Carpathian Journal of Earth and Environmental Sciences February 2025, Vol. 20, No. 1, p. 5 – 17; DOI:10.26471/cjees/2025/020/309

DEMOGRAPHIC CAUSES AND ENVIRONMENTAL CONSEQUENCES OF LAND USE CHANGE IN NAIROBI (KENYA)

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Abstract: Using 1995 Landsat Thematic Mapper (TM) imagery, 2013 and 2020 Enhanced Thematic Mapper Plus (ETM +) imagery, this study analyses changes in land use and land cover (LULC) in Nairobi during the last three decades. A quantitative method was applied involving the use of Geographic Information System (GIS) data to produce maps that depict LULC changes. The findings show that built-up areas increased while grasslands decreased during the examined period. Grasslands in Nairobi National Park, Karura, and Ngong' forests display a high level of naturalness. The increase in built-up land use improved economically the areas where it occurred but led to negative environmental impacts. The main policy recommendation of this study is to regulate the type of buildings and the rate of new construction to curb this phenomenon. Similarly, instead of single homes, attached buildings should be adapted to reduce the extent of built-up areas.

Keywords: change detection, land cover, land use, spatial-temporal changes, quantitative analysis

1. INTRODUCTION

In urban centres, change is often continuous as new buildings emerge from time to time (Al Jarah et al., 2019). The use of remote sensing techniques is a critical tool for understanding changes in land use or land cover (LULC) (Raziq et al., 2016; Siro, 2017). Change detection is the process that aims at discriminating variations in the state of a phenomenon or an object by looking at divergent periods (Patela et al., 2015). The process of detecting change requires the use of various multitemporal sets of data to distinguish areas of land use or land cover between the imaging dates (Dutta & Das, 2019). Africa is a rapidly urbanising continent, particularly Sub-Saharan Africa (SSA). In 1960, Africa's urbanisation rate was 15%, but by 2010 it had risen to 40%. In 2050, it is expected to reach 60% (UN-HABITAT, 2010. Rapid population growth causes urban sprawl on agricultural land, posing a serious problem in sub-Saharan African countries (Moisa & Gemeda, 2021). Uncontrolled growth in the outskirts of most cities in the developing world is common (Saghir & Santoro, 2018). Many SSA countries' GDP is centred, if not entirely reliant, on the productivity of their cities (Albert et al., 2020). It is uncommon to go from a low-income nation (LIC) to a middle-income country (MIC) without first undergoing an urbanisation process. However, many metropolitan areas in SSA are currently unprepared to deal with problems that come with urbanisation, and as a result, urban sprawl is commonplace (Sakketa, 2023). In selected Ghanaian cities, for example, rapid population expansion without better infrastructure and services can, and has, had detrimental consequences on SSA (Amponsah et al., 2022). With a high rate of urbanisation, South Africa, for instance, is characterised by high levels of inequality, particularly in informal settlements. With the largest population in Africa, Nigeria has seen a significant increase in urbanisation of more than 50% in 2020 from 17% in 1960. Less populated countries like Chad and Ethiopia have a relatively low level of urbanisation (Sakketa, 2023).

Unplanned development activities coupled with unprecedented population growth have led to urbanisation in Kenya, although with limited basic infrastructure and utilities facilities, which has resulted in rich agricultural land and forests being converted to concrete jungles (Shadrack, 2015). Urbanisation in Kenya takes place linearly along highways or in a radial direction around well-established towns (Mundia & Aniya, 2006). Kenya's population grew from 22.94 million in 1989 to 47.5 million in 2019 (KNBS, 2019). The urban population has also been increasing over the years. For instance, the population of Nairobi grew from 1.32 million in 1989 to 4.38 million in 2019 according to the Kenya housing and population census. Population is a primary driver of land use and development of human settlements, as well as a determinant of other characteristics such as solid-waste generation rates and distribution of basic infrastructure. While the city's population steadily grows, the demand for limited development land also rises, triggering resource conflicts, especially around Nairobi National Park (Chepkorir, 2016).

Nairobi is one of Africa's fastest developing cities, and one of the three largest cities in the African Great Lakes region (Mwathi, 2016). This has seen the city experience urbanisation challenges stemming from the city's historical, socioeconomic, and physical development characteristics coupled with inadequate and weak implementation of urban development policies (Nairobi County Assembly, 2022). The NIUPLAN is the most recent land use plan for the city (2014-2030). The plan aims to address one of Nairobi's current significant development concerns, which is the result of controlling land use developments and planning for environmental sustainability. The zonal considerations proposal, transport-oriented development, and the NIUPLAN technique to the delineation of the Nairobi city county were used primarily (Sub Centres). At least 14 sub-centres, junctions, and stations were suggested at the crossroads of two modes of transportation, such as road and rail, and the intersection of two roads. Upper hill, Karen-Langata, Runda-Ruaka, Dandora, Imara-Daima, Makadara, Ruai, and Kasarani are some of the proposed sub-centres. Although there have been measures to improve the development of Nairobi city, such as the NIUPLAN, they have not been fully implemented and have given rise to informal settlements like Kibera slum (Agayi & Serdaroğlu Sağ, 2020).

Several studies have been done regarding the relationship between environmental change and changes in land cover. For example, Shalaby et al. (2012a) used NDBI and Landsat data to study the increase in urban expansion in Fayoum, Egypt, between 1972 and 2009 and discovered that blending remote sensing and GIS provided valuable information on the spatial distribution of different land cover changes. The role of remote sensing in the assessment and prediction of changes in land cover was investigated by Al Kafy et al., (2021). In comparison to land surface temperature, the study predicted an increase of built-up area to 446 km^2 and 512.83 km^2 in 2030 and 2040 respectively in Bangladesh using a base of 158 km^2 in 1995. Chepsiror (2016) investigated the elements that influence the urbanisation of Kenya's informal cities and found that technological advancement and improved transport systems greatly influence the urbanisation of Eldoret town due to improved security, the availability of streetlights, and clean water supply. After researching the changing patterns of land use and land cover in Nairobi, Mundia & Aniya (2006) found that, among other things, unplanned growth and population growth have accelerated changes in LULC. However, there has been little current research on Nairobi's LULC changes using GIS and remote sensing techniques. Taking this into account, this study aims to answer the following research questions.

1. In what ways has LULC changed in Nairobi from the early 1990s to the present?
2. What is the pattern of the city's expansion?
3. What were the effects of LULC change on the environment between 1995 and 2020, particularly the city's grasslands, the Nairobi National Park?

The remaining part of this article is organised as follows: First, data collection techniques and analytical methods are described. Then, the main results of the study are presented. The following section discusses the results, comparing them with previous findings of the relevant literature. Finally, the article ends with some concluding remarks.

2. DATA AND METHODS

2.1 Study area

Nairobi lies between latitude 1°16' and 1°29' south of the equator and longitude 36°48' and 36°49' east. The elevation is 1,795m above sea level. Nairobi is the capital city and one of the 47 counties in Kenya (Figure 1). It is gently rolling to the east, characterised by steep valleys towards the city boundaries. There is Karura forest to the north and Ngong forest to the south. The Karen–Langata area is characterised by plains surrounded by the Nairobi National Park (NNP), which is a protected area. Three main rivers and several streams drain the area.

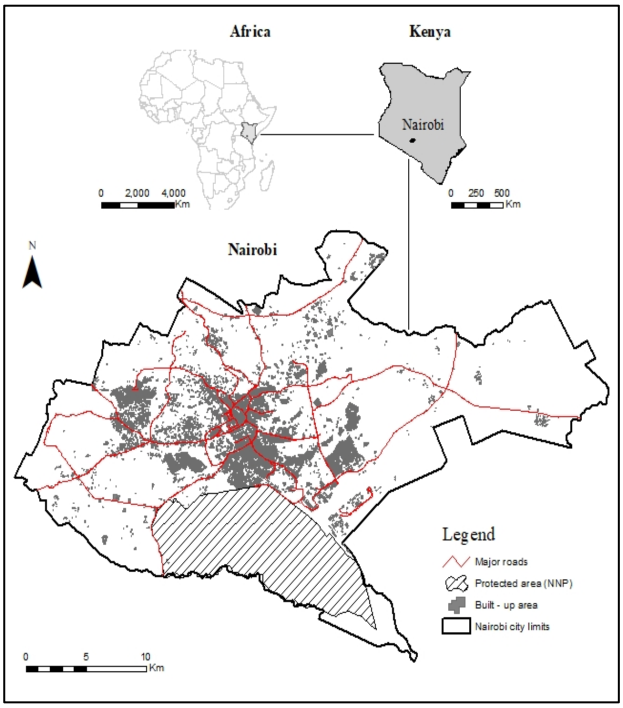


Figure 1. Administrative boundaries of Nairobi
Source: ICPAC Geoportal (2017)

Because of its high altitude, Nairobi experiences a cool climate with temperatures ranging from 10°C to 29°C. There are two primary seasons, the dry and rainy seasons. Long rains fall between March and May, while the short rains fall between October and December. The mean of the long and short rains is 899 mm and 638 mm, respectively. The annual rainfall is 768.5 mm. It is the most populous county and the third smallest in size by area.

2.2 Data and data sources

LULC changes within the research area were analysed using satellite images. Changes in land use and land cover were identified using the 1995 Landsat Thematic Mapper (TM) as well as the 2013 and 2020 Enhanced Thematic Mapper Plus (ETM+). The photographs obtained had a 30-m medium resolution, which is sufficient to provide information on LULC changes and urban sprawl (Almazroui et al., 2017). These phenomena take a long time and consequently demands longer time intervals to highlight the changes (Doygun, 2009).

A crucial first step toward a successful classification process is to choose appropriate sensor data (Ward et al., 2000). It is important to take into account variables including the size and features of the study region, the needs of the user, financial and schedule restrictions, atmospheric conditions, and the analyst's prior experience utilising the chosen image (Lu & Weng, 2007), thus the choice of Landsat images for 1995, 2013, and 2020. In addition, information on the population was obtained from the Kenya National Bureau of Statistics. As a result, the study used information from multiple sources and formats. (Table 1).

Table 1. Data types, sources, and description

Data type	Source	Description
Multispectral images	United States Geological Survey (USGS) [1]	Landsat EMT + (1995, 2013, 2020)
Kenya's population	Kenya National Bureau of Statistics (KNBS)	Kenya Population and Housing Census (1990, 2009, 2019)
Administrative boundaries	ICPAC Geoportal [2]	Shape file
Major roads in Kenya	Survey of Kenya [3]	Shape file

2.2.1. Image processing

This study compared classified images of Nairobi in the years 1995, 2013, and 2020.

Image processing techniques included preprocessing images, creating classification schemes, classifying images, evaluating the accuracy, and analysing changes in land use and cover (Figure 2). Erdas IMAGINE, ArcGIS, and QGIS were used to integrate the various data sets and perform the analysis. Image pre-processing involved layer stacking and sub-setting in Erdas IMAGINE. Furthermore, satellite images were projected onto the Universal Mercator Projecting system and the World Geodetic System WGS84 to ensure the homogeneity of the data sets throughout the analysis.

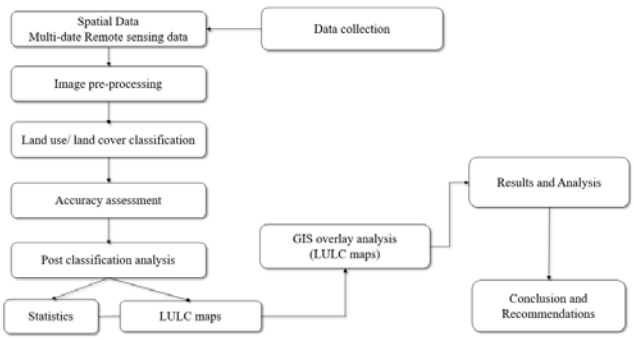


Figure 2. Methodological flow chart of the study

2.2.2. Image classification

Six classes were developed, taking into account the primary LULC groups in this study (Table 2). The supervised classification method (maximum likelihood) was used for this investigation due to the diversity of the study area. Due to its reliability and accessibility in image-processing software, maximum likelihood is among the most widely used parametric classifiers (Lu & Weng, 2007).

Table 2. Classes for LULC maps

	Class Name	Description
1	Water Body	Rivers, natural dams, and reservoirs
2	Bare land	Transitional areas and areas with bare rock, bare soil, and quarries
3	Built-up area	Land covered by buildings (residential, commercial, industrial, transportation, communication) and other artificial surfaces
4	Forest	Mixed forests with high-density trees, evergreen forests
5	Agricultural land	Cropland, horticultural farms, greenhouses, and other crops
6	Grassland	Sparsely distributed scrubs with ground layers covered with annual grass. Trees rarely above 5 m, and impoverished woodlands

The maximum likelihood algorithm calculates the probability that a given pixel belongs to a specific class by assuming that the statistics for each class in each band are normally distributed. A signature file from the training sample was created in ArcGIS with the six classes assigned and used as an input raster file for the maximum likelihood classifier. Following accuracy testing and post-classification applying ArcGIS's spatial analyst tools, the output raster was used to produce land use and land cover maps for the years 1995, 2013, and 2020. To determine the modification of the six classifications of LULC, an area calculation was also performed in ArcGIS. Excel was used to perform an additional analysis of the statistics that were produced, including creating charts and calculating percentages and frequencies. To determine the relative stability of each LULC class from 1995 to 2020, the maps were also overlaid in QGIS. Using ArcGIS's nearest neighbour tool, the maps were also overlayed with the study area's main road network to determine the trend of LULC change. Additionally, from 1995 to 2013 and from 2013 to 2020, the overlay maps were used to determine changes from one LULC class to another, as well as land transformations and the degree of naturalness of grasslands.

The population data for the study area for 1995, 2013, and 2020 were used to establish the correlation between population growth and increased artificial and built-up surfaces in Excel.

2.3 Accuracy assessment

Accuracy assessment compares a classified image with a different data source that is considerably accurate or ground-truth data. Though reliable, it is time-consuming to collect ground-truth data from the field. For this study, Google imagery for the corresponding years was used as reference data and local knowledge. The creation of accuracy assessment points, the update of accuracy assessment points, and the computation of the confusion matrix are the three geoprocessing tools that were used in Arc Map. Points were stratified according to the distribution of LULC classes as stratified random sampling was adopted.

Random selection of pixels reduces the possibility of bias. The reference data are compared with the pixels or polygons in a classified image using error matrices. The degree to which actual land cover classes can be categorised using errors of omission is known as producer accuracy. The likelihood that a classified pixel matches the land cover type of its associated real-world location is represented by user accuracy, which assesses errors of commission. The Kappa index agreement provides an overall assessment of the precision of the classification. The overall precision of the classification assessment was 91% with a Kappa coefficient of 0.83, 89% with a Kappa coefficient of 0.85, and 90% with a Kappa coefficient of 0.93 for 1995, 2013, and 2020 respectively (Table 3). The maps met the minimum 85% requirement of USGS accuracy according to the Anderson classification scheme (Anderson et al., 1976).

3. RESULTS

3.1 Changes in land use and land cover in Nairobi from 1995 to 2020

The post-classification method was used to detect changes in LULC, since it can provide descriptive data on the kind of changes that take place (Falcucci et al., 2006). Six primary groups of land use and cover were classified: built-up areas, bare land, water bodies, forests, agricultural land, and grasslands (Figure 3).

The dominant land cover type in 1995 was grassland, while water bodies covered the least area. Built-up areas followed the main roads and were the least concentrated to the east. Agricultural land and forests were located primarily west and northwest of the study area following undulating slopes (Figure 3). Specifically, the proportion of coverage of built-up areas rose from 8% in 1995 to more than 40% in 2020 (Table 4). Although grasslands were the dominant land cover type, it reduced significantly from 424.87 km^2 in 1995 to 210 km^2 in 2020. This implies the loss of natural ecosystems (Falcucci et al., 2006).

In addition to forests and grasslands, water bodies and bare lands decreased in coverage in the years 2013 to 2020 giving way to additional urban development (Table 4). For instance, water bodies shrunk by over half their initial coverage. The major transformations in LULC occurred between the years 1995 and 2013 (Figures 4 and 5). Specifically, four percent of the forests and over twenty percent of the grasslands were turned into built-up areas.

Table 3. Error matrix of LULC maps derived from Landsat data

Ground truth data

a) 1995	1	2	3	4	5	6	Total (User)	Producer’s accuracy%	User’s accuracy%
1	20	0	0	0	0	0	20	87	100
2	0	26	0	1	3	0	30	65	87
3	0	0	37	0	2	0	39	90	95
4	3	0	0	52	2	0	57	90	91
5	0	2	0	0	88	0	90	84	98
6	0	12	0	5	10	186	213	100	87
Total (Producer)	23	40	37	58	105	186	449		

Overall accuracy 91% Kappa Statistic 0.83

b) 2013	1	2	3	4	5	6	Total (User)		
1	11	1	0	0	0	0	12	100	92
2	0	16	0	0	0	0	16	89	100
3	0	0	142	0	0	0	142	99	100
4	0	1	0	40	2	4	47	100	85
5	0	17	0	0	63	4	84	93	68
6	0	18	1	0	3	141	163	95	87
Total (Producer)	11	53	143	40	68	149	464		

Overall accuracy 89% Kappa Statistic 0.85

c) 2020	1	2	3	4	5	6	Total (User)		
1	4	1	0	0	0	0	5	100	80
2	0	5	0	0	2	0	7	71	71
3	0	0	231	0	2	2	235	100	98
4	0	1	0	14	2	0	17	64	82
5	0	0	0	0	57	1	58	90	98
6	0	0	0	8	0	119	127	98	94
Total (Producer)	4	7	231	22	63	122	449		

Overall accuracy 90% Kappa Statistic 0.93

1, Water body; 2, Bare land; 3, Built-up area; 4, Forest; 5, Agricultural land; 6, Grassland

Table 4. Change in land cover/land use from 1995 to 2020

LULC classes	1995		2013		2020		1995–2013	2013–2020	1995–2020
	Area in km^2	Coverage	Area in km^2	Coverage	Area in km^2	Coverage	Change in percentage%	Change in percentage%	Change in percentage%
Agricultural land	121.41	17%	123.58	17.5%	170.25	24.1%	0.31	6.62	6.93
Bare land	28.40	4%	46.19	6.6%	0.69	0.1%	2.52	-6.45	-3.93
Built-up area	56.33	8%	201.77	28.6%	305.14	43.3%	20.62	14.66	35.28
Forest	70.53	10%	40.78	5.8%	16.06	2.3%	-4.22	-3.50	-7.72
Grassland	424.87	60%	287.18	40.7%	210.52	29.9%	-19.53	-10.87	-30.40
Water body	3.64	1%	5.69	0.8%	2.51	0.4%	0.29	-0.45	-0.16
Total	705.19	100%	705.17	100%	705.18	100%			

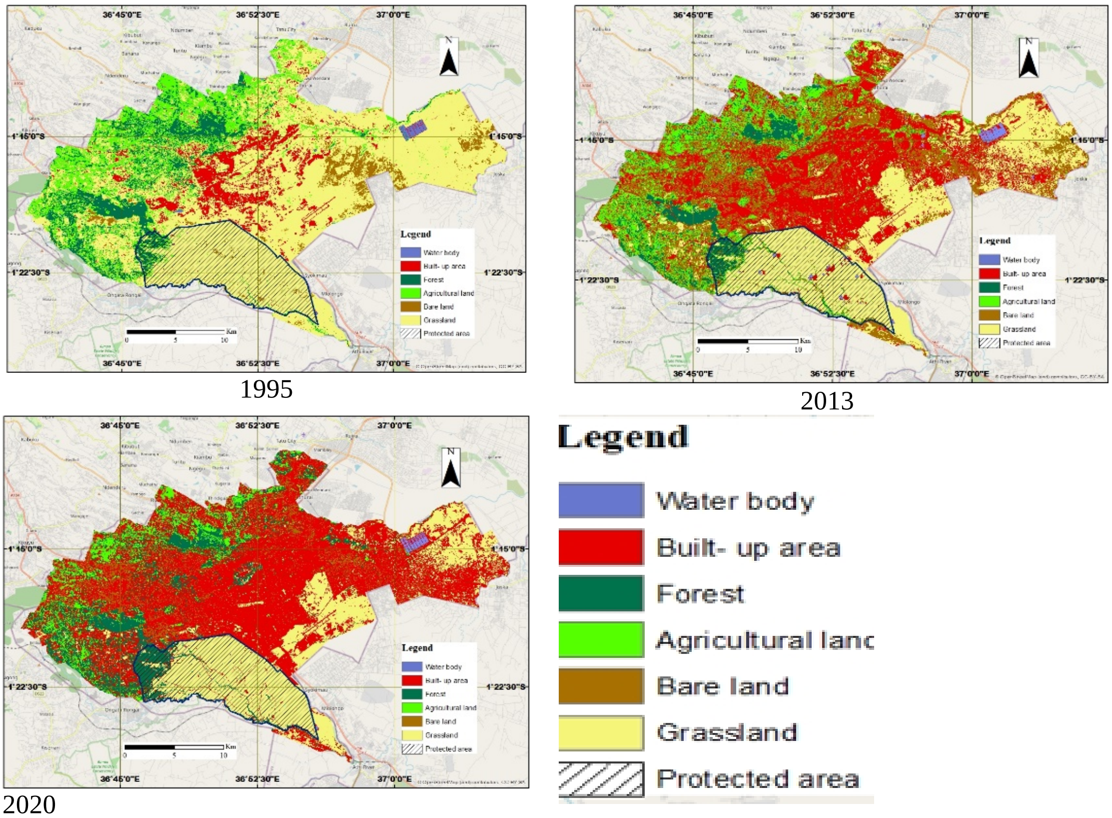


Figure 3. Classified LULC map of Nairobi in 1995, 2013, and 2020

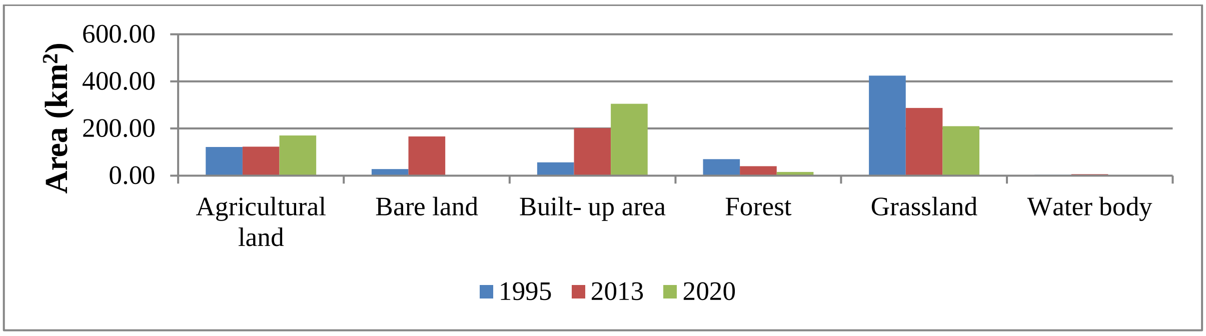


Figure 4. Transformations in LULC types in Nairobi from 1995 to 2020

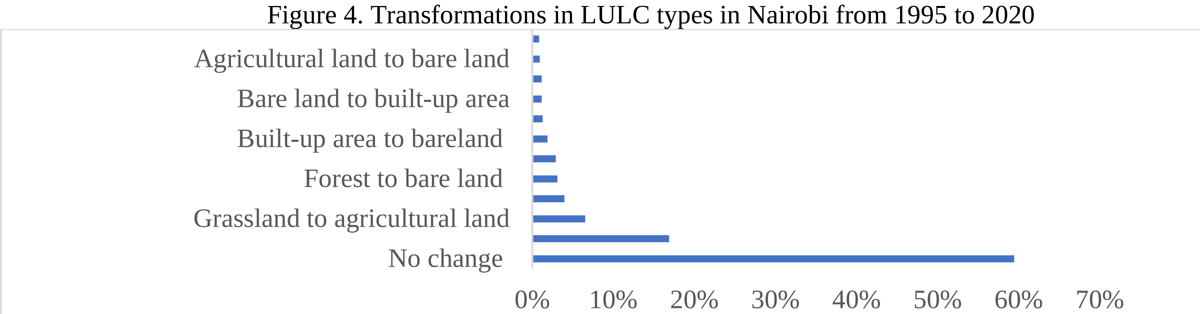


Figure 5. Percentage of land use/land cover transformations between 1995 and 2013; Percentage of total land area

Between 2013 and 2020, grasslands, bare surfaces, and land for agriculture were transformed into built-up areas (Figure 6). Cumulatively, there were significant changes in land cover and use from 1995 to 2020 (Figure 7). Throughout, bare land dropped by more than 100% while built-up areas increased by more than 250%. Although there were notable changes in the types of land cover and land use between 1995 and 2013, a significant amount of grassland remained the same (Figure 8). While some conversions occurred once, others occurred twice. Areas that were initially developed into built-up regions had one alteration. The grasslands, especially in Nairobi National Park in the south, Karura Forest in the north, and Ngong Forest in the west, remained relatively unchanged during the study period, displaying a high level of naturalness.

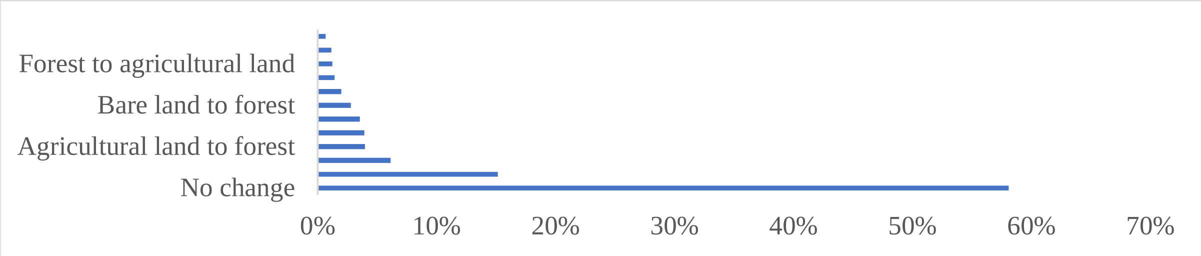


Figure 6. Percentage of land use/land cover transformations between 2013 and 2020; Percentage of total land area

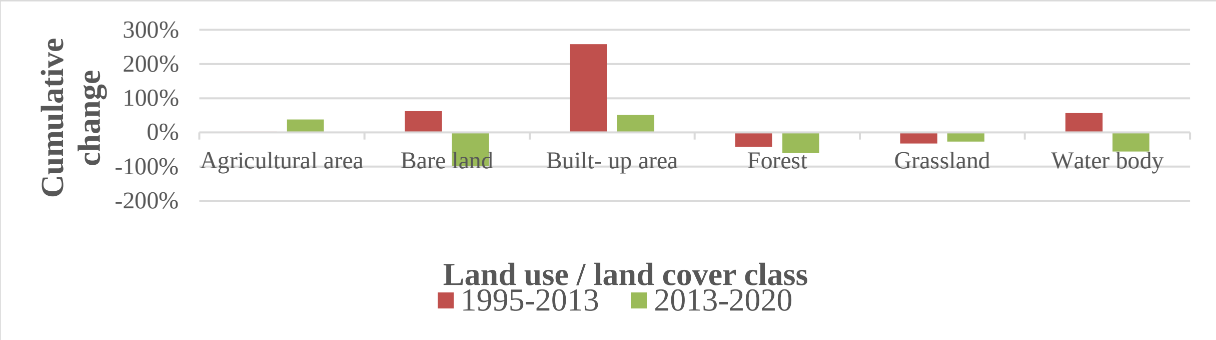


Figure 7. Cumulative changes in LULC from 1995 to 2013 and from 2013 to 2020; 0% is the total area of a given land use class in 1995

Calculations were made to determine the distance between the land cover categories and the closest major road. The built-up area was closest to the main road in 1995, 2013, and 2020 (Figure 9). The forest as a land cover type was closest to the main road in 2020.

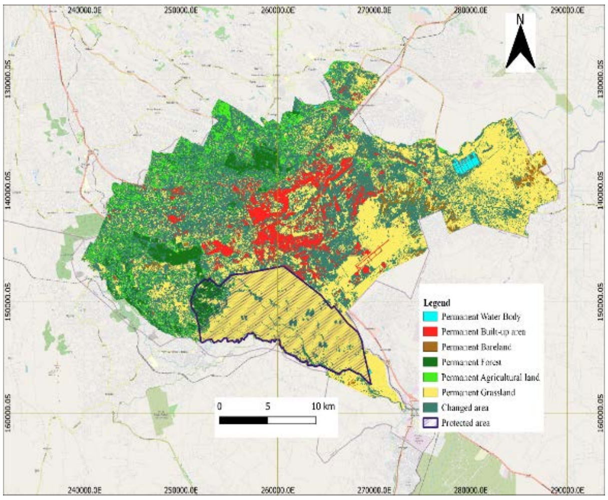
A correlation was drawn between Nairobi's population data for the years 1995, 2013, and 2020 and the corresponding built-up areas (Figure 10). Due to the normal distribution of the data values, the correlation was reported using Pearson's coefficient R, which is frequently used in many environmental studies (Cârlan et al., 2020). There is a direct relationship between population growth and built-up areas.

4. DISCUSSION

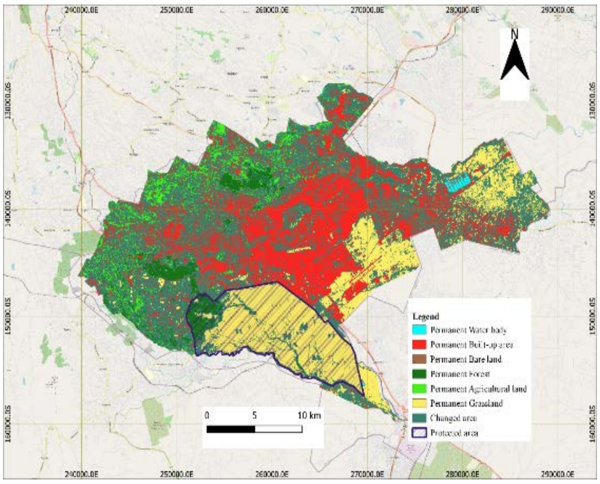
4.1 LULC changes in Nairobi from 1995-2020

The findings of this study demonstrated that, in 2020 there was a coverage of more than 40% in built-up area compared to only 8% in 1995 particularly in the northeast and eastern parts of Nairobi. These findings are consistent with the changes seen in selected countries where urban developments have replaced natural ecosystems such as grasslands and forests (Falcucci et al., 2006). This increase corresponded to the increase in the population of Nairobi of 4.7 million in 2019 compared to less than two million in 1995. There is a direct relationship between population increase and built-up areas (Majid & Yahya, 2010). In addition to natural growth, Nairobi attracts migrants from all over the country in search of jobs and better infrastructure. Nairobi is a net receiver of lifetime immigrants from all counties (Onyango et al., 2021). It also hosts the headquarters of most public services such education and health since it is the capital city. Moreover, foreign investment companies are also based in Nairobi (Mwaniki, 2017).

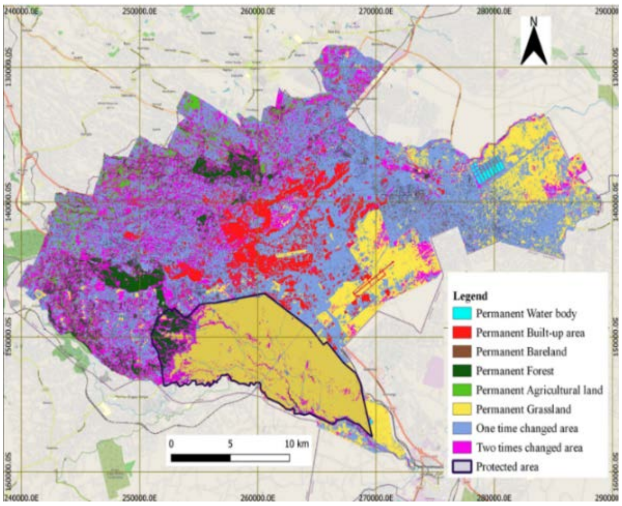
The findings also showed a decline in forests and water bodies (Figure 4). Bare land also decreased by almost 100% during the study period. An increase in the number of dwellings, migration from rural to urban areas, and natural population growth causes a significant loss of natural ecosystems in favour of anthropogenic activities (Gashu & Gebre-Egziabher, 2018).
Significantly, grasslands remained intact between 1995 and 2013, even though there were noticeable changes in other types of land use and cover (Figure 8). For example, much of the agricultural land was converted into built-up area. Bare land was also converted into agricultural land and by 2020 it was converted into built-up area (Figure 8). The grasslands exhibit a high degree of naturalness, particularly in Nairobi National Park, Karura Forest, and Ngong Forest in the south, the north, and the west, respectively. The Nairobi National Park is a protected are made up mainly of grassland. The Karura forest in the north of Nairobi was gazetted in 1932, which has served to preserve forest cover in Nairobi (Chepkorir, 2016). Protected areas do not suffer urban expansion and urban sprawl as an urban sprawl containment strategy, as they serve to preserve the natural ecosystem that provides the various ecosystem services (Amponsah et al., 2022).



A) Stability of LULC types from 1995 to 2013



B) Stability of LULC types from 2013 to 2020



C) Stability of LULC types from 1995 to 2020

Figure 8. Stability of land use/land use land cover types from A) 1995 to 2013, B) 2013 to 2020, C) 1995 to 2020,

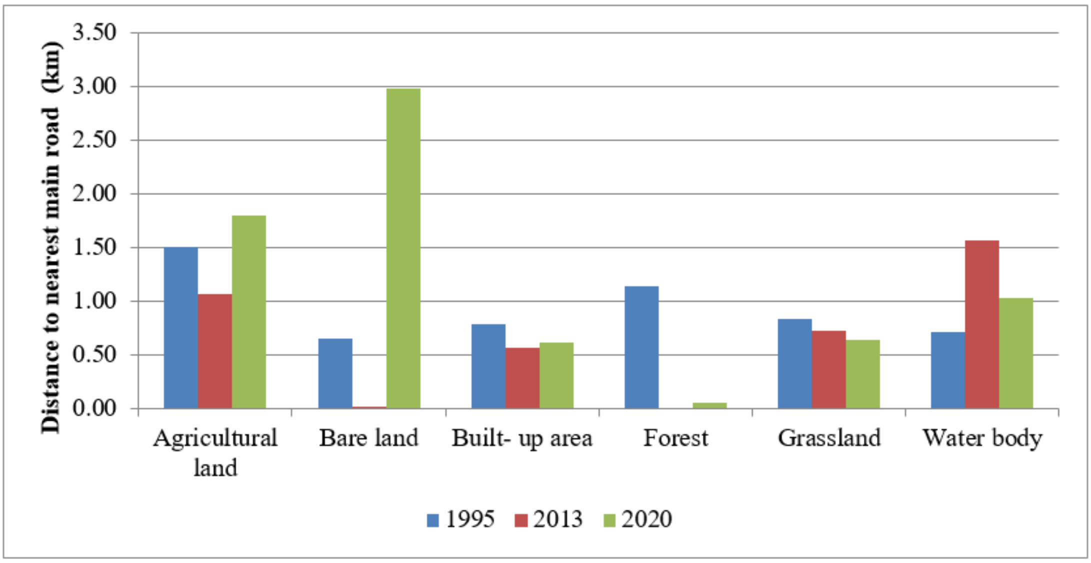


Figure 9. Distance of land use/land cover types to the nearest main road

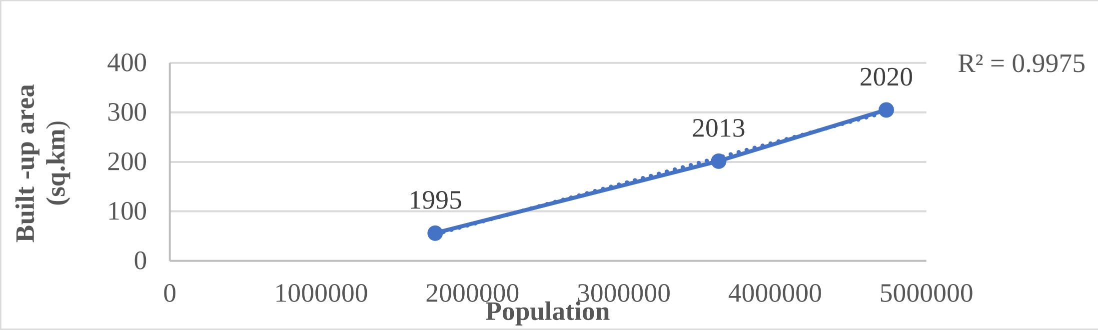


Figure 10. Correlation between the population of Nairobi and the built-up area

4.2 The pattern of the city's expansion

The direction of expansion in the study area has been greatly influenced by its terrain. The expansion to the northwest has followed the flat terrain (Figure 3). To the east of Nairobi city, where a poor road network initially limited growth and expansion opportunities, the trend changed after the year 2000 due to the onset of the construction of the Thika superhighway (Falcucci et al., 2006). The area also offers advantages in terms of building materials and a large expanse of land for residential development, which is inevitable due to increasing housing needs because of population increase (Nairobi City Council, 2004). Built-up and artificial surfaces predominantly covered the area in 2020 displaying the extent of urban expansion (Figure 3). The growth was linear and scattered, especially in industrial area and east lands. The cluster pattern of the built-up regions corresponds to the growth of companies and industries (Gashu & Gebre-Egziabher, 2018).

In addition, the expansion is a consequence of the housing needs resulting from the constant influx of people into the city. People move to urban areas in search of employment and better services (Haregewoin, 2005). Sporadic and appended sprawls at the rural-urban interface of cities in Kenya emerge in less expensive suburbia due to cost variations and population pressure (Mundia, 2017; Oyugi et al., 2017; Ayonga, 2020). Furthermore, the increase in taxes for property and businesses at the core of the city causes businesses to consider relocating to cost- effective locations (Amponsah et al, 2022). The new frontiers of economic development presented in this period allowed cooperatives and organised groups to purchase land for real estate development in the eastern lands. Commercial centres, schools, and medical centres, among other amenities, also sprung up displaying urban sprawl (Mahboob et al., 2015).

According to Martinuzzi et al., (2007), built-up areas and population growth are positively correlated. This is consistent with the findings of Majid & Yahya (2010) on sprawling cities, which demonstrated that there is a connection between the rate of population increase and the amount of land consumed in built-up areas. The built-up area was 56 km^2 when the population of Nairobi was 1,755,000 in 1995 and more than 300 km^2 in 2020 when the population was approximately five million (Figure 10). Housing needs, as well as demands for other physical infrastructure, are inevitable and therefore the tremendous increase in built-up areas to over 300 km^2 in the last three decades (Nairobi County Assembly, 2022).

Emerging construction was carried out along major roads such as Mombasa Road (A104) and Thika Superhighway, as well as the Eastern bypass and the Express Way. The common trend of urbanisation in Kenya is for settlements to expand along main roads (Katyambo & Ngigi, 2017). The construction of roads affects the change in land use, contributing to densification, loss of livelihoods, and inequalities (Gateri & K'Akumu, 2023). In addition to settlement following the main roads, expansion also occurred in areas further from the road (Figure 3) and around established institutions such as Kenyatta University (KU) and Jomo Kenyatta University of Science and Technology (Mundia & Aniya, 2006). Most informal settlements also sprung up until 2013 and beyond to accommodate a growing low-income population, which is a common phenomenon in African countries especially in southern Africa (Sulemana et al., 2019). Therefore, the results suggest that leapfrog and ribbon sprawl development patterns took place between 1995 and 2020, as further demonstrated by estimated distances between various land use and cover types and the closest major roadways (Figure 9).

The economic, social, and environmental aspects of Nairobi have been shaped in various ways. The urbanisation process contributes to socioeconomic changes in urban areas, leading to the increase of urban sprawl and the loss of forests (Yiran et al., 2020) and (Trócsányi et al., 2024). As a result, pressure and congestion in the city centre of Nairobi eased. In an economic sense, the creation of new industries in the peri-urban areas such as the use of the Western concept of an export processing zone (Wong & Tang, 2005) and the factories in Ruiru presented new employment opportunities which in turn improved the standard of living of the employed people. Services like banking that would attract people to the city centre got closer to the people, and therefore the pressure of people commuting to the city centre was eased. New construction of residential, commercial, and even industrial sites provides a market for construction materials and services. In recent decades, urban areas in Africa have experienced considerable expansion, significantly outstripping the ability of most urban areas to provide sufficient services to residents, leading to increased urban sprawl and loss of forest cover (Mundia & Murayama, 2010; Gashu & Gebre-Egziabher, 2018). In cities such as Nairobi, with an increasing population, there is also a need for amenities like hospitals, schools, and security, among others, which eases the pressure on the available facilities in the core and creates job opportunities in the peri-urban areas (Mundia, 2017).

4.3 Environmental consequences of LULC changes, especially in the natural and semi-natural grasslands (Nairobi National Park) in the city from 1995- 2020

The findings of this study demonstrate that LULC changes have led to serious environmental impacts over the years. For instance, forests and water bodies shrunk during the study period as built-up areas increased in correlation with the increase in the population of Nairobi. Agricultural land also increased. Anthropogenic encroachment affects water supply, wildlife habitats, and overall environmental quality (Musa & Odera, 2015). As stated earlier, there were significant changes in LULC from 1995 to 2020 particularly the increase in built-up area (Figure 3). Almost 20% of the grasslands and 4% of the forest area were converted to built-up areas. Urban sprawl and decline in forest cover are both consequences of urban expansion (Mundia & Aniya, 2006; Mundia & Mumina, 2014). These LULC conversions show an encroachment into natural ecosystems that not only degrades natural habitats, but also leads to fragmentation and isolation of the remaining ecosystems (Mwathi, 2016). Kibera slum and informal settlements in periurban areas in the east have suffered the most degradation (Nairobi City County, 2019). The expansion of Nairobi has been mainly to the periphery caused by affordable land and construction materials in the eastern part of the city. Besides that, the shrinking forests have compromised the natural ecosystem, resulting in a loss of flora and fauna (Nechyba & Walsh, 2004).

The Pipeline estates in Nairobi were once swampy areas. The water bodies decreased in area from 3.64 km^2 in 1995 to 2.51 km^2 in 2020. The loss of biodiversity from urban sprawl is evident and it affects the essential environmental functions (Hardi et al., 2020). Grasslands and forests reduced in area from 70.53 km^2 to 16.06 km^2 and from 424.87 km^2 to 210.52 km^2, respectively, during the study period. The loss of forests and grasslands means the loss of habitats for flora and fauna, which are important in balancing the ecosystem (Behnisch et al., 2022). Quarrying and sand harvesting to meet the demands for construction materials for new construction sites led to air pollution and left some parts of the land derelict. The resulting effects are both land pollution, water (Nairobi River and ground water), and air pollution. Air pollution has detrimental effects on both individual and community health as well as on the environment (Gul & Das, 2023). Furthermore, urban expansion results in the loss of open space (Falcucci et al., 2006).

The rise of informal settlements in the eastern lands and Kibera is eye sore. Since most people living in these informal settlements are low-income earners, they become poor since they are abandoned in these low-income areas as they cannot afford a car-based lifestyle (Osman et al., 2009). Additionally, these areas are always congested and lack adequate infrastructure and utilities, such as sewer, drainage, and solid waste disposal. The increase in buildings and residential units translates into an increase in the consumption of water and electricity (Oyugi & K'Akumu, 2007).

Since built-up areas increased by more than 40% from 1995 to 2020 while forests and grasslands reduced by 8% and 30%, respectively, there was a subsequent increase in impermeable surfaces and decrease in vegetation cover. Impermeable surfaces increase surface runoff and increase the risk of floods in the rainy season (Shadrack, 2015).

5. CONCLUSION

This study used a post-classification method to detect changes in LULC in Nairobi from 1995 to 2020. The changes are evidenced by an increase in built-up area and agricultural land and a decline in grasslands, forests, water bodies and bare land. There is a positive correlation between increased built-up area and population growth. Therefore, among other factors, natural population increase, migration from rural to urban areas, as well as a surge in the housing ratio, all contributed to the dramatic development of built-up areas. The findings suggest that the pattern of the city's expansion mostly follows a ribbon sprawl and leapfrog development sprawl types as well as cluster patterns in the industrial areas.

Although urban expansion relieves congestion and pressure in the city centre, the increase in the built-up area negatively impacted the natural environment by severely diminishing grasslands, leading to a decline in flora and fauna. The water bodies considerably shrunk. Although other factors may exist outside of the scope of this study, human activity on riparian land could be attributed to the disappearance of water bodies. Evidently, there is a prominent level of naturalness in Nairobi National Park, Karura forest, and Ngong' forest despite the various changes in land use/land cover. These regions should be protected from urban invasion and expansion because they help to conserve the natural ecosystem that provides a variety of ecosystem services. The protected area of Nairobi National Park should be extended and made continuous to Ngong' forest, as it serves as a corridor for plant and animal movement. Policies that regulate the type of buildings and the rate of new construction must also be enacted to curb this phenomenon. Instead of single homes, the arrangement of attached buildings should be adapted to reduce the extent of built-up area.

Acknowledgements

We are thankful for the contributions of the Department of Human Geography and the Department of Physical and Environmental Geography, Institute of Geosciences, University of Szeged. The Stipendium Hungaricum scholarship made the first author's MSc studies possible. We are grateful.

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Received at: 17. 08. 2024
Revised at: 04. 09. 2024
Accepted for publication at: 14. 10. 2024
Published online at: 28. 10. 2024