Built-up area growth in Kenya: Patterns. Magnitude, and Drivers between 1990 and 2015

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Abstract

This thesis explores the substantial increase in built-up area in Kenya from 1990 to 2015, characterized by a notable increase in the urban population and a corresponding transformation of urban spaces. A staggering 639% increase in built-up surface area was observed during this period. Metropolitan areas such as Nairobi and Mombasa exhibited significant expansion in built-up area, the intensity of built-up areas within these cities increased. Areas with a high intensity of increase in built-up surface, mostly grassland was displaced. In other areas cropland rainfed has lost significant amount of land due to it being converted into built-up surface. Next to natural urban growth the primary drivers of this expansion were identified as population growth and accelerated urbanization, driven by the availability of better opportunities in urban areas. The findings of this research provide insights into the transformative urbanization process in Kenya and its broader implications on land use patterns.

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1. Introduction

Urban areas have experienced a remarkable surge in growth worldwide over the past few decades, driven primarily by population expansion (Araya and Cabral, 2010). Based on data from the United Nations, more than half of the global population currently resides in urban areas, and this is projected to become approximately two-thirds of the world's population by 2050 (Desa U, 2018). Another significant factor contributing to this urban growth is internal migration, particularly the movement from rural to urban areas (Mberu et al., 2017). Internal migration refers to the relocation of individuals within a country, often in search of better economic opportunities or improved living conditions (National Council for Population and Development, n.d.).

The most significant changes the African continent will see in the twenty-first century are those brought on by urbanization. Over the past three decades the number of cities in Africa has doubled. This growth Is accompanied by a notable population growth of five hundred million individuals (Oecd et al., 2022). According to projections, the majority of the population growth is anticipated to occur in urban areas (Cohen, 2004). By 2050, it is estimated that Africa will house approximately a quarter of the global urban population, totaling around 1.3 billion people (Cobbinah et al., 2015). As result of this rapid urbanization, Africa's cities are experiencing rapid growth, characterized by youthfulness and dynamic changes, and their influence on the economic, social, and political landscape of the continent is expected to be profound in the years to come (Xu et al., 2019a).

Like many other African countries, the rate of urbanization in Kenya has also been accelerating in recent years, and the country is expected to continue experiencing significant growth in its urban population and built-up areas in the coming decades (Nyongesa et al., 2022) (World Bank Open Data, n.d.). In 2008, the Kenyan city Nairobi encompasses a significant portion, approximately 37.7 percent, of Kenya's overall urban population, making it the largest urban center in the country. Furthermore, it surpasses the second-largest city, Mombasa, in size by a considerable margin, being 3.7 times larger with a population of around 820,000 (UN-HABITAT, 2008).

This rapid urbanization and population growth creates intensifying pressure for land cover conversion, with agricultural land, forests, and other natural habitats being converted to urban uses (Mireri, 2006). This trend has important implications for economic, social, and environmental sustainability such as housing and infrastructure development (NASA Earth Observatory, n.d.).

Understanding the drivers behind these changes, the magnitude of change in built-up land and the previous land use at the location where built-up land was added can provide valuable insights for policymakers and planners in Kenya. Such knowledge can inform informed decision-making processes and facilitate sustainable urban development.

This research aiming to delve into the dynamics of built-up land expansion in Kenya between 1990 and 2015 is addressed by the following main research question: What determines the built-up land expansion patterns in Kenya between 1990 and 2015?

To comprehensively explore this research question the following sub-questions will be examined:
Sub question 1: What is the magnitude of built-up land expansion in Kenya between 1990 and 2015?
Sub question 2: At the expense of which land covers does the increase in built-up surface in Kenya occur?
Sub-question 3: What are the drivers behind land cover change and urbanization in Kenya?

By addressing these questions this paper intents to investigate the determinants, patterns, and magnitude of the expansion of built-up surface in Kenya during a specific time period. Through the use of GIS analysis, data analysis and literature review this study endeavors to address these questions and shed a light on the implications of urban and built-up land expansion for land cover in Kenya. The findings derived from this study will contribute to the existing knowledge, enhance our understanding of the dynamics between land use change and built-up surface increase and their implications in the Kenyan context. Additionally, it can contribute to the development of policies aimed at land use in Kenya and it can help raise awareness among the public and policy makers about the social and environmental impacts of land use change and built-up land expansion.

Research on land cover change and urbanization in Kenya from an earth, economy and sustainability perspective is fascinating because it can help us better understand how to manage and conserve our natural resources while ensuring economic growth and prosperity in a sustainable manner.

The structure this paper can be described as follows. Firstly, a detailed description of the research methods employed for each sub-question will be presented, along with an overview of the necessary data requirements specific to each sub-question Subsequently, the results obtained from the research will be presented in the next chapter, organized according to each research question. For sub-question one, tables and maps will be displayed to visualize the degree of the increase in built-up surface. Sub-question 2 will provide insights into the extent of land conversion to built-up areas categorized by land use types between 1990 and 2015. Lastly, the drivers of built-up surface increase and specifically urban expansion will be explored through a literature review, a discussion will be conducted to interpret the findings and address potential limitations or uncertainties. The final chapter will conclude the paper by providing recommendations for future research in this field, followed by a list of references and any relevant appendix materials.

2. Method

2.1 What is the magnitude of built-up land expansion in Kenya between 1990 and 2015?

To research this question, the Global Human Settlement built-up surface grid from the Global Human Settlement Layer (GHSL) dataset was utilized (Pesaresi & Politis, 2023). Additionally, a vector layer representing the sixty-nine districts in Kenya was downloaded (World Resources Institute & Landsberg, n.d.). These datasets were loaded into the QGIS software for further analysis and examination.

The distribution of built-up surfaces, given as a number of square meters, is shown in the built-up surface raster dataset of GHSL. The resolution of the data is one hundred meters, this means that a cell has a maximum of ten thousand square meters of built-up area. The total built-up surface and the built-up surface designated for non-residential applications are both reported in the statistics.

To research the amount of built-up land expansion, the years 1990 and 2015 were chosen. The year 1990 serves as a starting point to visualize a baseline of the initial state of the built-up area. On the other hand, the year 2015 is selected as the endpoint to evaluate the subsequent changes in built-up expansion over a substantial period.

For this research, four map layers were obtained from GHSL, specifically the built-up maps for 1990 and 2015. Both time periods, 1990 and 2015, included maps depicting the combination of residential and non-residential areas, as well as maps focusing solely on non-residential areas. These maps were individually downloaded per tile from GHSL, then they were merged in QGIS to form a complete Kenya. Following the merging process, the maps were clipped to a vector layer encompassing the district boundaries of Kenya. To ensure spatial consistency with the GHSL data, the vector layer was first reprojected to the world Mollweide projection.

A certain approach is used to analyze the data about the changes in built-up areas for the residential and non-residential land types separately. By subtracting non-residential from combined residential and non-residential data, distinct layers representing residential built-up areas are created for 1990 and 2015. Using raster statistics, the sum of built-up land for each raster layer is calculated. The resulting table reveals the magnitude of change in non-residential, residential, and total built-up surfaces, offering insights into the built-up land expansion in Kenya from 1990 to 2015. If the increase in non-residential built-up area is deemed insignificant, the focus for further analysis will be on the total built-up area.

By subtracting the 1990 from the 2015 layer, it gains visual insights into the change in total built-up area. Additionally, the amount of added built-up surface per district is calculated, enabling the visualization of the increase in built-up area per district as a share of the total size of the district through a map representation. Lastly, the two districts that experienced the most significant increase in built-up area will be shown.

2.2 At the expense of which land covers does the increase in built-up surface in Kenya occur?

2.2.1 Recalculating the total built-up layer and accounting for a threshold

For this research question the world Climate Change Initiative Land Cover data with a resolution of three hundred meters from 1992 was used (ESA, 2017). The legend of the Climate Change Initiative Land Cover is made using the Land Cover Classification System (LCCS), which was developed by the United Nations (UN) Food and Agriculture Organization (FAO) (Land Cover CCI Product User Guide

Version 2.0, 2017). Also vector layer containing the districts was used (World Resources Institute & Landsberg, n.d.).

To determine changed surface, it is important to name locations as changed. The layer total built-up change is therefor recalculated. For this a lower limit is important because otherwise very large areas are designated as changed (Figure 1). To choose a relevant limit a sensitivity analysis is done and visualized in the results.

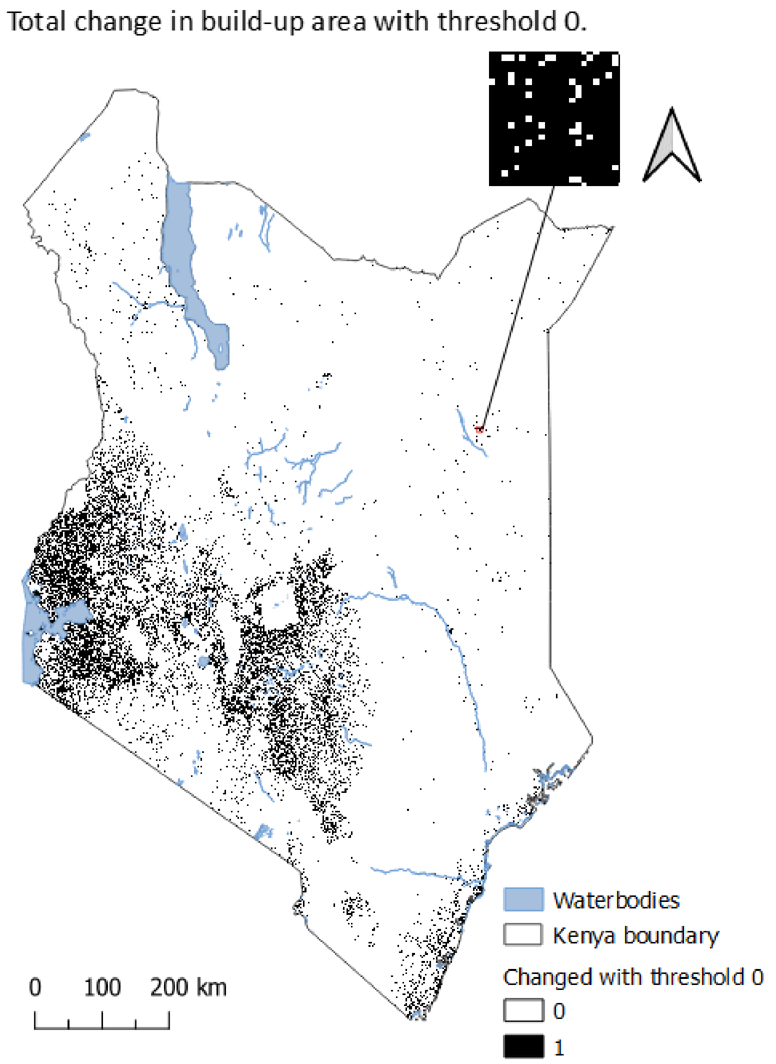

Figure 1: Method of recalculating the total change in built-up area in 0 (no added built-up area) and 1 (some sort of added built-up area) with a threshold of >0. The thresholds represent the from what percentage of built-up within a cell for it to be classified as built-up surface. The classification of cells as one indicates that these cells experienced added built-up surface ranging from one to ten thousand square meters from 1990 to 2015

2.2.2 Displaced land use due to built-up land expansion per built-up threshold

The land cover map is clipped to the vector of Kenya and subsequently reprojected from the World Geodetic System 84 to the World Mollweide projection using the nearest neighborhood resampling method in the QGIS warp. It was performed with the georeferenced extend and resolution of the GHSL built-up layer. The output was a land cover map with a resolution of one hundred meters, which matches the built-up layer's resolution.

After warping the land cover layer, it is multiplied with the recalculated layers which indicate the increase in built-up, using various threshold. This result in maps that display the previous land use (as of 1992) of the cells that have experienced change (marked as 1). Zonal histograms are then used to determine the amount of land affected per land cover type, and this information is presented in graphs.

2.3 What are the drivers behind land cover change and urbanization in Kenya?

To explore this sub-question, a comprehensive literature study was conducted. The purpose of this study was to delve into existing research, scholarly articles, reports, and publications that supply insights into the determinants, patterns, and implications of urban and built-up expansion in Kenya. The research sought to compile a variety of viewpoints, hypotheses, and data on the causes influencing urban land growth, the scope of expansion, and the related land use changes in Kenya between 1990 and 2015 found in literature. Also, the relation between population growth and increase in built-up surface will be analyzed in depth for Kenya as a whole and per county.

3. Results

3.1 What is the magnitude of built-up land expansion in Kenya between 1990 and 2015?

The overall built-up surface in square kilometers for the various built-up levels in Kenya between 1990 and 2015 is shown in Table 1. The total built-up area covered 283.6 square kilometers in 1990, with residential accounting for 276.2 square kilometers and non-residential accounting for 7.3 square kilometers.

By 2015, the total built-up area expanded significantly, with a total built-up area encompassing 2095.7 square kilometers. Residential built-up covered a vast area of 2077.9 square kilometers, while non-residential built-up occupied a smaller extent of 17.8 square kilometers.

Table 1: Built-up land expansion in Kenya from 1990 to 2015.

Total built-up area (km²)				Residential area (km²)				Non-residential area (km²)			
1990	2015	Added absolute	Added relative	1990	2015	Added absolute	Added relative	1990	2015	Added absolute	Added relative
283.6	2095.7	1812.1	639%	276.2	2077.9	1801.7	652%	7.3	17.8	10.5	143%

Table 1 also represents the absolute and relative changes in built-up surface area for different surface types in Kenya between 1990 and 2015. The "added absolute" column shows the number of square kilometers added for each surface type, while the "added relative" column indicates the percentage increase in built-up surface compared to the initial value in 1990.

The total built-up area increased by an absolute amount of 1,812.1 square kilometers between 1990 and 2015, which corresponds to a relative growth of 639%. Similar to this, the residential built-up area by itself had a notable absolute increase of 1,801.7 square kilometers, representing a relative growth of 652%. The non-residential built-up area, on the other hand, showed a modest absolute increase of 10.5 square kilometers, or a relative growth of 143%.

These results show substantial expansion in built-up areas in Kenya over the specified period, with mostly residential areas experiencing considerable growth. Since the non-residential area is considerably smaller when compared to the residential area, the rest of the paper will focus solely on the total built-up area.

Among the examined regions during the specified time period, the top five areas exhibiting the largest absolute increase in built-up surface are displayed in Table 2. Nakuru takes the lead with an additional built-up surface of 98.16 km², followed by Machakos, Makueni, Nairobi, and Thika. It is noteworthy that Nairobi appears in both tables, indicating its significant expansion in built-up area and transformation.

Table 2: The top five districts with the most absolute built-up expansion between 1990 and 2015.

District	Area district (km²)	Added built-up surface between 1990-2015 (km²)	Added built-up surface, as share of the district size (%)
Nakuru	7467.4	98,2	1.31%
Machakos	6226.6	88.1	1.42%
Makueni	7997.2	72.3	0.90%
Nairobi	695.3	58.9	8.47%
Thika	1961.2	55.7	2.84%

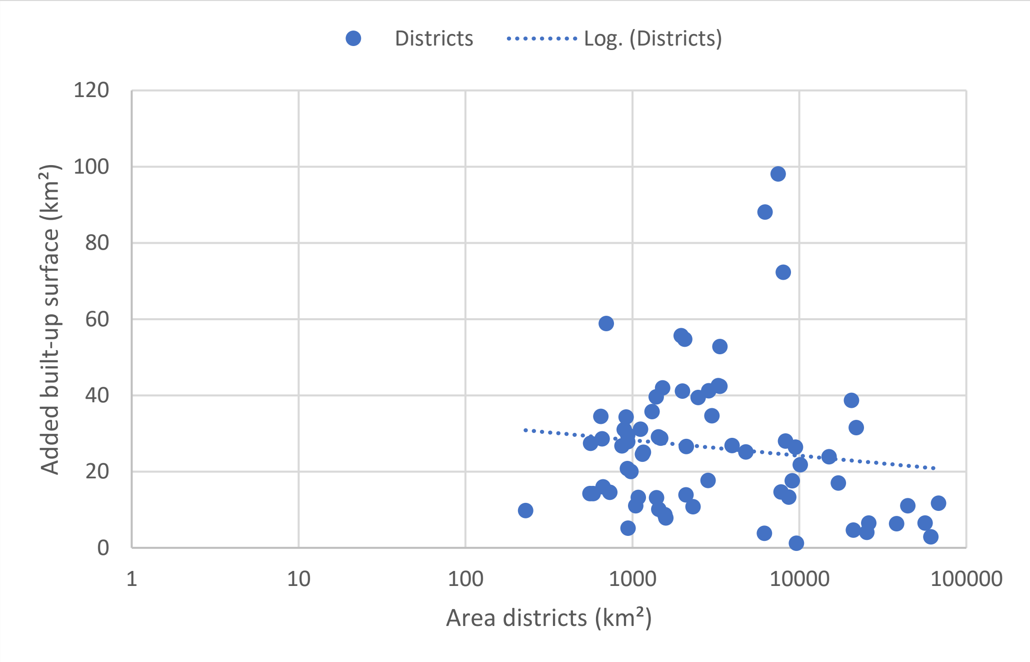

Figure 2: relation between the size of the district and the absolute added square kilometers of built-up surface per district.

Figure 2 implies a decreasing relationship between the size of districts and the built-up surface. The negative logarithmic trendline suggests that as the size of districts increases, the built-up surface tends to decrease. In other words, smaller districts tend to have a larger built-up surface compared to larger districts. Smaller districts may have higher population densities or more concentrated urban development, leading to a greater proportion of built-up area compared to their size. On the other hand, larger districts may have more rural or undeveloped areas, resulting in a smaller proportion of built-up surface.

Figure 3 illustrates a map depicting the percentage growth in total built-up area per district in Kenya between 1990 and 2015, as a share of the total size of each district. The map visually represents the varying degrees of built-up expansion and development across the country during the specified time period. The color gradient on the map indicates the magnitude of the percentage growth, with darker shades representing higher percentages. This visual representation offers insights into the spatial distribution and scale of built-up land expansion within different districts in Kenya over the studied period.

Percentage growth in total build-up area per district in Kenya between 1990 and 2015.

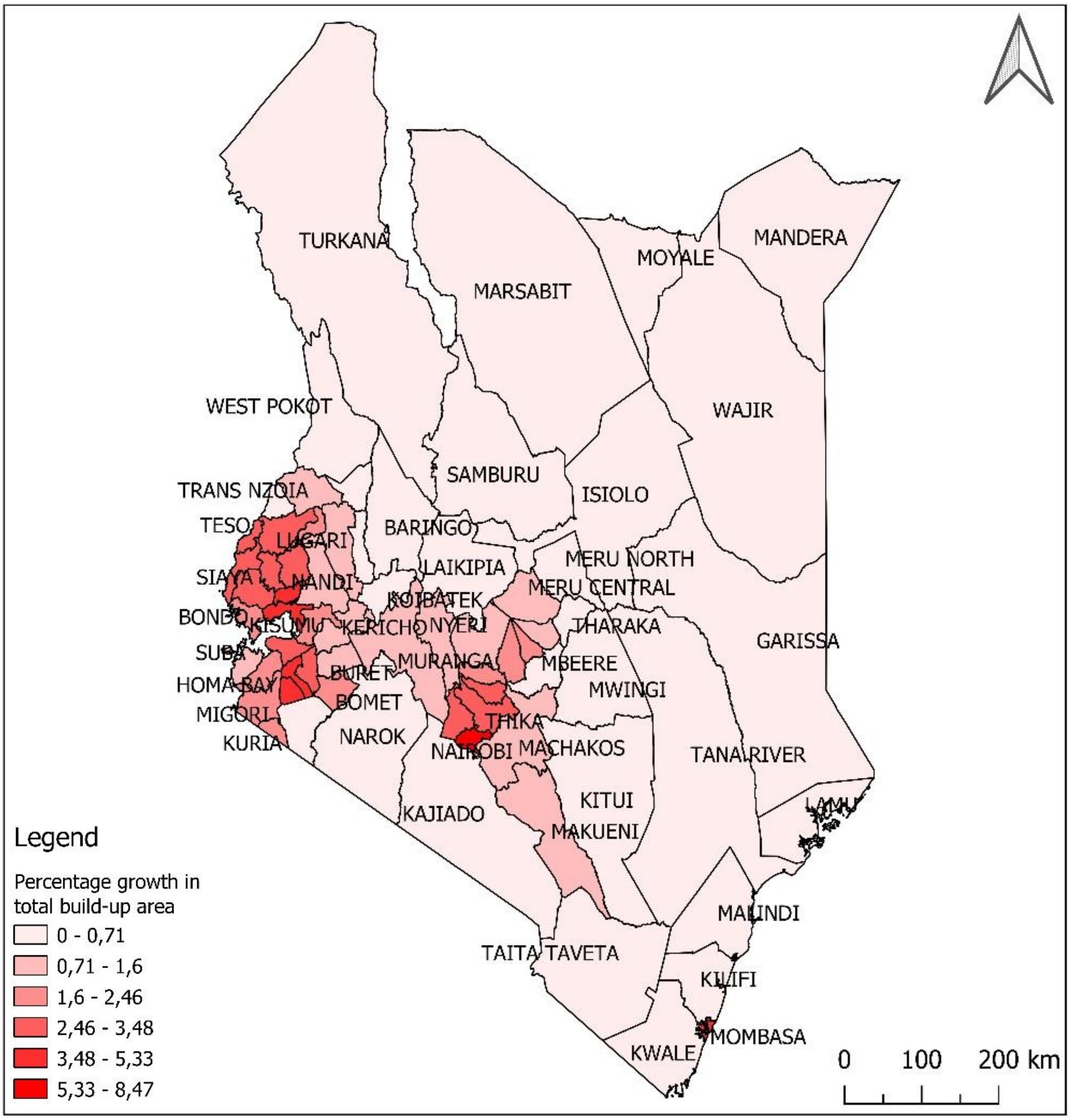

Figure 3: Map of the percentage growth in total built-up area per district in Kenya between 1990 and 2015 as a share of the total size of the district.

Table 3 lists the Kenyan districts where the growth in built-up surface, in relation to the district size, exceeded 4% between 1990 and 2015. These districts include Central Kisii, Gucha, Mombasa, Nairobi, and Vihiga. Nairobi is notable for having the most increased built-up surface at 8.47% as a share of the size of the district.

Table 3: Districts with more than a four percent of increase in built-up surface between 1990 and 2015 as a share of the total size of the district. The complete table for each district can be found in Appendix 1.

District	Area district (km^2)	Added built-up surface between 1990-2015 (km^2)	Added built-up surface, as share of the district size (%)
Nairobi	695.3	58.9	8.47%
Central Kisii	646.6	34.5	5.33%
Vihiga	560.1	27.5	4.90%
Gucha	657.4	28.6	4.35%
Mombasa	228.9	9.8	4.27%

The scatterplot in Figure 4 illustrates the districts and the percentage growth in built-up surface. Each data point represents a district and its corresponding percentage growth value. The x-axis displays size of the districts, while the y-axis represents the percentage growth in built-up surface between 1990 and 2015, accounting for the size of each district. The top five districts that exhibit the highest growth rates are also the one of the smallest districts. Figure 4 shows a decline in percentage growth in total built-up area per district in Kenya as share of the total size of the district as the size of the district increases.

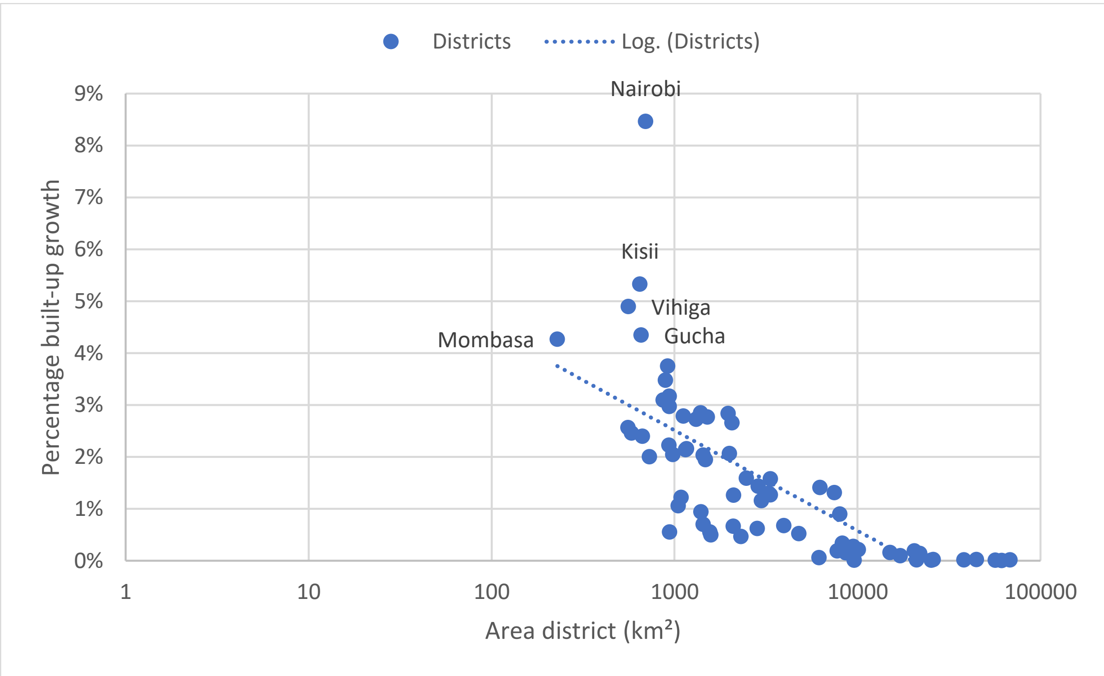

Figure 4: Percentage growth in total built-up area between 1990 and 2015 per district in Kenya as share of the total size of the district in relation to the size of the district.

The two districts with the most increase in built-up surface, relative to the district's total area, are Nairobi and Central Kisii. The visual representation of this change is depicted in Figures 5 and 6, where the intensity of red in each pixel corresponds to the magnitude of added built-up surface between 1990 and 2015. It appears from the maps, the distribution of added built-up surface in Central Kisii is characterized by a relatively uniform spread across the entire district, with a distinct concentration observed at the road Y-junction situated in the district's central area. Conversely, Nairobi has some noticeable areas where limited or no additional built-up surface has occurred. Particularly in the eastern region, where among other things a sewage treatment plant is located.

Furthermore, minimal built-up surface expansion is observed in the southern part, where a park is located, as well as in the southeast region which houses an international airport.

Change in total build up surface in Nairobi between 1990 and 2015.

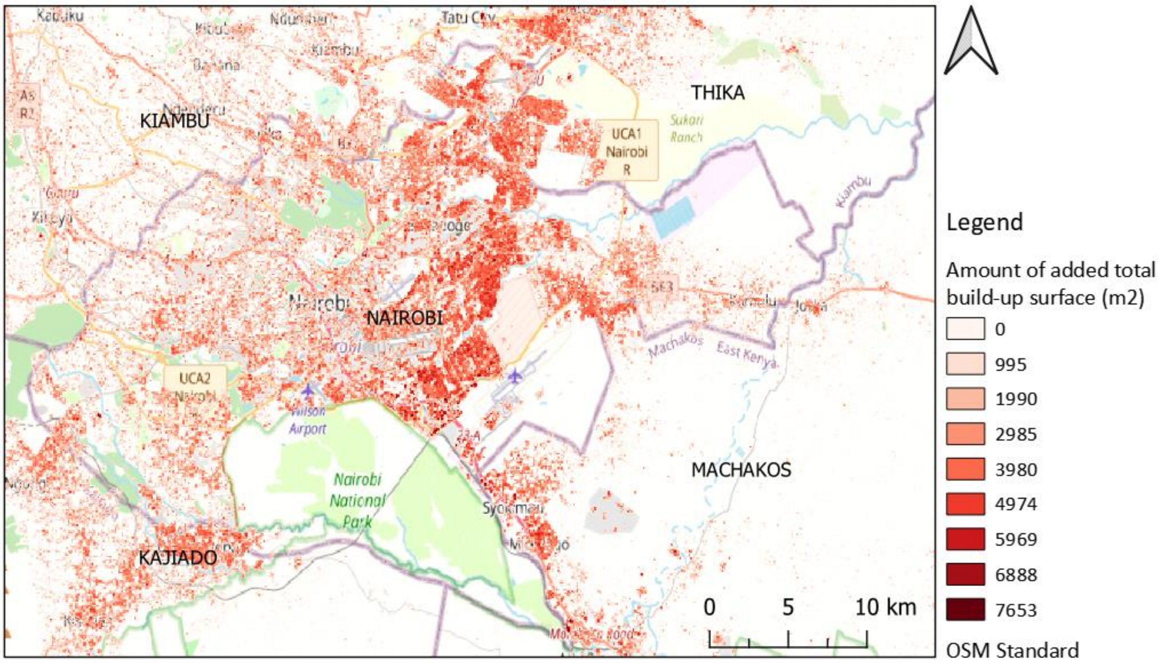

Figure 5: Map of the number of square meters change in total built-up surface in Nairobi from 1990 to 2015.

Change in total build up surface in Central Kisii between 1990 and 2015.

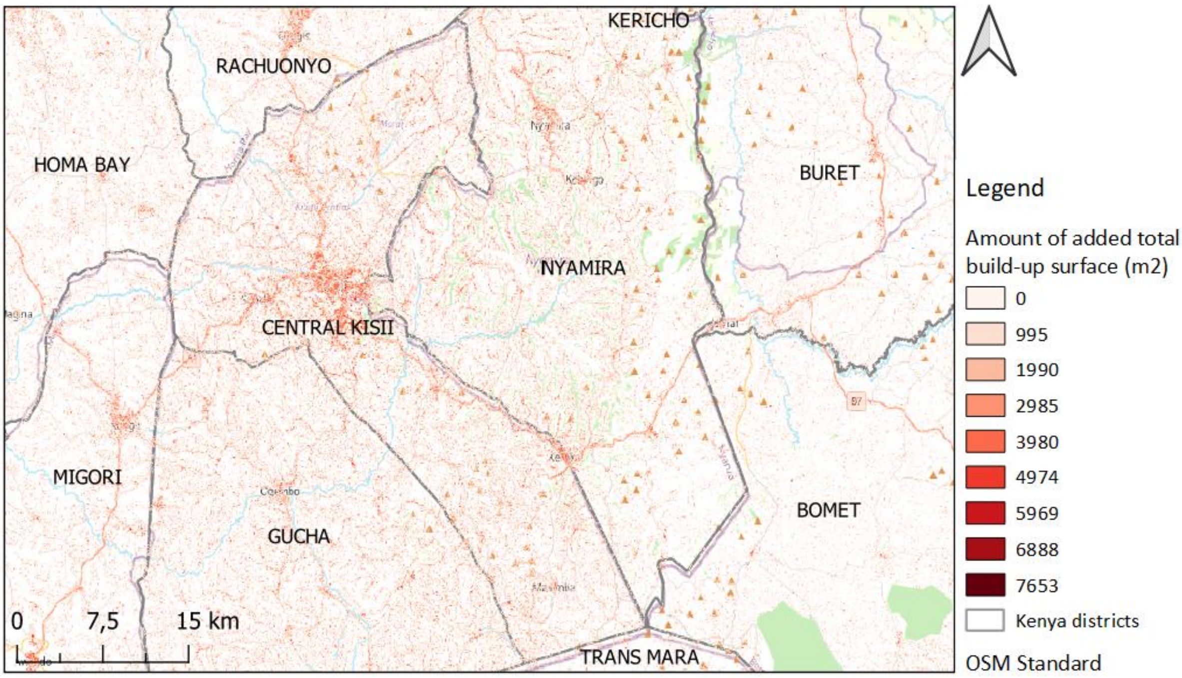

Figure 6: Map of the number of square meters change in total built-up surface in Central Kisii from 1990 to 2015.

It is clear from the maps that Nairobi has a very different growth in built-up surface than Kisii. This can also be described form Table 4 and 5.

Despite the fact that a significant portion of Kisii + Gucha's population is classified as rural, the data also indicates a considerable urban population. The data is from 2019 and therefore takes into account the increase in built-up surface. The built-up surface in this district compared to its total size suggests that it is experiencing a more dispersed form of urbanization. Figure 6 and Table 4 supports this finding which means that towns and smaller urban settlements are growing in number and expanding, resulting in a more spread-out pattern of urban development.

According to Table 5 Nairobi is entirely classified as urban, with the total population living in urban classified area. The NCPD report of 2012 also states that no area in Nairobi is classified as peri-urban. This distinguishes Nairobi from the second largest city in Kenya, Mombasa, where a small portion (approximately 2%) of the urban population is classified as peri-urban.

The differentiation between Nairobi and Kisii is significant because it indicates that any growth which occurred in built-up areas can be categorized as urban intensification and expansion for Nairobi, whereas this may not necessarily be the case for Kisii. For Kisii this could also mean that there was some growth in rural settlements next to growth of previous existing urban area.

This can also be concluded for the data analysis done in from the built-up surface. Areas such as Nairobi, Mombasa and Kiambu already had more built-up area in 1990 than other districts. So, the increase in built-up surface in those districts mostly occurred next to previously existing built-up surface, which indicates urban intensification. While other districts were more devoid of built-up surface and increased more in rural settlements.

Table 4: Urbanization in Kenya between 1948 and 2009 (NCPD, 2012)

Year	Total Population (x million)	No. of Urban Centers*	Urban Population (x million)	Percent of Urban to Total Population	Intercensal Growth Rate (%)
1948	5.41	17	0.29	5.3	-
1962	8.64	34	0.75	8.7	6.3
1969	10.96	47	1.08	9.8	7.1
1979	15.33	91	2.32	15.1	7.7
1989	21.45	139	3.88	18.1	5.2
1999	28.16	180	5.43	19.3	3.4
2009	38.41	230	12.02	31.3	8.3

* With a population of 2,000 and above.

Table 5: Distribution of population (Kenya National Bureau of Statistics, 2019)

District	Total population			Rural population			Urban population		
	Total (x million)	Land area (km²)	Density (person per km²)	Total (x million)	Land area (km²)	Density (person per km²)	Total (x million)	Land area (km²)	Density (person per km²)
Nairobi	4.40	704	6247	-	-	-	4.40	704	6247
Kisii + Gucha	1.27	1323	957	1.12	1284.0	869.0	0.15	40	3811
Vihiga	0.59	564	1047	0.53	537.0	991.0	0.06	27	2152
Mombasa	1.21	220	5495	-	-	-	1.21	220	5495

3.2 At the expense of which land covers does the increase in built-up surface in Kenya occur?

3.2.1 Amount of change area between 1990 and 2015 per threshold.

The number of added built-up surface between 1990 and 2015 is calculated at 1812 square kilometers in sub-question 1. As said in the method description, by not implementing a threshold to, the amount of area classified as built-up land is exceptionally larger than was concluded in sub-question 1. To assess the influence of various thresholds, multiple thresholds were experimented with, and the resulting built-up areas are documented in a Figure 7. Figure 7 highlights the impact of different thresholds on the classification of built-up surface, with higher thresholds resulting in smaller classified areas.

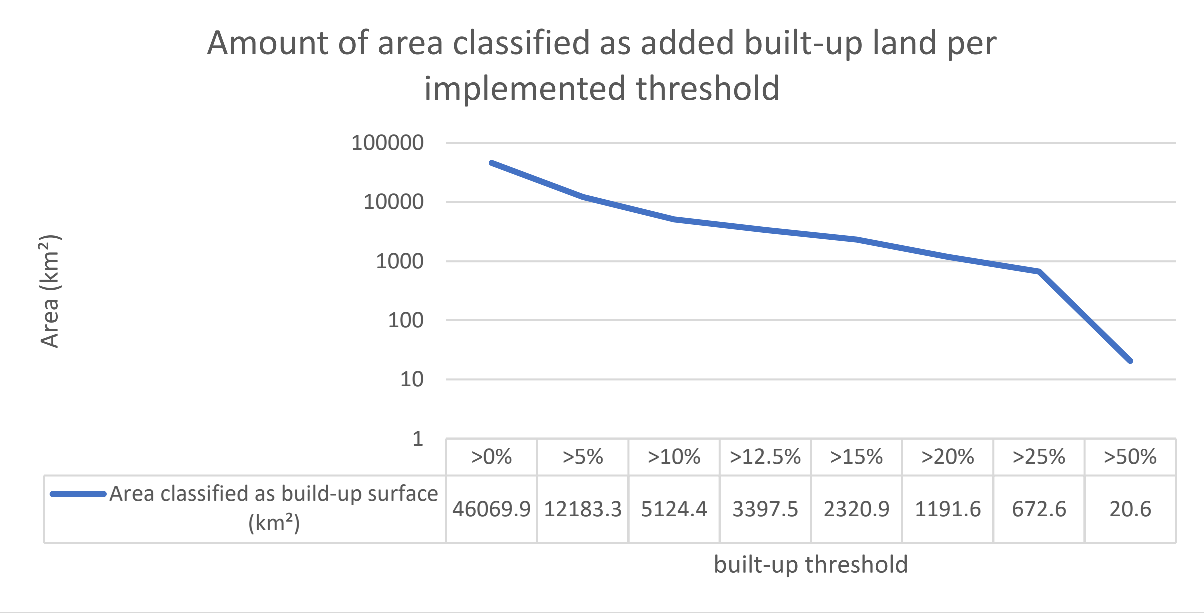

Figure 7: The impact of different thresholds on the extent of classified built-up area on a logarithmic y-axis.

3.2.2 Displaced land use due to built-up surface expansion per built-up threshold

Three thresholds, 10%, 15%, and 50%, were selected to depict the outcomes. The 15% threshold closely represents the actual increase in built-up area. Whereas the ten and fifty percent thresholds are chosen to see difference in low density development of possible rural areas and high-density development near large cities.

Figure 8 to 10 represents the proportion of land cover affected by displacement relative to the total affected area, taking into account a built-up surface threshold greater than ten. It specifically highlights land covers that make up more than 1% of the total share. The land cover types encompass a wide range of categories from the legend of the land cover map, but only the land cover types which were affected by the increase in built-up surface are listed.

Figure 8 show that with a threshold of ten percent, cropland rainfed was the most displaced land cover type accounting for 38.1% of the total conversion. Followed by herbaceous cover with 23.8%.

When comparing the blue and orange bars, it appears that a significant portion of cropland rainfed was converted into built-up surface despite representing a smaller overall percentage of the total land area. Conversely, 'shrubland (+deciduous)' that comprises a significant portion of land cover at 29.31%, only saw a moderate conversion rate of 5.57%. This comparison hints at the potential stress on certain land cover types.

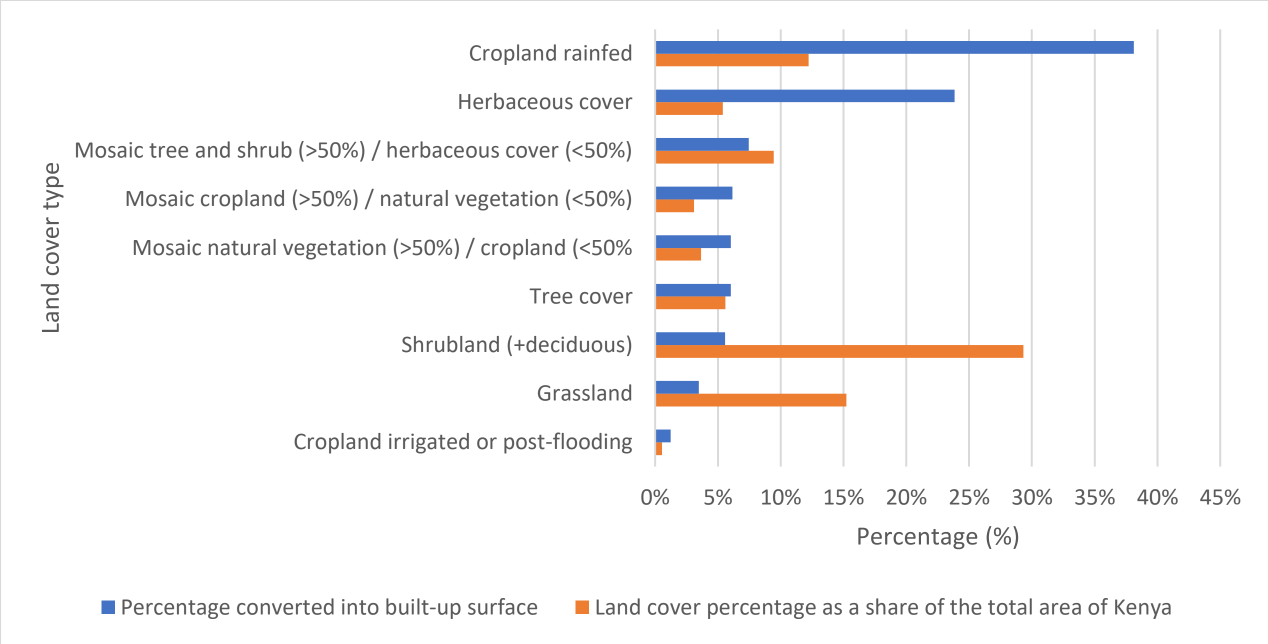

Figure 8: Blue: percentage of land cover affected by displacement compared to the total affected area, considering a built-up surface threshold greater than ten percent. The graph displays only the land covers that contribute more than 1% to the total share. A detailed table can be found in Appendix 3. Orange: percentage of land cover as a share of the total size of Kenya available in 2015.

In Figure 9 the threshold further increases to greater than 15%. Here, the land cover types that stand out in terms of impact are herbaceous cover at 22.3%, cropland rainfed at 33.0%, and mosaic tree and shrub (>50%) / herbaceous cover (<50%) at 9.6%. The top four places remain the same as in Figure 8. Some land cover categories, such as tree cover, have an equal percentage in terms of conversion into built-up areas and overall land cover in Kenya. Others, like the top two display significant discrepancy between these two metrics. But the same discrepancy goes for shrubland, grassland and mosaic herbaceous cover/ tree and shrub but then the other way around. This difference indicates uneven levels of development.

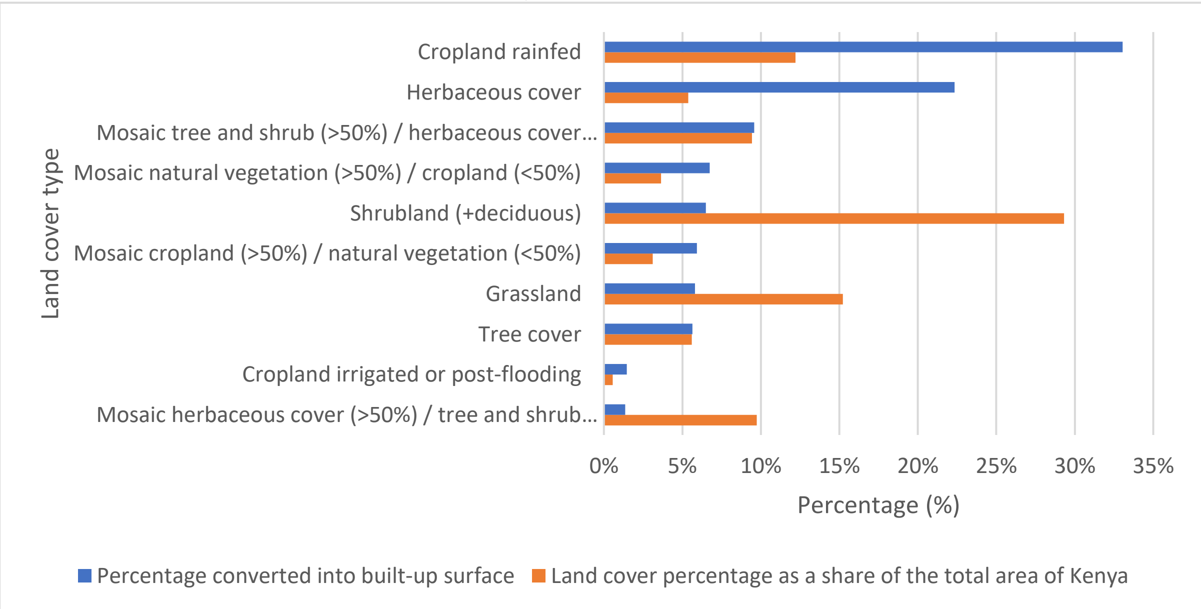

Figure 9: Blue: percentage of land cover affected by displacement compared to the total affected area, considering a built-up surface threshold greater than fifteen percent. The graph displays only the land covers that contribute more than 1% to the total share. A detailed table can be found in Appendix 4. Orange: percentage of land cover as a share of the total size of Kenya available in 2015.

Finally, in Figure 10, which considers a threshold greater than 50%, a different pattern is shown., The land cover types with the highest percentage are tied between grassland and mosaic tree and shrub (>50%) / herbaceous cover (<50%), which both display substantial displacement at 20.3%. Followed by cropland rainfed at 17.4%, and next by shrubland (+deciduous) at 9.24% and herbaceous cover at 9.1%. This suggests that when using an extremely high threshold, indicating higher intensity development, the displacement mainly affects these specific land cover types. Compared to Figure 8 and 9, the discrepancies are not as big, except a few outliers.

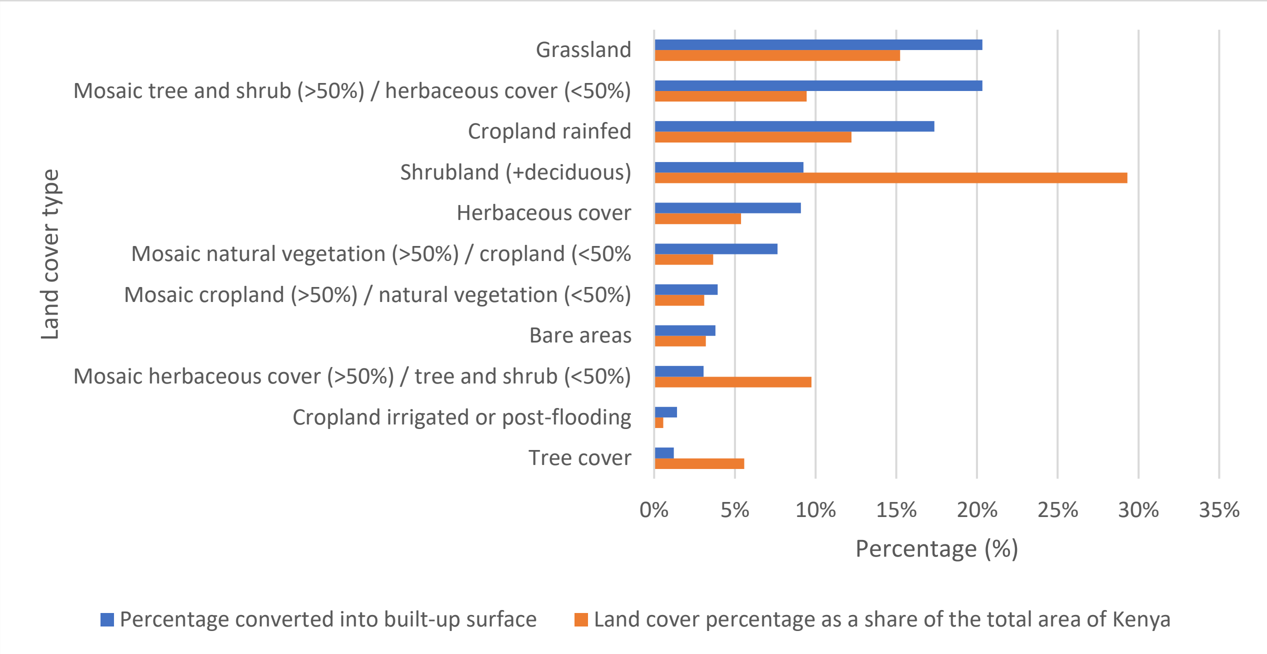

Figure 10: Blue: percentage of land cover affected by displacement compared to the total affected area, considering a built-up surface threshold greater than fifty percent. The graph displays only the land covers that contribute more than 1% to the total share. Orange: the A detailed table can be found in Appendix 5. Orange: percentage of land cover as a share of the total size of Kenya available in 2015.

3.3 What are the drivers behind land cover change and urbanization in Kenya?

3.3.1 (Urban) population growth

The drivers behind land use change and urbanization in Kenya can be attributed to various factors. Over the years, Kenya has experienced significant population growth and urbanization rates. From 1963 to 2006, the population grew at a rate of 3%, accompanied by a rapid urbanization rate of 6% during the same period (Mireri, 2006). Urban centers also witnessed substantial growth, increasing from 7.8% in 1962 to 27% in 1999 (Mireri, 2006).

According to World Bank Open Data, the population of Kenya expanded from 23.2 million in 1990 to 46.9 million in 2015, representing a growth rate of approximately 102.2%. On an annual basis, this translates to an average population growth of around 4% (n.d.). High fertility rates have been a significant driver of rapid population growth in Kenya. In 2009, the fertility rate was 4.4 births per woman, but it is expected to decrease to 2.6 by 2030. Throughout history Kenya has always experienced high fertility rates, being 8.1 in the 1980’s (NCPD, 2013).

The urban population in Kenya has witnessed a remarkable increase over time. During Kenya's independence in 1963, the number of residents in urban areas accounted for only eight percent. However, over the years, this share witnessed a steady rise, reaching 19 percent in 1999, 31 percent in 2009, and approximately 34 percent in 2011 (NCPD, 2013).

Additionally, UN-HABITAT reports that Kenya's urban growth rate from 2015 to 2020 stood at 4.2% (n.d.). This growth is further exemplified by the urban population, which reached 28.5 % in 2021 (Macrotrends & World Bank, n.d.) (Figure 11). It is expected that by 2050 over 50% of the total population will be living in urban areas, emphasizing the ongoing process of urbanization in the country (UNHABITAT, n.d.).

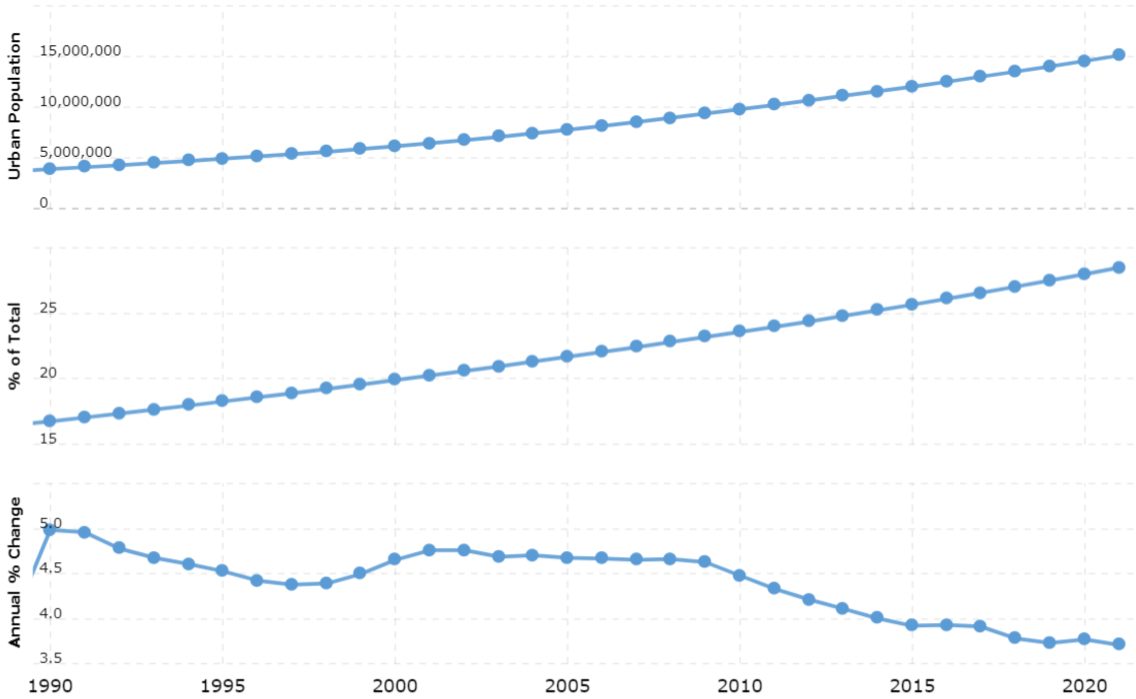

Figure 11: Kenya urban population between 1990 and 2023.

Such substantial population growth and urbanization have resulted in significant structural changes in urban development (Mireri, 2006). However, they can also lead to adverse environmental impacts. The rapid increase in population, if not accompanied by proportional expansion of natural resource opportunities, can undermine per capita shares, and have negative effects on economic growth and employment (Mireri, 2006).

Furthermore, the population trends in certain rural areas of Kenya, including Kiambu, Kakamega, Vihiga, Kisii, and Kisumu counties, have led to higher population densities, surpassing five hundred persons per square kilometer, compared to the national average (NCPD, 2013). Figure 12 also shows the population distribution in Kenya and highlights the urban areas with the most population. When compared to Figure 3

the two figures follow the same pattern, with most added built-up surface in the same places with the most population mainly in the southwest and on the Indian Ocean coast. These population trends in specific regions contribute to the overall land use change and urbanization patterns observed in Kenya.

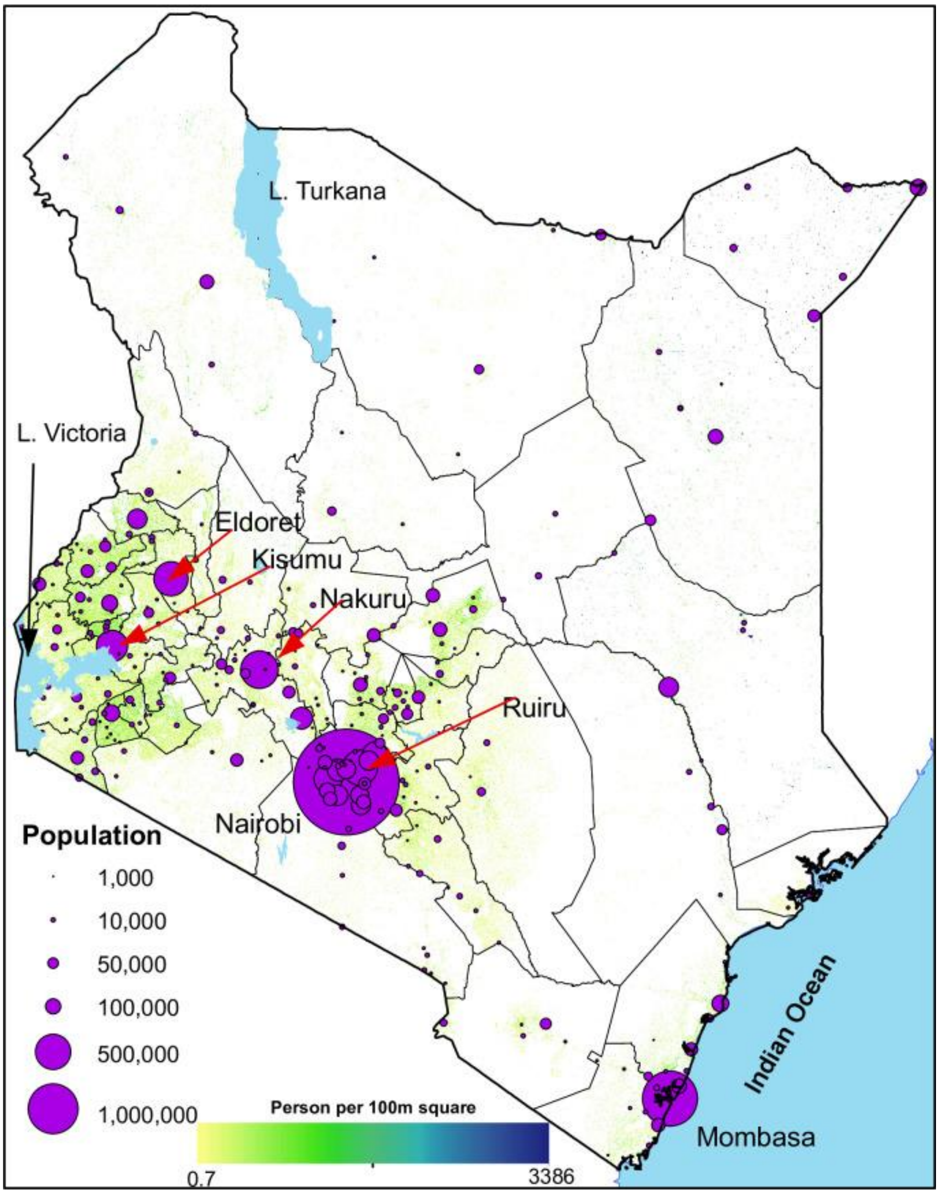

Figure 12: Population in relation to the size of urban area (Macharia et al, 2021)

3.1.2 Relation built-up land expansion and population growth

The increasing linear trendline in Figure 13 suggests that as the total built-up surface grows, the total population also tends to increase. This indicates that there is a relationship between the expansion of built-up areas and population growth. In other words, as the built-up surface area expands, it can accommodate and attract more people. But in this case the other way around is also true,

The positive correlation could be attributed to factors such as urbanization, economic development, and infrastructure expansion. As the built-up surface area grows, it provides more housing, commercial spaces, and amenities, which can attract people and drive population growth.

The outlier with the highest population growth is Nairobi, and the one with the biggest built-up surface increase is Nakuru, in accordance with Table 2.

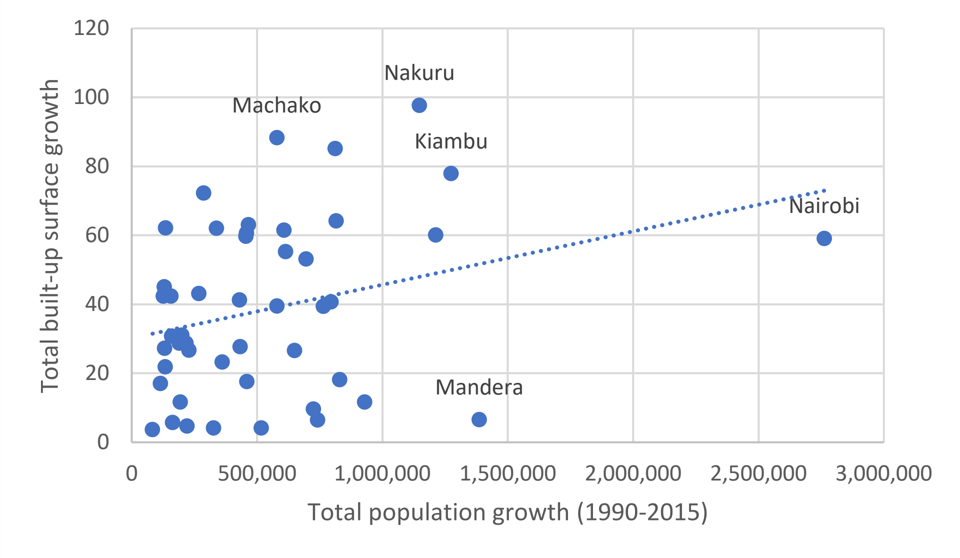

Figure 13: The relation between total square kilometers built-up surface increase per county and the total population increase between 1990 and 2015, which was interpolated and extrapolated from the population data of 1999, 2009 and 2019 (NCPS, 2013).

Figure 14 shows the difference between the relative population and built-up surface growth. This indicated that while the population more than doubled and grew with 102%, the amount of built-up surface grew disproportionate with 639%.

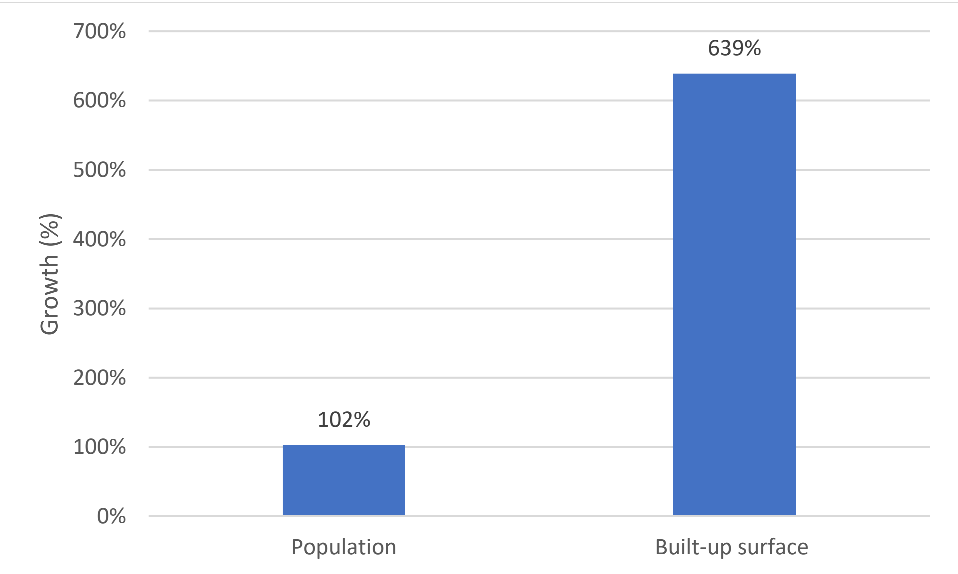

Figure 14: comparison of the relative increase in population and the relative increase in built-up surface in Kenya.

3.3.2 Growth of urban centers

In addition to the motivations behind individuals relocating to urban areas, there are additional elements that contribute to the ongoing expansion and progress of cities in Kenya. factors play a crucial role in attracting people to urban centers. Each city has its own unique factors that contribute to its growth. Some examples include having easy access to reliable transportation networks, a strong economy, a surrounding area with abundant resources, improved infrastructure, and services, and providing various employment opportunities (NCPD, 2013)

The shift from rural to urban civilizations is greatly aided by smaller cities or towns, generally with populations under 500,000. They act as crucial hubs at this time. However, extremely big cities with populations more than five million provide important benefits known as agglomeration economies. These advantages result from the concentration of different companies, which creates network effects that boost productivity and stimulate innovation. Additionally, big cities provide both individuals and corporations a wealth of economic prospects (Rueda-Sabater, 2021). But these smaller towns can have its upsides, mostly to lower poverty rate and they can also provide better surroundings to reside and work (Rodríguez-Pose & Griffiths, 2021).

According to the Kenya National Bureau of Statistics report, there has been a consistent increase in both the population and number of small (population between 2000 and 9999) and medium-sized urban centers from 1962 to 2009. This trend is expected to continue in the future. The report also concludes that the majority of urban centers in Kenya are typically categorized as small or medium in size. Furthermore, since gaining independence, Kenya has witnessed the establishment of its first city with a population exceeding one million. Additionally, between 1999 and 2009, the number of urban centers with a population between 100,000 and 999,999 experienced a significant increase, rising from four centers to twenty-two centers (2012).

The number of urban areas has also increased with 43 percent between 2009 and 2019 and rose therefor to 307 centers. Macharia et al. states that this can be mostly explained by natural increase and rural to urban migration. Next to that, the number of urban centers with a population bigger than 100.000 inhabitants increased with 57 percent (Njoka, et al. 2016).

Figure 12 shows the most densely populated urban areas worldwide, while the Figure 15 specifically highlights the urban centers within Kenya based on the population statistics from 2019. These maps reveal a significant overlap, indicating that the areas with the highest population concentrations in Kenya align with locations this a high number in urban centers and highest increase in built-up surface (Figure 3) and therefore the broader global trend of densely populated urban regions (Macharia et al, 2021).

The NCPD mention in their report that small to medium-sized urban areas will persist in their growth as seen in Table 4 and accommodate a growing share of the urban population, while major urban centers are likely to extend into neighboring urban areas just as is seen in Nairobi. (2013)

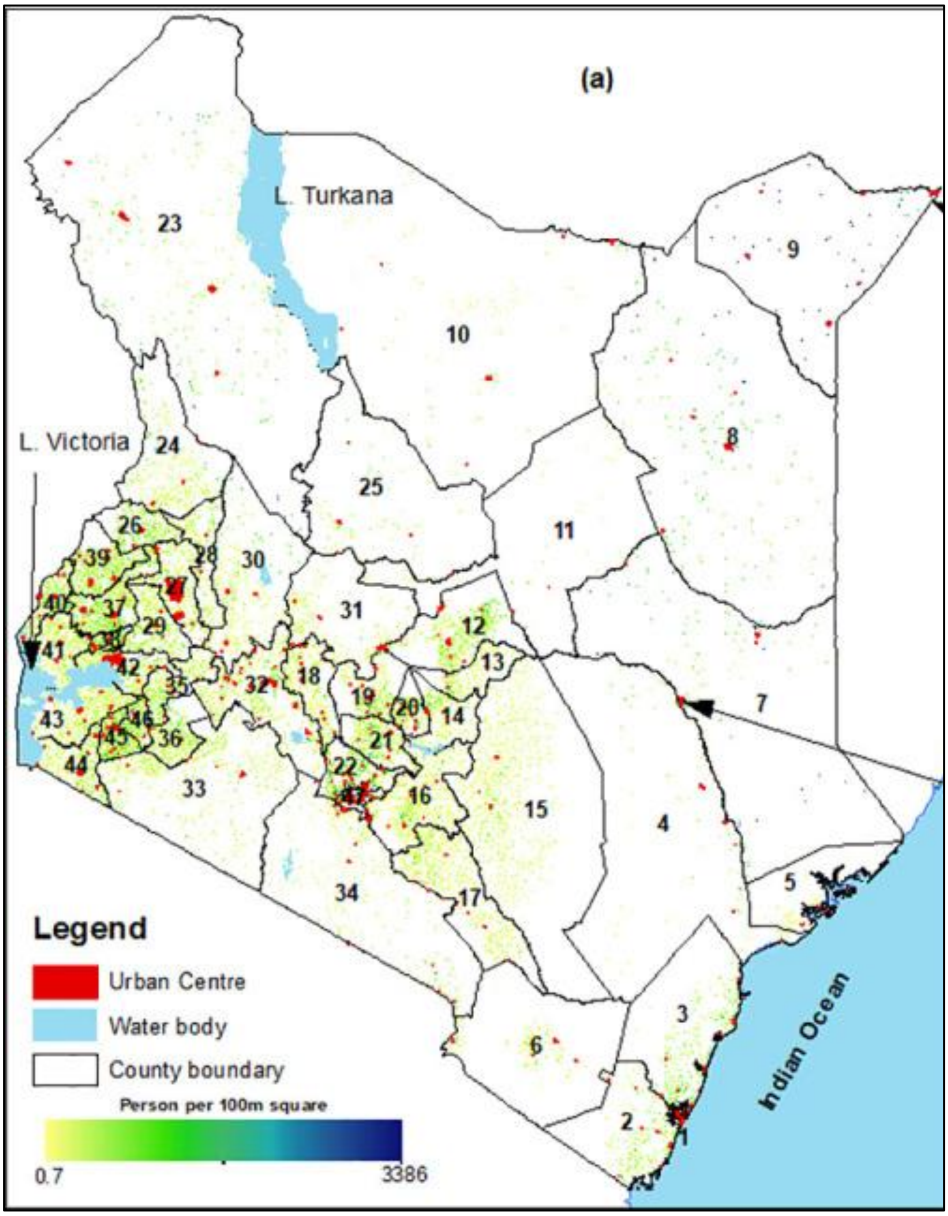

Figure 15: Urban centers in Kenya marked with red for the 2019 population census. Districts: Mombasa 1, VIhiga 38, Kisumu 42, Kisii 45, Nairbobi 47 (Macharia et al, 2021).

3.3.3 Rural-urban migration

The phenomenon of rural to urban migration is a significant driver of urbanization in Kenya, influenced by rapid population growth rates (NCPD, 2013). Urban centers are perceived to offer greater prospects in terms of employment and services (Mireri, 2006). This migration occurs as individuals seek better economic opportunities, improved services, and an enhanced quality of life, leading to the expansion of urban areas (Khan et al., 2014).

Following Kenya's independence in 1962, the removal of colonial policies that restricted internal migration led to an upsurge in internal migration within the country. Rural residents were drawn to urban areas by the prospects of improved, employment opportunities, social services and other benefits for themselves and their families. This sparked a migration culture that persists in modern-day Kenya, with the youth comprising a significant portion of the migratory population (Oucho, 2020).

A comparative analysis between the map layer containing land cover data and the map illustrating the increase in built-up surface highlights certain geographical trends. Specifically, regions in the southwest displaying an increase in built-up surface of more than 0.71% predominantly comprise cropland rainfed. This aligns with the widely dispersed increase in built-up surfaces observed, primarily associated with emerging or expanding rural settlements located on agricultural land.

In contrast, other regions of Kenya have minimal to no cropland rainfed and are largely characterized by shrubland and grassland. The districts with little built-up surface in 1990 mostly in the north and east of Kenya each hosts a relatively small urban center, typically located at the intersection of major roads or near rivers. These urban centers have also seen increase in built-up surface, but also new urban was formed in these districts. This pattern suggests a dual phenomenon of urban land intensification and expansion, coupled with the formation or growth of rural settlements. Hence, both urban and rural landscapes are evolving, signifying a dynamic land use pattern across Kenya.

Rural to urban migration has been a common occurrence since the era of colonization, as migrants were drawn to cities in search of employment and better access to social services (UNESCO, 2016). Given the absence of a comprehensive internal migration policy in Kenya, it becomes imperative to incorporate migration into broader development planning and policies (NCPD, 2013). This historical trend continues to shape the urbanization process in Kenya, contributing to land use changes and the expansion of urban areas (UNESCO, 2016).

3.3.4 Economic development

Economic development is a key driver of urbanization and urban expansion. Population growth and development are interconnected, with economic development generating resources for improving education and health. These improvements can lead to lower and mortality and fertility rates. The paradox of this is, that high population growth can strain investment resources, hindering progress in education, health, poverty reduction, and other areas. Challenges such as housing shortages, employment issues, and social unrest arise from a growing population. Comprehensive strategies are needed to address these concerns and promote sustainable development (NCPD, 2013).

Multiple studies have shown a strong correlation between economic growth, demography, and urban land expansion. Thapa & Murayama (2010) and Zhang et al. (2014) highlight the role of economic growth and demographic factors in driving urban land expansion. According to Mahtta et al. (2022), Africa is characterized by a cluster of cities experiencing urban land expansion at a higher rate than the GDP per capita.

While urbanization initially may have a positive impact on economic growth, there is a threshold beyond which this impact may diminish, as noted by Shaban et al. (2022). This can be attributed to the shifting of industries to peripheral regions and more favorable infrastructure development in rural areas (Shaban et al., 2022). However, Nairobi stands as a testament to the economic significance of urban areas, contributing over 50% to Kenya's GDP (County Nairobi City, 2014).

The phenomenon of younger generations migrating from rural to urban areas is significant, particularly in lower and middle-income countries. Africa exemplifies this trend, with a substantial influx of individuals relocating in search of employment opportunities. This has led to a remarkable increase in the urban population across the continent. Nairobi serves as a prominent example of this migration, experiencing rapid population growth and expanding geographical boundaries (NASA Earth Observatory, n.d.).

In conclusion, process of urbanization in Africa is closely linked to economic advancement, but its rapid pace can pose challenges without a simultaneous transformation of the economy to create sufficient employment opportunities (NCPD, 2013).

3.3.5 Infrastructure

Infrastructure plays a crucial role in driving land use change and urbanization in Kenya. Urban centers in the country serve as major educational hubs, with higher literacy rates and school completion rates, particularly in primary education (Tacoli et al., 2015; UNICEF, 2019; Munene, 2002). Additionally, a majority of universities in Kenya are located in urban centers, emphasizing their significance as educational and knowledge centers (Tacoli et al., 2015; UNICEF, 2019; Munene, 2002).

Urban centers in Kenya benefit from significant investments in infrastructure, including airports, highways, and power grids, improving transportation and communication networks (UNICEF, 2019). This facilitates trade, making urban areas important agricultural trading hubs and enhancing food security (Frelat et al., 2015; Schmitz et al., 2012). Financial institutions like banks are abundant in urban centers, providing business loans (UNICEF, 2019). With most major headquarters and government facilities are in urban areas (Weiss et al., 2015; Munene, 2002; Government of Kenya (GoK), 2012), employment opportunities are more abundant, attracting rural-to-urban migration for better livelihoods (Darrouzet-Nardi & Masters, 2015).

Infrastructure disparities between cities and rural areas in Africa are evident in the varying levels of access to essential services such as piped water, electricity, and telecommunications networks. The greatest contrast is observed in terms of electricity provision (OECD et al., 2022). The gap between rural areas and cities, is much larger than the gap between small and large cities (Figure 16).

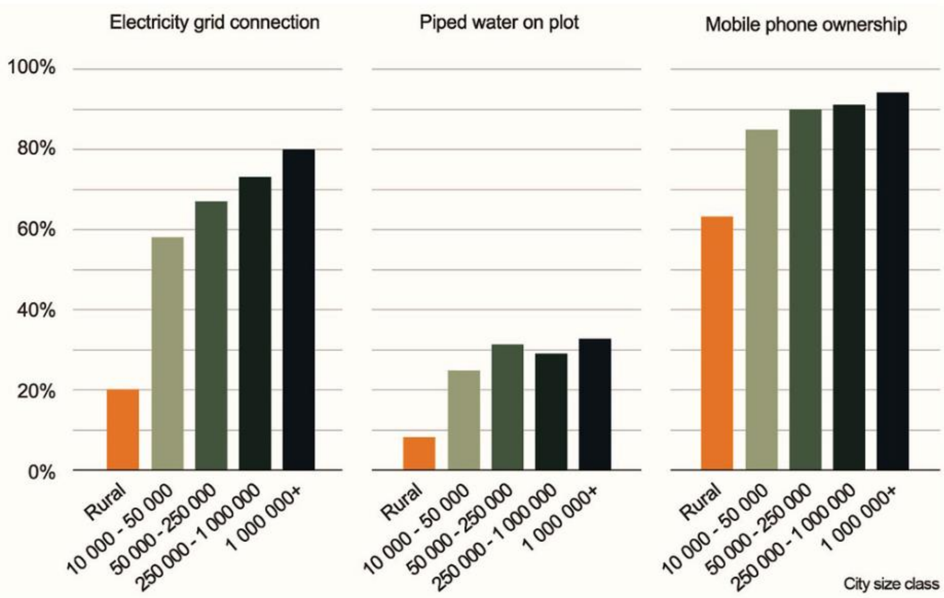

Figure 16: Access to public utilities based on surveys in different countries in Africa. It demonstrates the overall distinctions between rural areas and cities of varying sizes. (OECD et al, 2022)

The growth of urban areas is driven by the construction of transportation infrastructure such as roads and railways, as well as the emergence of urban amenities. However, this rapid growth has strained the cities' existing infrastructure and services. As a result, there are numerous crowded and informal settlements lacking proper facilities such as sewage systems, clean water, and adequate housing. This situation has contributed to increased poverty and social problems (NCPD, 2013).

3.3.6 Government, policies, and investments

Nairobi City is increasingly facing threats from congestion and decay due to the fast urbanization, poor management, inadequate planning, and illegal land use. The 1948 Master Plan aimed to create neighborhoods with ample public open spaces. However, after Kenya gained independence in 1963, the Master Plan was mostly disregarded. The rapid urbanization that followed has led to public open spaces originally intended for 250,000 people now being strained by a population of over three million. As a result, these areas have experienced negative effects, including limited recreational opportunities and inadequate leisure facilities for city residents (Makworo & Mireri, 2011).

Over the years, Nairobi has been subjected to several master plans, but their implementation and impact have been limited, both at the local and national levels. Unfortunately, none of the plans accurately predicted the speed and direction of peri-urban growth, despite the emerging ground realities over time (County, Nairobi City, 2014). Consequently, investment decisions related to urban infrastructure, social housing, and spatial aspects of urban economic development began to contradict the actual spatial dynamics of urban growth. It seems that very few lessons have been learned from these past mistakes (UN-HABITAT, 2008).

Unregulated urbanization has given rise to unplanned land use, informal settlements, housing shortages, and uncontrolled growth in residential and commercial areas, contributing to various challenges such as waste management, air pollution, and infrastructure development in Kenyan urban environments (Nyongesa et al., 2022; Kiboi et al., 2014).

To tackle these challenges and cater to the growing population, it is essential to have efficient administration and thoughtful strategizing in place (NCPD, 2013). Although migration and urbanization offer prospects for socio-economic progress, as well as resource optimization, their unanticipated and unstructured occurrence can lead to significant political and economic disruptions. Ensuring effective governance is essential to manage these processes and minimize their negative effects (NCPD, 2013).

4. Discussion

While various sources provide information on population growth, urbanization rates, and the growth of urban centers, there is a significant lack of sources quantifying the increase in built-up surface in the districts of Kenya (UN-HABITAT, 2008; Mireri, 2006; NCPD, 2013; World Bank Open Data, n.d; (Macrotrends & World Bank, n.d.). This research addresses this knowledge gap by providing a comprehensive analysis of the precise amounts of land cover converted into built-up surface and at with expense this happened.

The findings reveal a substantial growth of 639% increase in built-up areas in Kenya between 1990 and 2015, indicating the expansion of both residential and non-residential land uses. Notably, Nairobi experienced the largest increase in built-up surface, represented as a percentage of the district's overall area, which is consistent with its status as the dominant metropole of the country. (Mireri, 2006).

The examination of land conversion patterns complements the existing literature. The conversion of land cover into built-up surface is predominantly observed in cropland rainfed areas, supporting the notion that urban expansion often takes place on agricultural land (D'Amour et al., 2017). Additionally, it is common for urbanization to occur on forest and vegetation land cover as well (Chakraborty et al., 2022). The GHSL layer also has problems with over and underestimation in high and low dense areas, according to research form Lui et al (2021)

According to available evidence, it is observed that in Kenya, as population density rises, landholding sizes and cultivated areas tend to diminish. This trend is particularly evident among smallholders in densely populated regions, raising concerns about the future availability of land for small-scale farming. Additionally, the rapid population growth in Kenya has led to the conversion of agricultural land into settlements in various counties. This conversion is a consequence of the increasing population and has resulted in land fragmentation (NCPD, 2018).

But while the results conclude the increase in built-up surface mostly happened on cropland rainfed, the land cover data suggests that between 1990 and 2015 the amount of cropland rainfed land area has with 0.20% (Appendix 6). While it was other landcovers such as bare land and certain tree covers did decline. This is because of the big interplay between the conversing of land covers. Next to that the amount of cropland, which was conversed into built-up land, is also relatively small compared to the total amount of cropland (Figure 9 till 10)

The thresholds which were implemented to calculate the land cover conversion affects the spatial patterns and distribution of the classified built-up areas. A lower threshold may result in more fragmented and dispersed built-up areas, reflecting incremental or scattered urban expansion. In contrast, a higher threshold tends to generate larger, more cohesive built-up areas, representing more concentrated or prominent urbanization patterns.

A lower threshold increases the sensitivity to smaller changes, allowing for the detection of subtle built-up surface increase, but this can result in an extremely larger classified area which may also include more noise or false positives.

The drivers behind land use change and urbanization in Kenya include urban population growth, rural-urban migration, economic development, and infrastructure development. These factors contribute to socio-economic progress but can also lead to political and economic disruptions if not managed effectively.

That Nairobi had the biggest increase in built-up surface as a share of the total district area, but not the biggest absolute increase is also not an unexpected result. As Nairobi is the dominant city in the Kenya also well before 1990. But its size is relatively smaller that most other districts.

Figure 5 illustrates that the increase in built-up surface was more concentrated around existing urban areas rather than being widespread. This pattern is consistent with the typical formation of new urban areas adjacent to established urban centers (Chakraborty et al., 2022). Nairobi and Mombasa, as prominent cities with substantial existing built-up areas, experienced intensified growth in their built-up surface (Mireri, 2006).

Shortcomings

The GHS-BUILT-S dataset, which depicts the distribution of built-up surfaces between 1975 and 2030, has some limitations that need to be considered. The data used for analysis oof the built-up surface in Kenya, classifies all area which looks built-up as built-up surface. Although this is mostly residential and non-residential are, it may happen that slums and rocks are also classified as built-up surface which may impact the amount of actual built-up surface

Van Den Hoek & Friedrich mention in their paper that satellite settlement layers often focus on bigger urban centers and not so much on rural settlements which covers a lot of population therefore, the small settlements particularly in the global south are often not well mapped (2021). Next to that recent small settlements are also not visualized well and the building areas which are a significant factor to the built-up layer are often underestimated (Van Den Hoek & Friedrich, 2021).

Another limitation is the use of Landsat satellite imagery, which has inherent constraints such as cloud cover, sensor resolution, and potential inaccuracies in land cover interpretation and classification. These limitations can impact the accuracy and precision of the built-up surface estimates, particularly in areas with complex land cover patterns or small-scale urban developments

When working with the Global annual LC maps there are several potential shortcomings to consider. The most important one is the spatial resolution of the maps. While the built-up surface map has a resolution of one hundred meters the land cover map has a resolution of three hundred meters. The relatively coarse spatial resolution can limit the ability to capture fine-scale details and variations in land cover. This can be a challenge when analyzing specific regions or studying localized land cover changes. So, when analyzing the land cover conversion into built-up surface at a higher threshold, which means detailed areas the coarse resolution may impact the results.

Another potential shortcoming to consider is the possibility of small GIS inconsistencies that may arise during the data analysis process. These inconsistencies can occur due to variations in data sources, data collection methods, or data processing techniques. For example, there may be slight differences in the total area (in square kilometers) attributed to each district within the GIS analysis, which could impact the accuracy of the results. Also, reprojection and changing resolution can introduce spatial inaccuracies in the data. The transformed data may not align perfectly with the original data or may have slight distortions, affecting the accuracy of spatial analysis and interpretation.

The analysis primarily focused on the expense of urban expansion, with cropland being the primary victim. However, it appears that no cropland has been lost (Appendix 6). As said before, it is possible that other land cover areas were converted to cropland to compensate for the loss, as noted in East Africa (Bullock et al., 2018). Bullock et al concluded in their research that between 1998 and 2017 East Asia has seen and 35 percent in cropland area in East Africa. Future research should consider these dynamics to gain a more comprehensive understanding of land use changes and their impacts on sustainable development.

In conclusion, while the research contributes to understanding urban expansion in Kenya, it is crucial to recognize the limitations of the data and methodology used. These limitations include the classification of built-up surface, satellite imagery constraints, threshold selection, and potential GIS inconsistencies. Considering these limitations, further research and analysis can provide a more comprehensive understanding of urban expansion dynamics and support informed decision-making for sustainable urban development in Kenya.

5. Conclusion

In conclusion, the urban land expansion patterns in Kenya between 1990 and 2015 were characterized by a significant increase in built-up surface. The built-up surface in Kenya experienced a remarkable growth, with a relative increase of 639% between 1990 and 2015. This expansion resulted in the built-up surface expanding from 283.6 km^2 in 1990 to an extensive 2095.7 km^2 by 2015. Notably, Nairobi and Central Kishii witnessed the highest increase in built-up surface, expressed as a proportion of the district's total size. However, this expansion came at the expense of cropland rainfed and herbaceous land cover. Conversely, areas experiencing the most significant increase in built-up, as identified through a high threshold, mainly displaced grassland and mosaic tree and shrub/herbaceous cover.

Figures 3, 12, 13, and 15 depict the correlation between increased built-up surface, population growth, and the expansion of urban centers in southeast Kenya. A comparative map analysis reveals that along with urban expansion and intensification near existing centers, there's significant built-up growth in rural agricultural areas, indicating a more dispersed pattern. Even districts in the north and east with less built-up surface show new urban centers' emergence and growth, suggesting dynamic urban and rural landscape evolution across Kenya.

It is evident that Kenya's urban expansion is primarily driven by the country's substantial population growth, fueled by high fertility rates. The economic advantage, opportunities, infrastructure, and facilities offered by larger urban areas further attract an influx of people. Paradoxically, this rapid urbanization has led to a decline in the quality of living, particularly in major urban centers like Nairobi, due to pollution and poor living conditions. To ensure a sustainable future for Kenya, it is imperative to consider the predominantly urban population and prioritize high-quality living standards in future planning efforts. The demand for urban land is significantly influenced by population and employment growth, further emphasizing the drivers behind urban land expansion in Kenya. The results contribute to a better understanding of urban expansion patterns can inform policymakers and urban planners in making informed decisions regarding sustainable land management and urban development strategies

Recommendations

In a possible further research, the relative contribution of several factors to urban expansion could be analyzed through a statistical analysis. This could give insight into the relation and the significance of several factors such to the development of new built-up area.

To improve the accuracy of land cover classification and built-up area detection, future studies could employ higher resolution satellite data. These data sources may offer better detail and accuracy, especially in areas with small-scale urban development or complex land cover patterns.

Next to that, incorporating machine learning techniques for land cover classification could potentially increase the accuracy of identifying built-up areas. This approach could be especially useful in areas where the landscape is complex or where built-up areas are rapidly changing.

As this thesis showed that urban expansion is predominantly occurring at the expense of cropland rainfed and grasslands. More research could be done to further understand the socio-economic and environmental implications of these land use conversions. This could include studies into changes in local livelihoods, agricultural productivity, and biodiversity.

Lastly, a comparative analysis with other countries in the East African region could be beneficial. It would provide a broader perspective on the processes, drivers, and effects of urban expansion, which might help in the formulation of regional policies and strategies.

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8. Appendix

Appendix 1: District-wise analysis of built-up surface increase in Kenya (1990-2015)

District	Area district (km^2)	Added built-up surface between 1990-2015 (km^2)	Relative added built up surface (%)
BARINGO	8626.96	13.39	0.16%
BOMET	1432.27	29.17	2.04%
BONDO	980.38	20.09	2.05%
BUNGOMA	2058.08	54.77	2.66%
BURET	1393.71	13.17	0.95%
BUSIA	1117.18	31.15	2.79%
BUTERE/MUMIAS	934.92	29.66	3.17%
CENTRAL KISII	646.63	34.48	5.33%
EMBU	729.95	14.63	2.00%
GARISSA	44676.24	11.11	0.02%
GUCHA	657.35	28.62	4.35%
HOMA BAY	1148.86	24.61	2.14%
ISIOLO	25369.41	4.12	0.02%
KAJIADO	21891.05	31.57	0.14%
KAKAMEGA	1388.49	39.63	2.85%
KEIYO	1434.15	10.13	0.71%
KERICHO	2104.95	26.59	1.26%
KIAMBU	1311.97	35.78	2.73%
KILIFI	4781.80	25.21	0.53%
KIRINYAGA	1475.48	28.83	1.95%
KISUMU	915.79	34.39	3.76%
KITUI	20464.62	38.73	0.19%
KOIBATEK	2304.41	10.82	0.47%
KURIA	580.96	14.30	2.46%
KWALE	8258.63	28.02	0.34%
LAIKIPIA	9472.82	26.46	0.28%
LAMU	6169.72	3.87	0.06%
LUGARI	667.40	16.02	2.40%
MACHAKOS	6226.59	88.12	1.42%
MAKUENI	7997.23	72.34	0.90%
MALINDI	7758.46	14.70	0.19%
MANDERA	25981.95	6.52	0.03%
MARAGUA	865.54	26.81	3.10%
MARAKWET	1580.58	7.89	0.50%
MARSABIT	61423.95	2.92	0.00%
MBEERE	2092.91	13.97	0.67%
MERU CENTRAL	2985.74	34.70	1.16%
MERU NORTH	3955.61	26.86	0.68%
MERU SOUTH	1085.36	13.30	1.23%
MIGORI	1993.64	41.18	2.07%
MOMBASA	228.88	9.78	4.27%

MOYALE	9596.33	1.26	0.01%
MT ELGON	939.48	5.21	0.55%
MURANGA	933.12	20.80	2.23%
MWINGI	10096.15	21.87	0.22%
NAIROBI	695.33	58.88	8.47%
NAKURU	7467.43	98.16	1.31%
NANDI	2862.95	41.23	1.44%
NAROK	15065.75	23.96	0.16%
NYAMIRA	892.87	31.06	3.48%
NYANDARUA	3272.48	42.57	1.30%
NYANDO	1163.45	25.14	2.16%
NYERI	3339.51	42.46	1.27%
RACHUONYO	936.94	27.85	2.97%
SAMBURU	21066.58	4.72	0.02%
SIAYA	1514.12	41.97	2.77%
SUBA	1046.78	11.12	1.06%
TAITA TAVETA	17119.99	17.02	0.10%
TANA RIVER	38244.77	6.33	0.02%
TESO	556.32	14.29	2.57%
THARAKA	1559.72	8.70	0.56%
THIKA	1961.24	55.68	2.84%
TRANS MARA	2835.22	17.73	0.63%
TRANS NZOIA	2474.69	39.49	1.60%
TURKANA	68158.13	11.74	0.02%
UASIN GISHU	3340.61	52.82	1.58%
VIHIGA	560.14	27.45	4.90%
WAJIR	56724.12	6.57	0.01%
WEST POKOT	9069.64	17.66	0.19%
Total	**580664.48**	**1812.13**	

Appendix 2: Area with no urban in 1990, but experienced change into urban in 2015 (km²) and the percentage change.

District	Area district (km²)	Area with no urban in 1990, but experienced change into urban in 2015 (km²)	Area experienced change in built-up surface (km²)	Percentage changed which was first not urban (%)
BARINGO	8684.78	692.04	699.69	99%
BOMET	1441.68	595.49	853.24	70%
BONDO	986.74	462.1	473.73	98%
BUNGOMA	2072.18	1179.5	1228.48	96%
BURET	1403.01	279.87	369.15	76%
BUSIA	1124.54	532.92	578.23	92%
BUTERE/MUMIAS	941.19	568.09	587.82	97%
CENTRAL KISII	651.14	422.81	468.01	90%
EMBU	735.08	201.06	294.06	68%

GARISSA	44973.11	227.31	250.8	91%
GUCHA	661.74	388.56	457.9	85%
HOMA BAY	1156.54	560.69	572.38	98%
ISIOLO	25540.7	132.36	136.11	97%
KAJIADO	22038.68	1108.35	1149.58	96%
KAKAMEGA	1397.89	760.94	777.07	98%
KEIYO	1443.71	320.25	327.05	98%
KERICHO	2119.31	711.04	735.38	97%
KIAMBU	1320.74	332.82	523.28	64%
KILIFI	4813.65	646.53	735.17	88%
KIRINYAGA	1485.3	405.14	572.36	71%
KISUMU	921.92	439.44	482.62	91%
KITUI	20602.58	1526.11	1703.77	90%
KOIBATEK	2319.81	404.92	406.7	100%
KURIA	584.86	245.87	284.86	86%
KWALE	8314.55	899.7	967.87	93%
LAIKIPIA	9536.92	888.86	894.65	99%
LAMU	6211.2	185.92	197.3	94%
LUGARI	672.54	342.88	344.3	100%
MACHAKOS	6268.29	2249.99	2320.87	97%
MAKUENI	8050.91	2272.24	2338.14	97%
MALINDI	7810.61	351.91	405.52	87%
MANDERA	26155.51	170.87	187.74	91%
MARAGUA	871.4	341.76	416.08	82%
MARAKWET	1591.38	230.85	311.18	74%
MARSABIT	61835.19	142.37	156.09	91%
MBEERE	2107.08	626.29	645.72	97%
MERU CENTRAL	3005.94	585.61	774.64	76%
MERU NORTH	3982.03	576.73	726.2	79%
MERU SOUTH	1092.53	256.72	331.97	77%
MIGORI	2007.28	828.98	950.48	87%
MOMBASA	230.13	52.43	106.95	49%
MOYALE	9660.92	40.18	48.48	83%

MT ELGON	945.6	185.17	189.57	98%
MURANGA	939.61	314.68	413.77	76%
MWINGI	10164.03	1131.16	1188.96	95%
NAIROBI	699.96	247.63	386.18	64%
NAKURU	7517.6	1953.53	2007.77	97%
NANDI	2882.31	1088.07	1109.62	98%
NAROK	15166.9	1332.98	1365.17	98%
NYAMIRA	898.81	469.69	528.49	89%
NYANDARUA	3294.67	1051.26	1084.13	97%
NYANDO	1171.22	476.82	501.37	95%
NYERI	3361.87	720.13	887.74	81%
RACHUONYO	943.49	533.63	551.35	97%
SAMBURU	21208.12	301.58	313.89	96%
SIAYA	1524.56	820.74	859.7	95%
SUBA	1053.82	289.67	306.62	94%
TAITA TAVETA	17234.6	537.15	579.22	93%
TANA RIVER	38501.71	219.43	225.18	97%
TESO	559.99	285.65	326.14	88%
THARAKA	1570.25	392.35	401.26	98%
THIKA	1974.28	640.09	715.41	89%
TRANS MARA	2854.53	627.83	676	93%
TRANS NZOIA	2491.42	844.63	856.55	99%
TURKANA	68614.12	726.33	743.44	98%
UASIN GISHU	3362.71	1231.21	1254.74	98%
VIHIGA	563.89	365.19	390.91	93%
WAJIR	57104.87	312.82	325.77	96%
WEST POKOT	9130.7	1065.17	1089.33	98%

Appendix 3: Total area were conversion into built up surface between 1990 and 2015 using the land cover data reference of 1992 took place, with a threshold of ten percent

Land cover	Area (km^2)	Percentage
Sparse shrub/ herbaceous (<15%)	38	0.01%
Sparse vegetation	188	0.04%
Tree cover, water flooded	226	0.04%

Three or shrub cover	536	0.10%
Shrub or herbaceous cover, water flooded	684	0.13%
Urban areas	1000	0.20%
Water bodies	1036	0.20%
Bare areas	1996	0.39%
Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	4912	0.96%
Cropland irrigated or post-flooding	6266	1.22%
Grassland	17787	3.47%
Shrubland (+deciduous)	28528	5.57%
Tree cover	30810	6.02%
Mosaic natural vegetation (>50%) / cropland (<50%	30931	6.04%
Mosaic cropland (>50%) / natural vegetation (<50%)	31575	6.17%
Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	38193	7.46%
Herbaceous cover	122076	23.84%
Cropland rainfed	195243	38.13%

Appendix 4: Total area were conversion into built up surface between 1990 and 2015 using the land cover data reference of 1992 took place, with a threshold of fifteen percent.

Land cover	Area (km²)	Percentage
Sparse shrub (<15%)	25	0.0%
Tree cover, water flooded	112	0.0%
Sparse vegetation	115	0.0%
Three or shrub cover	264	0.1%
Shrub or herbaceous cover, water flooded	435	0.2%
Water bodies	672	0.3%
Urban areas	690	0.3%
Bare areas	1433	0.6%
Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	3158	1.4%
Cropland irrigated or post-flooding	3404	1.5%
Tree cover	13077	5.6%
Grassland	13437	5.8%
Mosaic cropland (>50%) / natural vegetation (<50%)	13741	5.9%
Shrubland (+deciduous)	15063	6.5%
Mosaic natural vegetation (>50%) / cropland (<50%)	15624	6.7%
Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	22209	9.6%
Herbaceous cover	51829	22.3%
Cropland rainfed	76623	33.0%

Appendix 5: Total area were conversion into built up surface between 1990 and 2015 using the land cover data reference of 1992 took place, with a threshold of fifty percent.

Land cover	Area (km²)	Percentage
Three or shrub cover	1	0.05%
Urban areas	14	0.68%
Water bodies	18	0.88%
Shrub or herbaceous cover, water flooded	20	0.97%

Tree cover	25	1.22%
Cropland irrigated or post-flooding	29	1.41%
Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	63	3.06%
Bare areas	78	3.79%
Mosaic cropland (>50%) / natural vegetation (<50%)	81	3.94%
Mosaic natural vegetation (>50%) / cropland (<50%	157	7.64%
Herbaceous cover	187	9.10%
Shrubland (+deciduous)	190	9.24%
Cropland rainfed	357	17.36%
Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	418	20.33%
Grassland	418	20.33%

Appendix 6: Land cover Kenya as a share of the total area of Kenya for both 1992 and 2015.

Land cover	1992	2015	Changed
Cropland rainfed	12.02%	12.22%	0.20%
Herbaceous cover	5.13%	5.38%	0.24%
Three or shrub cover	0.06%	0.06%	0.00%
Cropland irrigated or post-flooding	0.51%	0.56%	0.04%
Mosaic cropland (>50%) / natural vegetation (<50%)	3.07%	3.10%	0.03%
Mosaic natural vegetation (>50%) / cropland (<50%	3.60%	3.65%	0.05%
Tree cover, broadleaved, evergreen, closed to open (>15%)	1.40%	1.45%	0.05%
Tree cover, broadleaved, deciduous, closed to open (>15%)	0.78%	0.65%	-0.13%
Tree cover, broadleaved, deciduous, closed (>40%)	0.02%	0.02%	0.00%
Tree cover, broadleaved, deciduous, open (15-40%)	1.97%	2.00%	0.03%
Tree cover, needle leave**d**, evergreen, closed to open (>15%)	0.01%	1.47%	1.46%
Tree cover, mixed leaf type (broadleaved and needle leave**d**)	1.44%	0.00%	-1.44%
Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	10.65%	9.44%	-1.21%
Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	9.23%	9.74%	0.51%
Shrubland	28.96%	29.29%	0.33%
Deciduous shrubland	0.02%	0.02%	0.00%
Grassland	13.62%	15.24%	1.61%
Sparse vegetation (tree, shrub, herbaceous cover)	0.63%	0.40%	-0.23%
Sparse shrub (<15%)	0.07%	0.08%	0.00%
Sparse herbaceous cover (<15%)	0.00%	0.00%	0.00%
Tree cover, flooded, fresh or brakish water	0.05%	0.05%	0.00%
Tree cover, flooded, saline water	0.02%	0.02%	0.00%
Shrub or herbaceous cover, flooded, fresh/saline/brakish water	1.56%	1.65%	0.08%
Urban areas	0.01%	0.08%	0.07%
Bare areas	3.93%	2.22%	-1.71%
Consolidated bare areas	0.99%	0.97%	-0.02%
Unconsolidated bare areas	0.00%	0.00%	0.00%
Water bodies	0.23%	0.24%	0.00%