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Assessing land use/land cover change in Kigali City, Rwanda

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Land use prediction
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Satellite images

Abstract

The unsustainable impact of global urbanization has had a profound effect on urban landscapes across the globe. This study comprehensively assesses spatial characteristics, causes, and negative effects of Land Use and Land Cover Changes in Kigali City over the past two decades. Landsat images from 2003, 2013, and 2023 were classified using ArcMap software to assess LULC dynamics. Furthermore, the Molusce plugin in QGIS was employed to compute and forecast the expansion of built-up areas from 2023 to 2033. (1) The classified images' findings show that the built-up surface's expansion experienced substantial growth. (2) Additionally, the predicted changes reflect the persistent increase in the built-up surface and reduction of the non-built-up surface. (3) Besides, the study highlights the challenges of population growth, contributing to negative impacts on agricultural land, global warming, and the urban heat island effect. In light of ongoing development and expansion in Kigali, researchers have advised implementing integrated land-use planning strategies, such as establishing compact and mixed-use areas (comprising Midrise or Highrise apartments). These strategies seek to manage urban sprawl, maintain a harmonious relationship between urban growth and the environment, and foster a sustainable and livable city for its inhabitants.

1. Introduction

Land plays a crucial role in shaping human existence and serves as a fundamental source of essential resources: including energy, water, and food, which are essential for humanity to survive (Li et al., 2021). Throughout history, humans have continuously discovered diverse ways to utilize and benefit from the land through human interaction and the natural environment (Liu et al., 2021). However, the strain on the land has intensified with the world population rapidly expanding and its accompanying demands increasing. As a result, fragile ecosystems, particularly forest-covered areas of wetlands, have become vulnerable in the direction of human-induced land modifications. (Çağlıyan, & Dağlı, 2022)

Globally, persistent LULC significantly impacts the planet's atmosphere system functioning, immediately influencing biodiversity and contributing to climate change (Jung et al., 2020). These ecosystem service alterations disrupt biological systems' capacity to meet human needs (Regasa et al., 2021). Intense agricultural development and population growth are major drivers of LULC (Alemayehu et al., 2019). East Africa, including Rwanda, experiences land cover and land use alterations due to factors like high population pressure and other human and natural-caused forces (Nkundabose, 2021). Mugiraneza et al. (2020) state that LULC change is a trending research topic, particularly in rapidly developing urban centers such as Kigali City in Rwanda.

Understanding the dynamics of land transformation and its impacts on the environment, socioeconomic conditions, and urban development is crucial for sustainable planning and decision-making (Dong, 2020). This study aims to extensively analyze LULC in Kigali City between 2003 and 2023, integrating evidence-based data and rational discourse from various academic fields. It also emphasizes the anticipated alteration in land use and land cover (LULC) that will likely occur in the built-up areas from 2023 to 2033. This change is expected to affect the people living in Kigali adversely.

2. Method

Three Landsat images were downloaded from the USGS to analyze LULC shifts in Kigali City. The images comprised Landsat 7 for 2003, 7 for 2013, and 8 for 2023. All images had a grid cell size of 30 meters and shared the same WRS path/row of 172/161. The projection used was UTM, zone 36. In addition to the satellite images, spatial locational data for the wetland and Kigali city were obtained from Rwanda Spatial Data Hub and DIVA-GIS. Regarding the mapping and computation aspect, the classification of Landsat images from 2003,

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2013, and 2023 using ArMap 10.8.2. Additionally, the Molusce plugin in QGIS Desktop 2.16.3 was utilized to calculate and predict the dynamıc of built-up areas between 2023 and 2033. The analysis results were then interpreted and discussed within the context of the research objectives. It is shown in the following workflow chart.

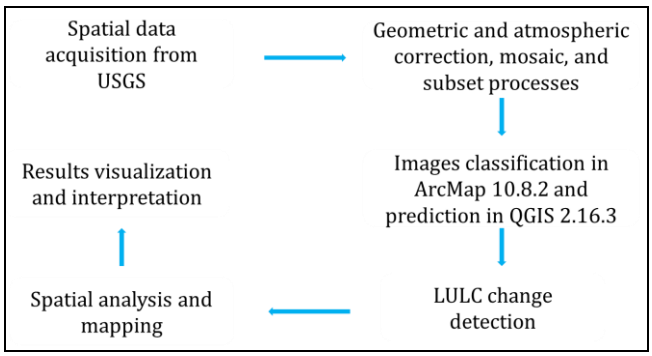

Figure 1. Research design chart

2.1. Study area

Kigali, the capital city of Rwanda in East Africa, at Latitude: -1° 56' 22.79" S and Longitude: 30° 03' 20.40" E. The main urban center of Kigali has undergone significant development and growth over time (Nduwayezu et al., 2021). The city was founded as a German colonial administrative settlement in 1907, and it experienced growth beyond its humble origins as a small neighborhood on Nyarugenge Hill. It encompasses 730 square kilometers (sq. km). In terms of population growth, in 1907 and 2002, the city had approximately 357 and 608,141 individuals, respectively, and in 2022, the population was about 1,745,555 (NISR, 2023). In 2006, administrative reorganization transformed Kigali into a metropolitan area comprising three districts, namely Nyarugenge, Kicukiro, and Gasabo (Mugiraneza et al., 2020).

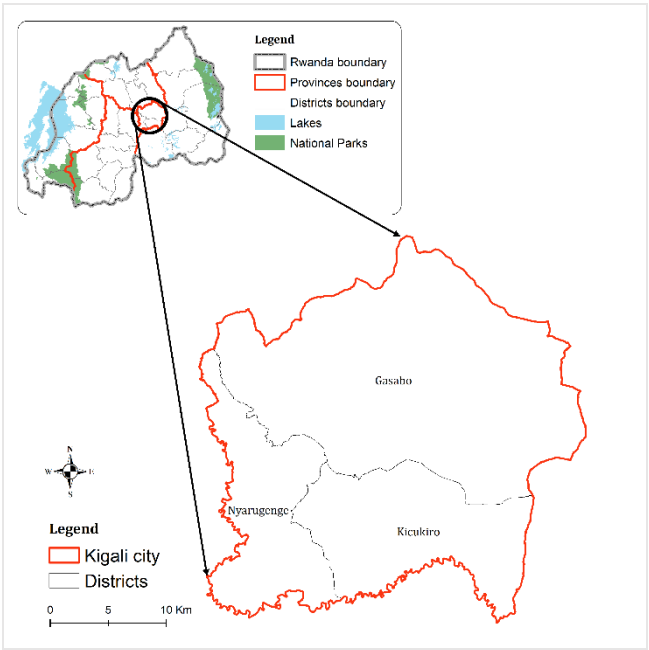

Figure 2. Study area map

3. Results

The LULC maps of the city of Kigali were classified in ArcMap using 2003, 2013, and 2023 Landsat images. The classified images and prediction results are shown in Fig 3.

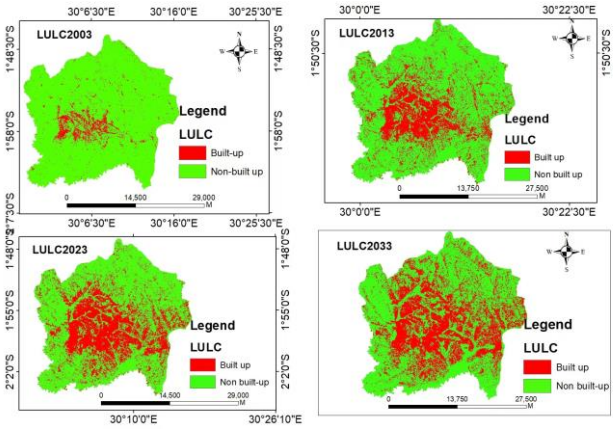

Figure 3. LULC change and prediction maps

Table 1. The summary of the area in sq. km changed in two past decades.

LULC\Year	2003	2013	2023
Built up	48.59	184.88	238.07
Non-built-up	681.41	545.12	491.93

The change detection map of Kigali between 2003 and 2023 is shown in Fig 4. It also illustrates the expansion of built-up surfaces over the city's outskirts.

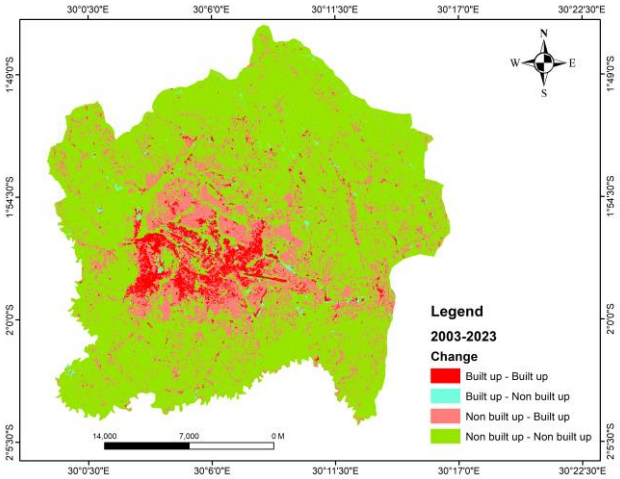

Figure 4. Change detection map of Kigali (2003-2023)

The calculated and extracted areas of Kigali city converted into another use and cover are shown in hectares in Table 2.

Table 2. LULC conversion between (2003-2023)

LULC change	Area in sq. km
Non-built-up to built-up	142.4
Built-up to non-built-up	8.6

4. Discussion

Over two past decades, from 2003 to 2023, notable transformations have occurred in LULC. In the range of ten years between 2003 to 2013, built-up areas increased from 6.6 % to 25.3%, whereas non-built-up reduced

from 93.3% to 74.6%. This means approximately 18.6% of non-built-up was converted to built-up, as shown in the figure below.

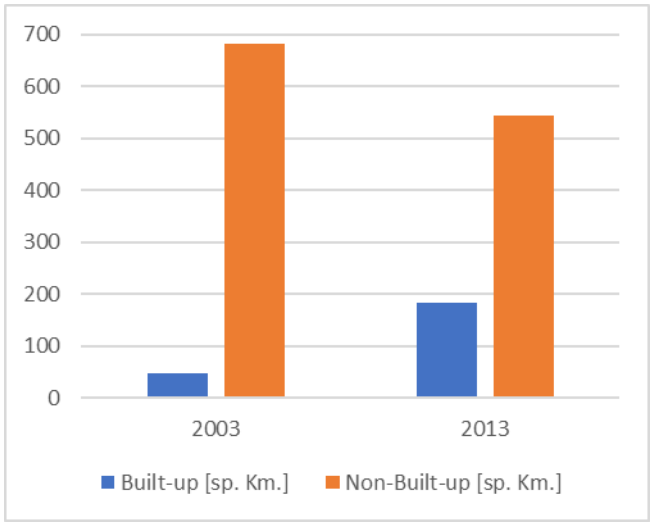

Figure 5. LULC between 2003 and 2013

The Figure 6 highlights that in the range of ten years between 2013 to 2023, built-up areas increased from 25.3% to 32.6%, whereas non-built-up reduced from 74.6% to 67.3%. This means that approximately 7.2% of non-built-up was converted to built-up.

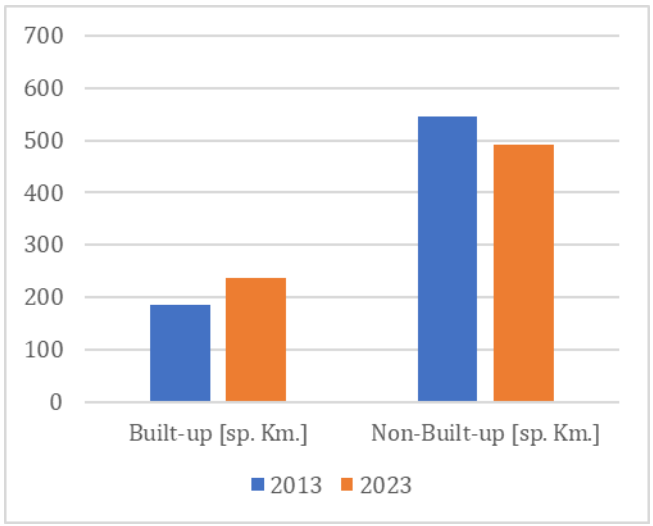

Figure 6. LULC between 2013 and 2023

The primary driver behind these changes is the population increase, followed by poor sustainable planning. Notably, in the range mentioned above of 20 years, approximately 8.6 sq. km of built-up land was converted into non-built-up. This indicates the efforts of the Rwandan government in resettling people from areas such as wetlands and landslide-prone regions, prioritizing their safety and well-being. This strategy is commendable as it helps to safeguard lives and mitigate the risks associated with natural hazards.

However, despite these measures, the study reveals that the population continues to increase steadily. This poses a challenge as it contributes to the negative change observed; urban built-up areas, in particular, have experienced significant growth, expanding approximately 5 times since 2003. This translates to 189.48 sq. km of new built-up areas, compared to the initial 48.59 sq. km in 2003. This change has adverse effects not only on human beings but also on the environment. It leads to a reduction in agricultural land and the depletion of oxygen-producing trees, which are vital for maintaining ecological balance. Additionally, since feeding a growing population requires more land, this non-built-up to built-up conversion increases global warming and the urban heat island effect through construction activities and deforestation.

Figure 7 indicates that if no serious precautions are implemented to stop the urban sprawl problem, in the coming ten years, between 2013 to 2023, built-up areas will increase from 32.6% to 36.3%, whereas non-built-up will reduce from 67.3% to 63.6%. This means that approximately 3.6% of non-built-up will change to built-up. Figure 7 shows how the problem will be in the coming decade.

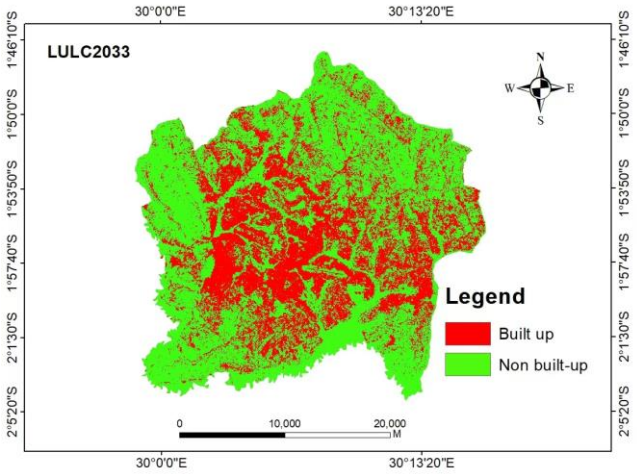

Figure 7. LULC prediction map of 2033

Figure 8 illustrates the significant decline in vegetation cover within Kigali over three decades. This stands for climate change negatively.

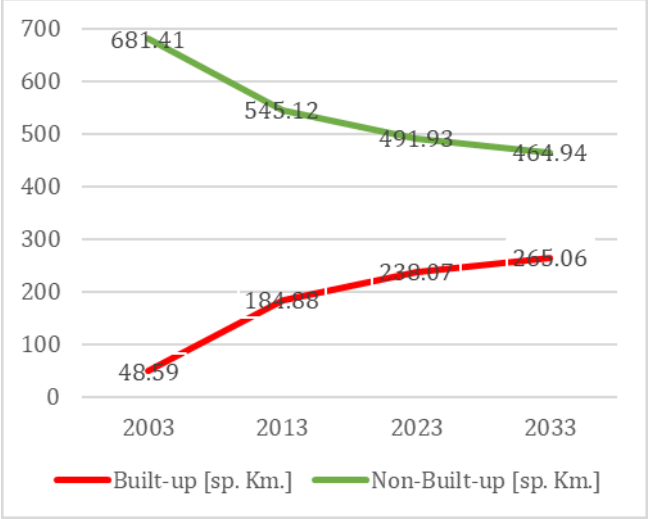

Figure 8. LULC trend between 2003 and 2033

Regarding the afore-highlighted graphs, it is evident that the built-up areas will persistently grow at a high rate without serious measures to curtail the uncontrolled expansion of settlements. The prediction indicates that by 2033, the non-built-up land area available in

2023 will diminish to a mere 3.6%. This projection underscores a profoundly negative impact that will have far-reaching consequences like losing valuable space for essential purposes such as urban parks, agriculture, and open spaces.

Several valuable mechanisms can be considered to ensure sustainable land management, urban planning, and policy formulation in light of the LULC spotted in Kigali, Rwanda. Firstly, it is crucial to prioritize integrated land-use planning approaches that balance urban development with preserving natural resources and green spaces. This can be achieved by establishing compact and mixed land use patterns, promoting efficient land use, and minimizing urban sprawl. Secondly, there should be a focus on enhancing environmental conservation and biodiversity by preserving and restoring ecosystems, including wetlands and forests, which provide vital ecosystem services. Thirdly, sustainable transportation systems and infrastructure should be prioritized to reduce the dependence on private vehicles and promote public transit, cycling, and pedestrian-friendly designs. Also, sustainable land management practices should be promoted, such as sustainable agriculture, reforestation initiatives, and green building standards.

Collaboration among stakeholders, including government authorities, communities, and researchers, is crucial to develop and implementing effective policies and strategies that ensure the long-term sustainability and resilience of Kigali City's land use and urban development.

5. Conclusion

In conclusion, the LULC of Kigali during the past two decades has been thoroughly analyzed, shedding light on the spatial patterns, drivers, and negative effects of these changes. Significant changes to the LULC map were uncovered through the study, emphasizing the noticeable growth in built-up areas. The research findings highlight the efforts of the Rwandan government in resettling people from vulnerable areas, demonstrating a proactive strategy to safeguard lives. However, population growth remains a challenge, contributing to the negative impacts of LULC on agricultural land, oxygen production, climate change, and urban heat island effects. It is of utmost importance to adopt integrated land-use planning strategies that prioritize sustainable transportation systems and environmental conservation in order to ensure the long-term sustainability and resilience of Kigali City. By promoting compact and mixed-use developments, including midrise or highrise apartments, and encouraging the preservation of green spaces, the city can effectively manage and prevent urban sprawl. Furthermore, implementing sustainable land management practices, such as optimizing resource utilization and minimizing land degradation, will foster a harmonious relationship between urban development and the environment. These measures collectively aim to create a city that is both livable and sustainable, offering residents a high-quality urban experience while simultaneously safeguarding natural resources and minimizing the ecological impact.

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