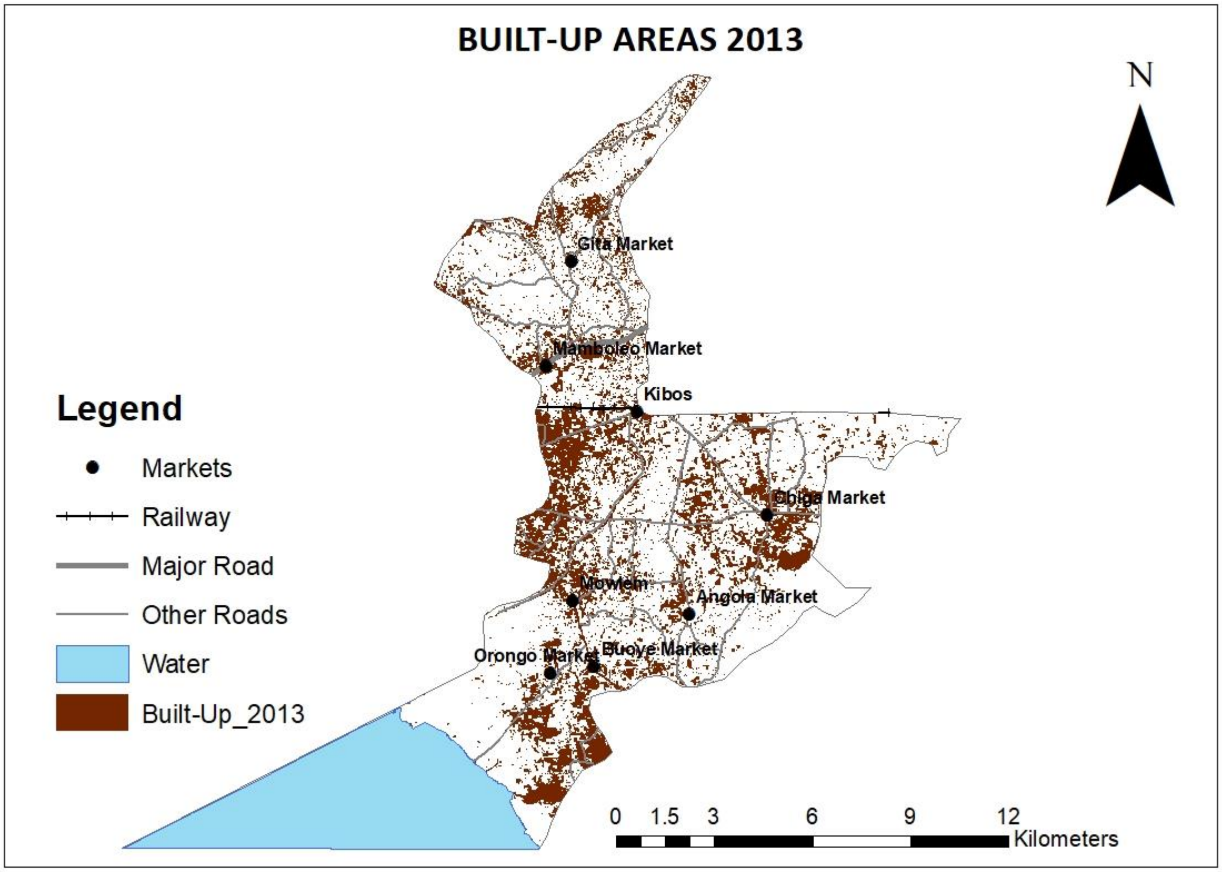

Figure 14: Built-up Areas for the Year 2013

Figure 15 shows built-up areas in Kisumu East in the year 2022. Northwards around Gita there is a significant drop in numbers but Mamboleo area has an upward trend in population. there are settlements on both sides of the C34 road. The area between the railway line and the C34 has been filled with more settlement and the area around Kibos Market also experienced a population surge. Chiga area is also densely populated. Mowlem, Buoye, Orongo and Angola market areas also experienced densification. This Figure shows that there is a general population densification of the inner areas of Kisumu East and some significant fanning out towards the North and South.

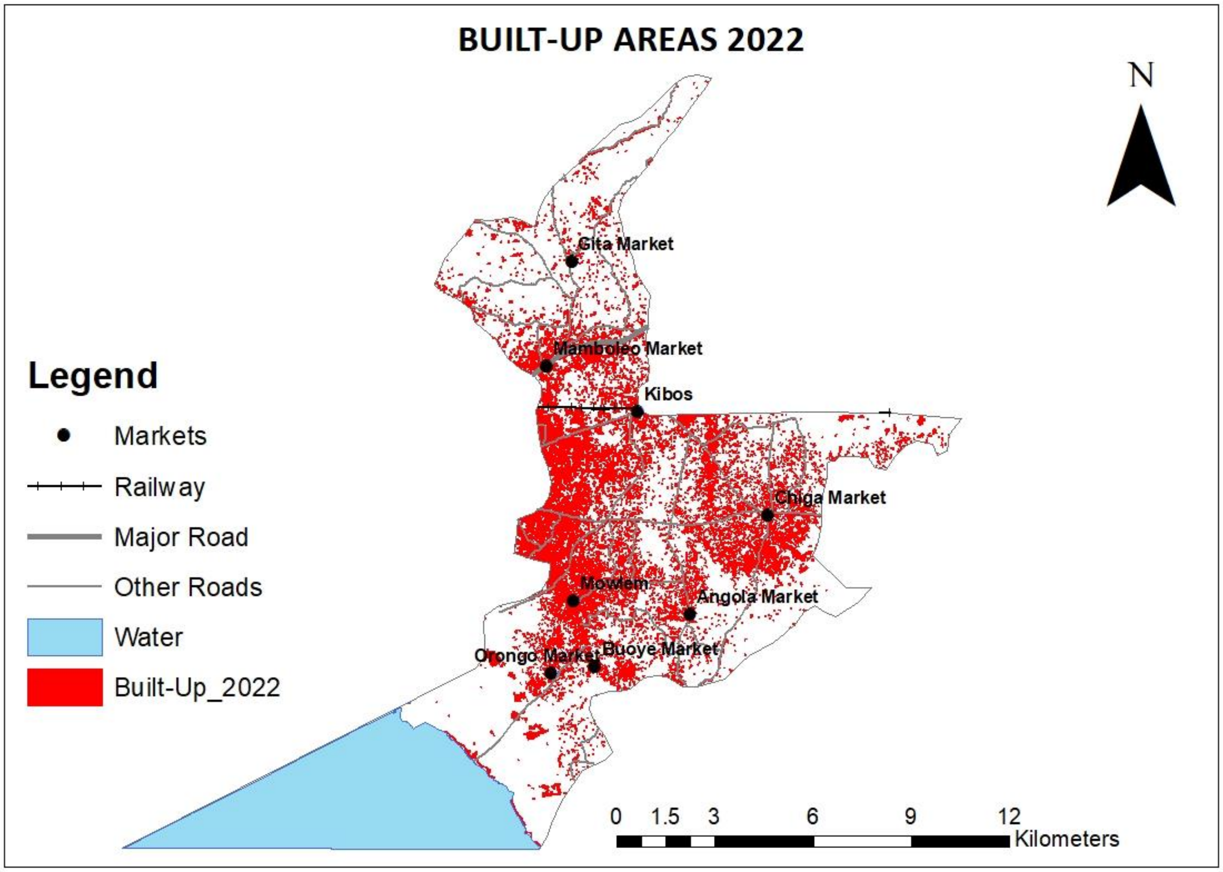

Figure 15: Built-up Areas for the Year 2022

4.7.1 Built-Up Areas Overlay Map

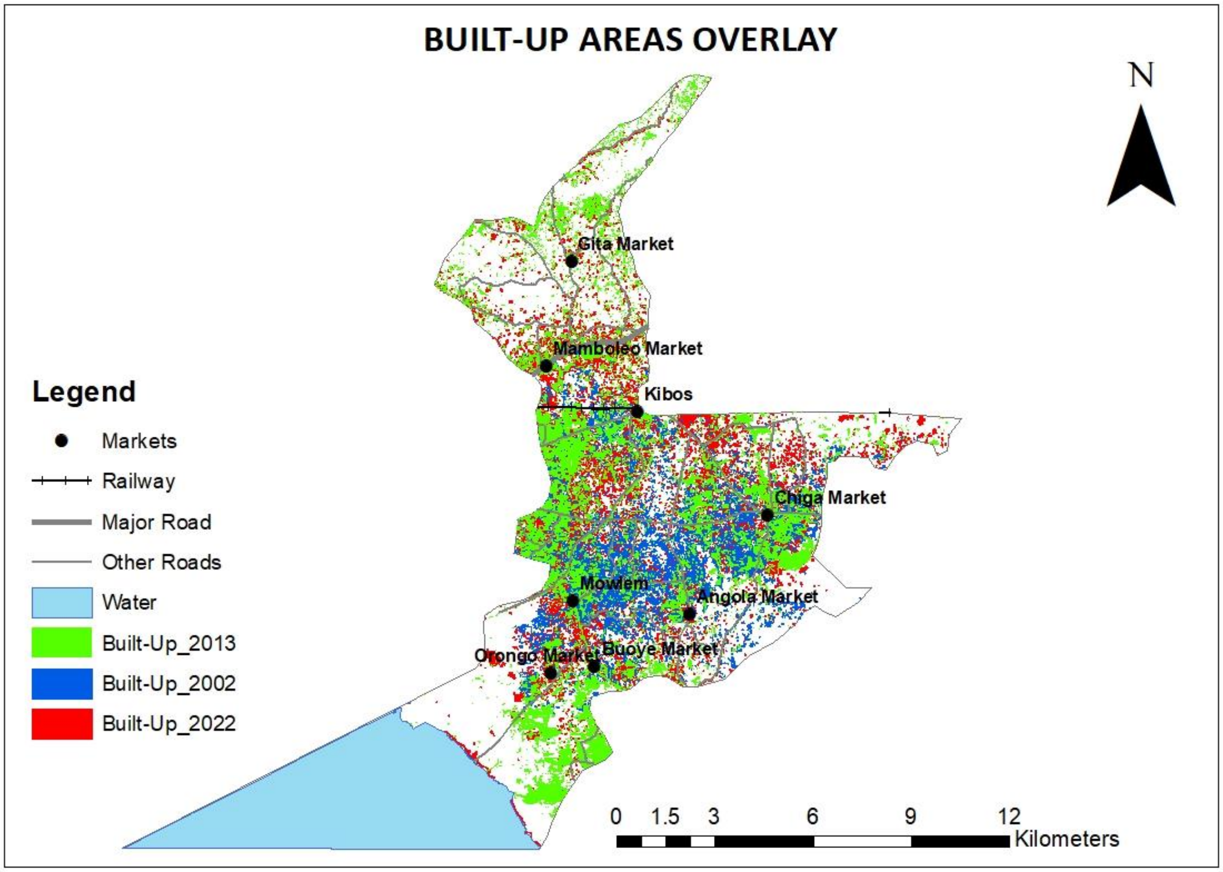

Figure 16: Built-up areas Overlay

Figure 16 details the built areas over the three study epochs. The area in blue is the settlement as at 2002. The area in green is the settlements as at 2013 and the areas in red are settlements as at 2022. The overlay analysis shows that most of the original settlements in blue were phased off since the areas have not been occupied by the colours of the latter years. The settlement in 2013 mostly increased towards the extreme ends of the area of study. This kind of urbanization is fanning out. Later in 2022 there was more of infill where the open areas in the areas at the centre of the study area were occupied by more settlement.

4.7.2 Potential for Sustainable Urbanization in Kisumu East

Kisumu East has a lot of potential owing to its position as a Gateway to Nandi and Vihiga Counties. There is potential for affordable housing, forestry, garbage recycling plants, industrialization and agriculture. The forest cover for Kisumu East is way below the stipulated National average of 10% forest cover by 2030. As an area that sits close to the equator, this is an area that can be easily tapped to create employment and as a way of conserving the environment.

The issue of housing needs addressing by the county government. With the operationalization of the Kisumu Port in the Kisumu Central Sub County, there are many job opportunities that will arise from warehousing and general trade in the area. This calls for concerted efforts to house new populations in a safe and dignified environment.

4.8 Land Consumption Rate (LCR) and Land Absorption Coefficient (LAC)

Table 12: Land Consumption Per Capita

Year	2002	2013	2022
Population	59,656	166,356	238,687
Built-Up Area (Ha.)	1,508.13	3,663.00	2,566.98
Land Consumption Rate (LCR)	0.0253	0.0220	0.0108

Table 13: Land Absorption Coefficient

Inter-Epoch Periods	2002-2013	2013-2022
Population Change (P2-P1)	106,700	72,331
Area Change(A2-A1)	2,154.87	-1,096.02
Land Absorption Coefficient (LAC)	0.0202	-0.0152

4.9 Implications of LCR and LAC

LCR is a measure of compactness of urban areas, that is, an indication of the spatial progression of an urban area. A high LCR depicts an urban area that is crowded while a low LCR depicts spaces in an urban area. From the results in Table 12 the LCR for the year 2002 was 0.0253, the LCR for the year 2013 was 0.0220 and for 2022 it was 0.0108. the results indicate that the Kisumu East is experiencing urban sprawl as the compactness of the city is on a downward trend(Oyugi *et al.*, 2017).

LAC measures the consumption of land by a given land use over a given period of time by each unit increase in population. The results of this study indicate that the LAC for the period between 2002 and 2013 is 0.0202. The LAC for the subsequent period of between 2013 and 2022 is -0.0152. The trend in these figures indicate that there was a considerable rise in consumption of land by built environment between the year 2002 and 3013 while the period between 2013 and 2022 indicates that there was a drop in the consumption of land by built-up areas(Sharma *et al.*, 2012).

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study's main objective was to determine the Land use and land cover changes that have occurred in Kisumu East between 2002 and 2022. The specific objectives were to determine the changes in built-up areas and agriculture in Kisumu East for the period between the year 2002 and 2022; to determine the changes that have occurred in the area covered by water bodies and vegetation for the period between 2002 and 2022 in Kisumu East and to find out the implications of the LULC changes to environmental sustainability in Kisumu East.

The study found out that there was indeed a mix of LULC changes in Kisumu East over the study period. For land under agricultural use, christened croplands in this study, there was an overall decrease from 6060.06 hectares in 2002, to 5620.23 hectares in 2013 and 2157.84 hectares in 2022. For built-up areas there was mixed changes starting at 1508.13 hectares in the year 2002, to 3663 hectares in 2013 and finally 2566.98 hectares in 2022. This marked an increase followed by a decrease in coverage. Overall, the change in built-up areas was an increase of 1.58.85 hectares. Bare lands covered 3986.01 hectares in the year 2002. This decreased to 1730.88 hectares in the year 2013 and 4055.76 hectares in 2022. The overall change was an increase of 69.75 hectares throughout the study period.

In 2002 vegetation cover occupied 1505.52 hectares of land, which increased to 2323.71 hectares in 2013 and 4380.57 hectares in 2022. This land cover exhibited an ever-increasing trend in growth during the study period with a general increase of 2875.05 hectares throughout the study period. Water bodies covered 2932.83 hectares in 2002, followed by 2725.83 hectares in 2013 and by 2022 water bodies covered 2849.4 hectares. This marked an overall decrease of 83.43 hectares.

For environmental sustainability, Land Consumption Rate (LCR) and Land Absorption Coefficient (LAC) values were calculated for built-up areas. This was done to determine the urban compactness of Kisumu East. The resultant values were low which indicated that Kisumu East is experiencing urban sprawl which is unsustainable to the environment.

5.2 Recommendations

As much as the methodological approach of this study gave reliable results, there was more insight into ways of conducting the study faster and much easier. For future studies of this nature, readily available land use and land cover data form sites such as Copernicus Global Land Service would be recommended instead of carrying out the tedious task of classification. In such instance, one would only have to carry out windowing of the area of study and change detection between the epochs. For data on areas covered by human settlement, the Global Human Settlement Layer datasets would be of great help. This data would be used to carry out calculations such as LCR and LAC much faster.

For future studies of this nature, more epochs with shorter intervals of around 5 years should be used for high frequency data to be generated regarding the LULC changes in the study area. This would show the pattern of the changes more clearly. Similarly, the area of coverage of the study should be increased to cover the whole county of Kisumu.

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