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Original Article

Land Use and Land Cover Change in the Urban Landscape of Butembo, Democratic Republic of the Congo (DRC)

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ABSTRACT

The expansion of built-up areas driven by a significant demographic explosion is a critical issue for urban land-use planning. The conversion of rural land to urban areas and other uses significantly impacts the range of products and services provided by natural ecosystems in urban environments. This study examines the spatial-temporal dynamics of land use in the city of Butembo. The Radom Forest model with a supervised approach to Landsat images on the Google Earth Engine (GEE) platform was applied to characterize land cover across three dates (2003, 2013 and 2023). The results reveal pronounced changes in land cover over a 20-year period. Dense forests lost 39.16% and 28.76% of their total area between 2003 and 2023, respectively. Conversely, anthropized classes, such as agricultural lands, built-up areas, and bare soil, experienced a dramatic expansion, with covered areas doubling over the same period. Landscape dynamics are primarily characterized by the fragmentation and reduction of forest classes, alongside the aggregation and creation of agricultural lands, built-up areas, and bare soil. The progressive increase in the landscape disturbance index over time indicates the anthropization of Butembo's landscape. These findings highlight the need for an integrated land-use plan for the sustainable management of Butembo and its natural resources.

APA CITATION

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INTRODUCTION

Around 50% of the world's population lives in urban areas, and this proportion is set to rise to 60% by 2030 (Cohen, 2006; ONU, 2010). In developed countries such as the USA, changes in urban land use are outstripping population growth (Alig *et al.*, 2004). For instance, the population of the USA grew by around 24% between 1980 and 2000. However, during the same period, the amount of urbanized land increased by over 34% (Alig *et al.*, 2004; Theobald, 2005). By 2025, the amount of developed land is expected to rise from 5.2% to 9.2%, an increase of 79% (Alig *et al.*, 2004). Changes in land use/land cover caused by urbanization greatly affect the structure and function of urban ecosystems.

According to the UN-habitat report (2010), Africa is urbanizing at a very rapid pace, with the urbanization rate rising from 15% in 1960 to 40% in 2010, and projected to reach 60% by 2050 (Freire, 2013). The continent is urbanized to 17 of the world's 100 fastest-growing cities, and if the upward trend continues, African cities will be urbanized to almost a quarter of the world's urban population, or around 1.2 billion people (Biau, 2010; UN-Habitat, 2010). If nothing is done, by 2050 Africa will have the fastest urban growth rate in the world (Biau, 2010; UN-Habitat, 2020).

In the Democratic Republic of the Congo, the ongoing wars in the Great Lakes region have caused many people to move to urban centres, leading to the expansion of towns such as Butembo (Kasereka, 2010). Constant insecurity in rural areas has prompted war survivors to migrate to this city, where a degree of security is guaranteed (Lusenge, 2008).

Butembo's current population is estimated at 983,560 with a density of around 4,920 inhabitants/km^2 (Balthazare, 2022). This migration is leading to unprecedented land occupation, transforming spaces formerly dedicated to agriculture into built-up areas and converting the city's green spaces into urban agriculture (Muhindo, 2011; Sikuzani *et al.*, 2018). Furthermore, the current configuration of the city, especially in the periphery, is characterized by an expansion of buildings and other artificial elements (Muhindo, 2011). The influx of people settling in Butembo poses a danger if the town lacks a comprehensive urban and cadastral plan, and if the population is not controlled and supervised (Balthazare, 2022).

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To create sustainable cities, it is necessary to control urban expansion upstream and systematically manage it to optimize land use (JICA, 2022). This study complements previous research in the city of Butembo. Current knowledge of the different land uses is important to identify the temporal and spatial evolution of land use, especially the extent of forest cover changes, to guide certain land-use planning decisions.

The study aims to address two major gaps: first, the lack of an updated database on the spatiotemporal evolution of land use in the city of Butembo, given that the available information on land use dynamics remains fragmented; and second, the insufficient knowledge regarding the impacts of land-use changes on local ecosystems. Indeed, transformations driven by urbanization significantly affect biodiversity and ecosystem services. The central hypothesis of this study posits that rapid urbanization and the expansion of built-up areas in Butembo lead to significant transformations in land use, characterized by a reduction in dense forests and an increase in anthropized lands. To test this hypothesis, the study aims to analyze the dynamics of land use in the urban landscape of Butembo over the period from 2003 to 2023. This analysis relies on a methodological approach combining geospatial data analysis, field surveys, and the calculation of specific indices.

Thus, the study will provide a detailed and updated analysis of land use dynamics in Butembo, highlighting spatio-temporal transformations, particularly the loss of green spaces and agricultural lands, as well as their impacts on local ecosystems and the services they provide. These findings will not only enhance understanding of the ecological consequences of rapid urbanization but also guide decision-making for sustainable land management.

MATERIALS AND METHODS

Study area

Butembo is located in the province of North-Kivu, in the north-east of the DRC. Its urban district lies between 0°08′ north latitude and 29°27'east longitude, 17 km north of the equator. It receives an average annual rainfall of 1,367 mm. The city is built on the highlands at an altitude between 1700 and 1800 meters (Kataomba *et al.*, 2010). The relief, resulting from Tertiary orogeny concomitant with the formation of the Albertine tectonic trough, is dissected and hilly, with metamorphic and granitic rocks dating from the Precambrian. The area features numerous valleys with flat, wide, and marshy bottoms. The town is surrounded by hills drained by rivers, the most important of which are Kimemi, Mususa and Lwirwa, forming a large part of its boundaries (Muhindo, 2011).

Butembo is characterized by a humid subtropical climate tempered by mountains. The average temperature is around 18°C, with two rainy seasons (March, April, May and August, September, October, and November) and two relatively dry seasons from June to July and January to February (Muhindo, 2012). The major environmental problems in this urban environment are erosion, inappropriate waste management, landslides, and flooding (Kaleghana, 2018). Butembo's original vegetation continues to disappear due to anthropic activities marked by systematic deforestation, leading to the presence of herbaceous ruderal groupings, post-cultivation weeds and exotic woody species (Muhindo, 2011). This disappearance of the original vegetation has given way to ruderal herbaceous, weedy, post-cultivation groupings and numerous introduced trees, such as *Eucalyptus* and *Grevillea* (Kataomba *et al.*, 2010).

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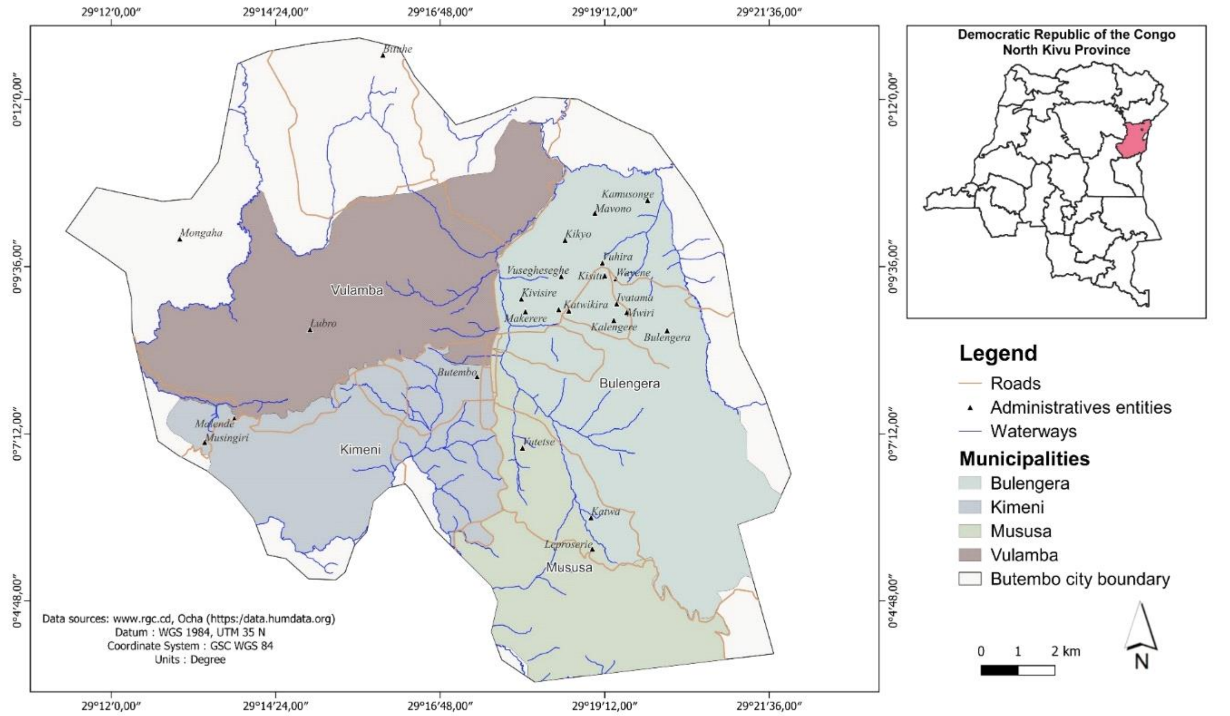
Figure 1. Geographical location of the study area



Method

Spatial data

To analyze the spatial-temporal dynamics of land use in the urban landscape of Butembo, the study used Landsat satellite images from 2003, 2013 and 2023. These annual composite images were downloaded from the SEPAL platform, established by the FAO for remote sensing monitoring of forest areas. The composites are derived from Landsat TM, ETM+ and OLI (Thematic Mapper, Enhanced Thematic Mapper plus and Operational Land Imager) images that have undergone atmospheric, radiometric, and geometric corrections. The SEPAL composites were chosen because they are cloud-free and allow for multi-date change analysis. They cover all countries in the Congo Basin and can be downloaded free of charge from the SEPAL website (https://sepal.io/).

SEPAL is a cloud-based platform for autonomous land monitoring using remote sensing data, integrated with Google Earth Engine and several other open-source software packages. In this study, the study used the Google Earth Engine (GEE) platform to process and classify images uploaded to the SEPAL. The three years were chosen based on significant events in the region: the recognition of the Butembo as a town by the Congolese state in 2003, the period of armed conflict and migratory flows in Butembo (2003-2013), the liberalization of the mining sector in the DRC (1998-2006), and the current period characterized by major infrastructure developments in 2023.

Supervised Image Classification in Google Earth Engine

Before classifying the images on the GEE platform, the false colour composite of Landsat images was created, combining the mid-infrared (MIR) and near-infrared (NIR) bands to clearly distinguish the different land cover units (Oszwald *et al.*, 2010). Five land-use classes were identified in the study area for supervised classification: dense forests, degraded forests/fallow lands, fields, buildings, and bare soils.

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Then various sampling points on each false color composite image were identified, using high-resolution imagery provided by GEE for accurate visual interpretation (Zhao *et al.*, 2023, Kouassi *et al.*, 2023). The sample points were collected in two categories: the first category of points was combined into a single collection and used as training input data, while the second category of points was combined into a single collection and used as validation input data (Kouassi *et al.*, 2023; Muteya *et al.*, 2023). For this study, supervised classification with the Random Forest model was used (Hayes *et al.*, 2014; Xia *et al.*, 2017).

The training data guided the Random Forest algorithm, which creates decision trees to assign each pixel to the associated land cover (Hayes, 2014). The RF model provides higher classification accuracy than other algorithms, such as support vector machine (SVM), k-nearest neighbour (k-NN) and maximum likelihood classifier (MLC) (Liu *et al.*, 2018). The entire Random Forest (RF) classification workflow, from creating training data to image classification and model performance evaluation, was fully deployed on GEE (Xia *et al.* 2017). This model offers improved classification accuracy for land use and land cover mapping (Zeferino *et al.*, 2020). Classification accuracy was also evaluated using the kappa coefficient and overall accuracy values. Image classification accuracy was assessed using the RF confusion matrix. (Kabuanga *et al.*,2021; Sikuzani *et al.*, 2023; Muteya *et al.*, 2023).

Classification validation

To validate the classification and determine the overall accuracy of the produced maps, the classified land use maps were compared against validation points collected using Google Earth Pro. 1,500 points were sampled for 2003-2013 and 1,600 points for 2013-2023. The GEE platform was then used to calculate the error matrix, expressed in terms of proportions of estimated areas, user's overall accuracy, producer's accuracy, and the Kappa coefficient to validate the classification for all land use classes (Wang *et al.*, 2013; Muteya *et al.*, 2023).

Analysis of spatial-temporal landscape dynamics

To quantify spatial-temporal land-use changes and analyze conversions between different land-use classes, the transition matrix method was used (Mbavumoja *et al.*, 2022). Two transition matrices for the periods 2003-2013 and 2013-2023 were generated.

Analysis of spatial transformation processes

The spatial transformation processes of the landscape were analyzed using certain spatial structure indices and the decision tree of Bogaert *et al.* (2004), by comparing patch area, patch perimeter density, and patch number during the observation periods. These "Landscape metrics" were calculated using FRAGSTAT v4.2 software to characterize the various spatial transformations in the landscape (Bogaert & Mahamane, 2005; Sikuzani *et al.*, 2023). Indices such as total area, number of patches were used, largest patch index, edge density and perimeter-area fractal.

The value of t = 0.75 was used to distinguish the fragmentation process from dissection, with values greater than 0.75 suggesting dissection and those less than or equal to 0.75 indicating fragmentation (Thalès de Haulleville *et al.*, 2018). The state of the anthropization of the landscape was assessed through the anthropization index (Sikuzani *et al.*, 2018), which is the ratio between the area of anthropogenic classes and that of natural classes (open forest, gallery forest, swamp). The index is greater than 1 when the landscape is dominated by anthropogenic classes.

RESULTS

Characterizing the spatial-temporal dynamics of land use

Figure 2 below illustrates the observable dynamics from 2003 (Kappa = 80%), 2013 (Kappa = 83%) and 2023 (Kappa = 86%) among the five land-use

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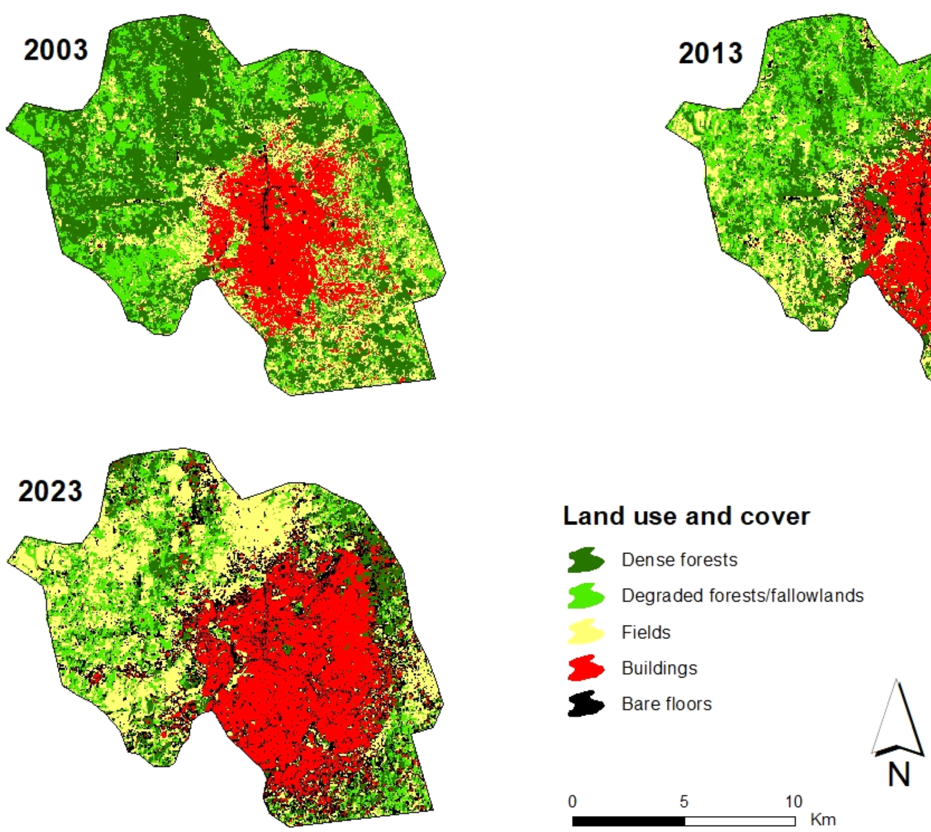
classes selected for this study: Dense Forest, Degraded Forest/Fallow, agricultural land, Built-up, and Bare Soil (Figure 2 and Table 1).

From 2003 to 2023, there has been an exponential expansion of built-up areas and bare soil, primarily spreading from the centre to the extreme right of the city, and then progressively to the extreme south, north, and west, agricultural lands and degraded/ fallow forests are notably prevalent towards the northwest extremes, where they encroach upon the continually diminishing dense forests. In this landscape, vegetation classes follow a succession pattern; dense forests give way to degraded forests/ fallows, which are then replaced by agricultural lands.

Table 1: Accuracy of supervised classification of Landsat images

	2003	2013	2023
Overall Accuracy (%)	85	87	90
Kappa (%)	80	83	86

Figure 2. Land-use maps of Butembo from 2003 to 2023 based on supervised classifications of Landsat images.



The dynamics of land-use class proportions (Figure 3, Table 2) between 2003, 2013 and 2023 show a regression of forest classes and an expansion of anthropogenic classes in the city of Butembo. Over a 10-year interval from 2003 to 2013, dense forests lost around 39.16% of their total area. This significant reduction indicates that dense forests may face total disappearance in the near future of Butembo. Conversely, the anthropogenic classes have expanded, with built-up areas increasing by

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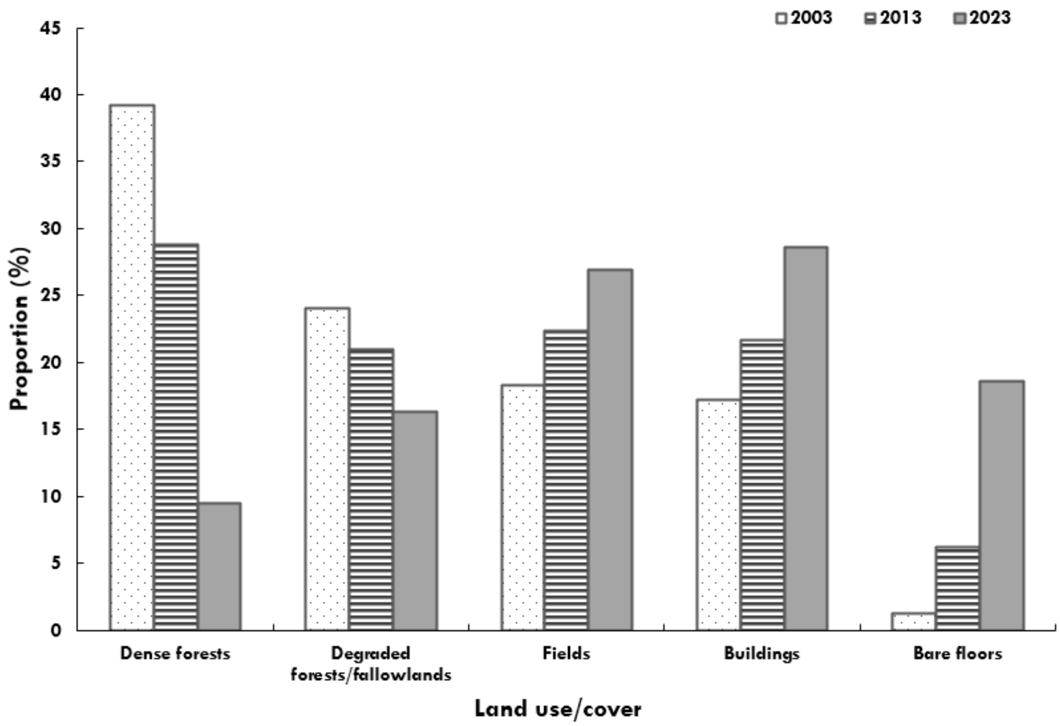
17.24% from 2003 to 2013 and by 21.65% from 2003 to 2023. Bare soil also experienced a dramatic expansion, rising from around 1.29% to 6.25% over the 20-year period from 2003 to 2023. Once dominant in Butembo, dense forests have been largely replaced by built-up areas, making them the least represented land-use class in the landscape.

Figure 3: Dynamics of land-use class proportions in Butembo: 2003, 2013 and 2023



Quantifying changes in land-use classes

Table 2 presents the transition matrix of land-use units in the city of Butembo from 2003 to 2023.

Analysis of the two transition matrices reveals that the areas of each land-use unit that remained unchanged are represented on the diagonal of the matrix. The other parts of the matrix illustrate different conversions between land-use classes in the Butembo landscape. From 2003 to 2013, the major transitions observed include the conversion of dense forests into degraded forest/fallow lands (5.21%) and agricultural lands (9.76%). Additionally, 11.26% of degraded forest/fallow lands were converted to agricultural lands, and 4.15% of the agricultural lands were converted to buildings. During the 2013-2023 period, similar transitions were noted but at a more accelerated pace. Specifically, 3.80% of the agricultural lands, 3.28% of dense forests, and 2.40% of bare soils were converted to buildings.

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Table 2 shows the land use class transition matrices for the urban landscape of Butembo between 2003-2013 and 2013-2023, derived from the classification of Landsat images. The total of each row represents the land-use states of the initial year, and the total of each column corresponds to those of the final year. The cells on the diagonal (in bold) correspond to areas that have not changed their state between the initial and final years (stable areas), while the elements outside the diagonal indicate the different conversions of land cover classes. The cell contents represent the percentage area of one land-use type (column) in the initial year that has changed to another land-use type in the final year (row).

2013							
	Land use/cover	**Buildings**	**Fields**	**Dense forests**	**Degraded forests/fallow lands**	**Bare floors**	**Total**
2003	Buildings	**14.35**	1.00	0.71	0.09	1.09	**17.24**
	Fields	4.15	**6.24**	3.67	1.88	2.32	**18.26**
	Dense forests	1.27	5.21	**20.11**	11.26	1.32	**39.16**
	Degraded forests/fallow lands	1.21	9.76	4.22	**7.73**	1.13	**24.05**
	Bare floors	0.68	0.15	0.05	0.02	**0.39**	**1.29**
	Total	**21.65**	**22.35**	**28.76**	**20.99**	**6.25**	**100**

2023							
	Land use/cover	**Buildings**	**Fields**	**Dense forests**	**Degraded forests/fallow lands**	**Bare floors**	**Total**
2013	Buildings	**18.46**	0.29	0.04	0.07	2.79	**21.65**
	Fields	3.80	**9.91**	0.95	2.46	5.24	**22.35**
	Dense forests	3.28	5.64	**6.55**	7.23	6.05	**28.76**
	Degraded forests/fallow lands	0.70	9.95	1.77	**6.22**	2.35	**20.99**
	Bare floors	2.40	1.08	0.20	0.39	**2.19**	**6.25**
	Total	**28.64**	**26.87**	**9.52**	**16.36**	**18.61**	**100**

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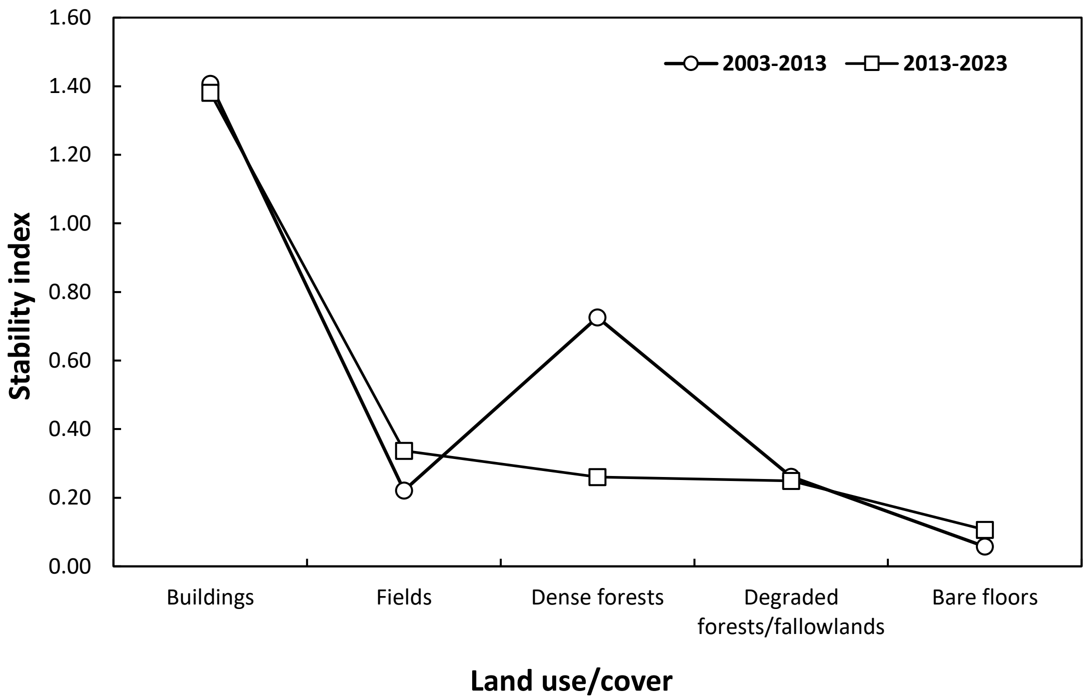
Furthermore, analysis of the stability indices for land use classes reveals low stability values for almost all land use units, regardless of the period. This indicates that the classes are generally unstable in the landscape. However, classes such as buildings, agricultural lands and bare soils show a slight increase in their stability index values from 2003-2013 to 2013-2023 (figure 4).

Figure 4: Evolution of the stability index of different land use classes between 2003 and 2013 and between 2013 and 2023



Analysis of spatial structure

Figures 5 (a, b, c, d, and e) summarize the different values of the spatial landscape structure indices calculated. Analysis of the spatial structure index values from 2003 to 2023 reveals a decrease in the total area and perimeter density of the dense forests and degraded forests/fallow lands classes, accompanied by an increase in the total number of patches in the dense forests. In contrast, the agricultural lands, buildings, and bare soil classes show opposite trends. This situation illustrates the fragmentation of dense forests to the benefit of the agricultural lands, buildings, and bare soils.

Regarding the landscape shape index (LSI), the results (figure 5 e) indicate that LSI values for the dense forests, degraded forests/fallow lands and agricultural lands classes decreased over the observation periods (2003-2023). This suggests that the edges of these land use classes are becoming increasingly regular (simple) in shape within the landscape. Conversely, the LSI values for the buildings and bare soil classes increase over the observation period, indicating that the edges of these land-use classes are becoming more irregular (complex) in shape. Moreover, the Butembo landscape, where dense forest had the highest large patch index (LPI=15.58) in 2003, has evolved by 2023, with buildings having the highest patch index (LPI=15.48). This demonstrates the significant conversion of dense forests into buildings within the landscape.

Table 3 provides information on the transformation processes of the different land-use classes that took place in Butembo between the 2003-2013 and 2013-2023 periods.

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The table shows that degraded forest areas experienced patch removal over both periods, while dense forests underwent patch fragmentation between 2003-2013 and patch removal between 2013-2023. In contrast, anthropogenic land uses (agricultural lands, buildings, and bare soil) experienced processes that favoured their expansion. Agricultural lands underwent patch aggregation over both periods, reflecting their expansion. Built-up areas experienced patch aggregation during the 2003-2013 period, followed by patch creation between 2013-2023. Bare soils were created during the 2003-2013 period and then aggregated between 2013-2023.

Figure 5. Spatial landscape structure indices in the urban landscape of Butembo, (a) Number of patches, (b) Edge density, (c) total area of patches, (d) largest patch index and (e) landscape shape index Processes of spatial transformation of the urban landscape of the city of Butembo

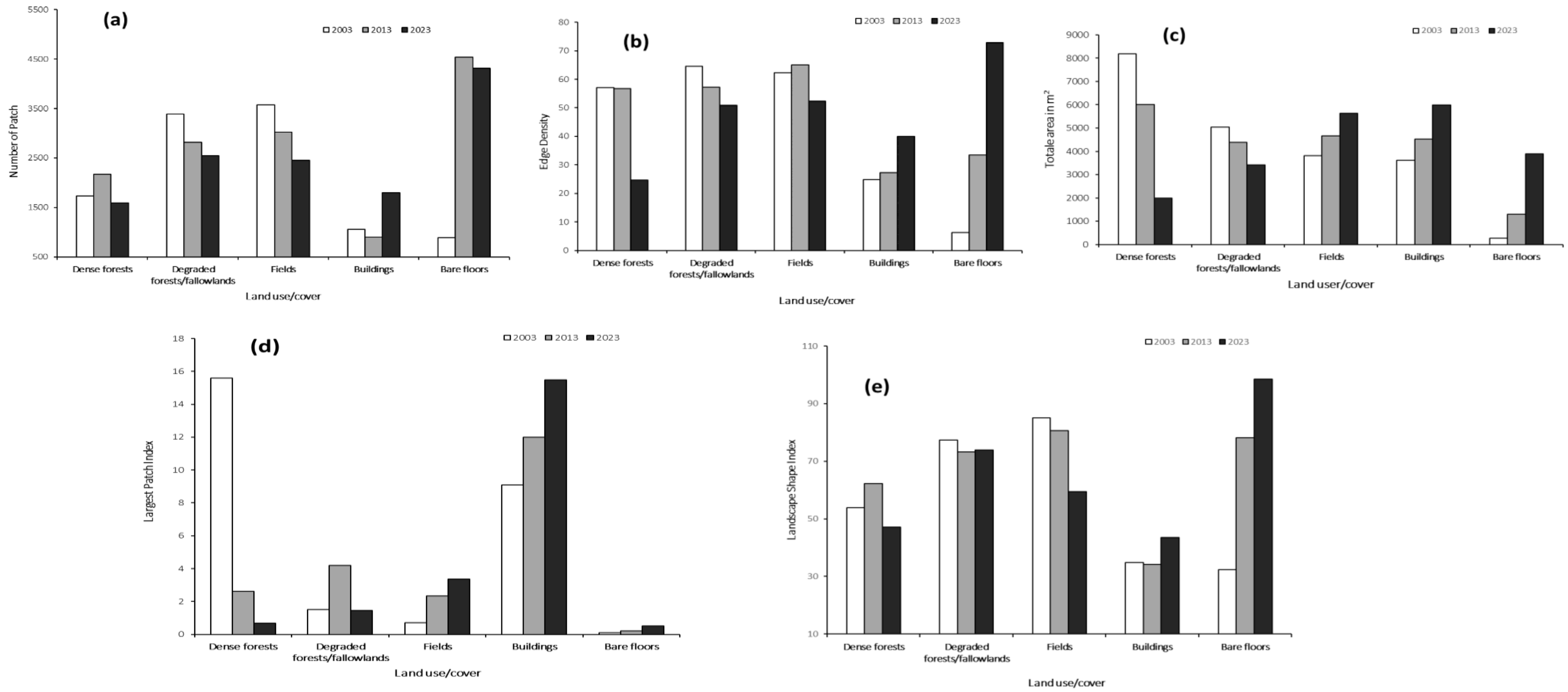

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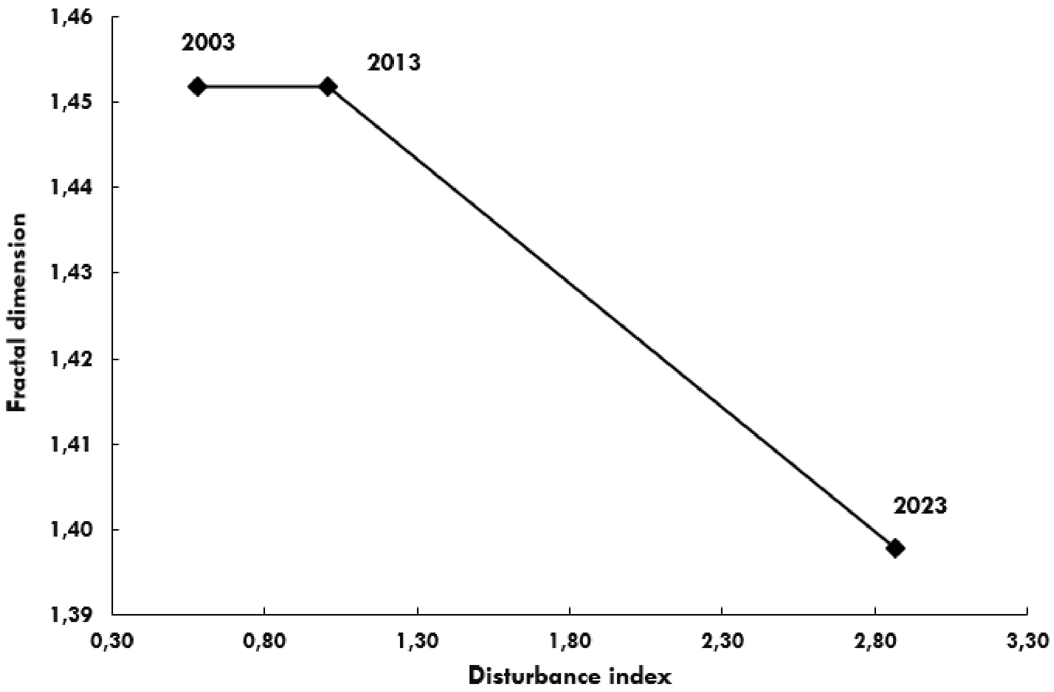
Table 3. Characterization of spatial transformation processes in the urban landscape of Butembo between the 2003-2013 period and 2013-2023 period based on the decision tree of Bogaert *et al.* (2004). The t_{obs} (0.75) were used to differentiate dissection from fragmentation (Thalès de Haulleville *et al.*, 2018).

Land use-cover	Spatial transformation process	
	2003-2013	2013-2023
Dense forests	Fragmentation	Deleting
Degraded forests/fallow lands	Deleting	Deleting
Fields	Aggregation	Aggregation
Buildings	Aggregation	Creation
Bare floors	Creation	Aggregation

Landscape anthropization

Figure 6 illustrates the evolution of the fractal dimension index of land use classes in relation to the landscape disturbance index in Butembo, based on map data from Landsat image processing in 2003, 2013 and 2023. Disturbance was more pronounced between 2013 and 2023 than between 2003 and 2013 during which the various land uses were more stable. Analysis of the curve in this figure shows that, at the scale of the Butembo landscape, the increase in the landscape disturbance index values over the years leads to a reduction in the fractal dimension index values of the land-use classes. This indicates that the more the landscape is disturbed, the more the patches of forest classes take on a regular shape, characteristic of anthropogenic landscapes.

Figure 6. **Index of the fractal dimension of natural land-use classes as a function of the landscape disturbance index in Butembo, eastern DRC. Based on map data from Landsat image processing in 2003, 2013 and 2023. The disturbance index is defined as the ratio of the cumulative area of anthropogenic classes (Agricultural lands, Bare soils, and Buildings) in the landscape to the cumulative area of natural classes (Dense forests and Degraded forests/fallow lands).**



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DISCUSSIONS

Land-Use Dynamics between 2003 and early 2023

Geospatial information is essential for the development of cities and regions. It enables us to analyze the causes of urban problems, explore potential solutions, and formulate appropriate action plans (JACA. 2020). The landscape was predominantly dense forests, accounting for 39.16% between 2003 and 2013 and 28.76% between 2013 and 2023. During these periods, there was a significant transformation of dense forests into degraded forests/fallow lands: 11.26% of dense forests became degraded forests/fallow lands, while only 4.22% of degraded forests/fallow lands returned to dense forests, resulting in a net flow of 7.04%. Conversely, non-natural classes saw their percentages increase, mainly at the expense of degraded forests/fallow lands (9.95% to agricultural lands and 2.35% to Bare soils).

The rapid growth in demand for building land is being met by converting agricultural land and linking agricultural plots to urban plots. Consequently, there is competition between agricultural land and building land (Muhindo, 2011). A recent study by Muhindo (2012) shows that the densification of buildings and other artificial surfaces, both inside and outside the city, is increasing. This land use change is driven by population growth, resulting from factors such as the influx of war survivors from the Great Lakes region, job seekers in this commercial city, people seeking better healthcare, quality education, and a high fertility rate (Balthazare, 2022).

Li, (2020) also noted that the increase in urban land use is 50% higher than population growth, which appears to be the case in the study area. The consequences are not limited to simple land use changes. Rapid population growth in developing countries leads to galloping urbanization at an unprecedented rate. Often, government agencies are unable to adequately address emerging problems such as traffic congestion, air pollution, flooding from heavy rains and solid waste disposal (JICA, 2022). Therefore, for socio-economic development to be sustainable and improve the quality of life, cities must rely on sound, long-term diagnoses, and strategies (Okanga *et al.*, 2018; Chenal, 2020).

Quantifying changes in land-use classes

The results of the study on Butembo clearly illustrate a trend toward the conversion of natural areas into urban zones, with significant changes in land-use classes over time. This conversion is mainly characterized by the growth of built-up areas at the expense of forest and agricultural zones. A similar dynamic is observed in other cities of the DRC (Balandi *et al.*, 2023; Muteya *et al.*, 2023; Muteya *et al.*, 2022), where demographic pressure and economic growth drive rapid urban expansion.

Previous studies on the urban landscape dynamics of Lubumbashi and Kisangani have also highlighted similar trends. For example, research by Sikuzani *et al.* (2017) and Balandi *et al.* (2023) showed a significant increase in building density in these two cities, with a corresponding decrease in natural areas. Kabanyegeye *et al.* (2021) observed a fourfold increase in the proportion of built-up area in the city of Bujumbura, while the proportion of vegetation was halved. At this rate of spatial transformation of Bujumbura's urban landscape, the sustainability of the ecosystem services provided by green spaces is seriously compromised. Similarly, a study by Salomon *et al.* (2020) in Cap-Haïtien revealed a strong conversion of agricultural land to urban areas. With major implications for food security and environmental sustainability.

The impact of these changes on the environment and society is also a major concern. The loss of green spaces and agricultural land can affect biodiversity, air quality and resilience to climate change. Additionally, the rapid growth of urban areas can lead to socio-economic challenges such as traffic congestion, access to basic services and waste management.

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Spatial transformation process

Transformation processes reveal the effectiveness of changes in the configuration and composition of land use in Butembo. The processes observed in forest formations lead to processes that lead to their disappearance (fragmentation. suppression). On the other hand, the processes observed at the level of anthropogenic areas favour their expansion (Aggregation and Creation). Forest formations gradually disappear and are replaced by anthropogenic formations (Mama *et al.*, 2020). These results are like those of Barima *et al.* (2009) and Mama *et al.* (2020), who found forest suppression processes in areas under anthropogenic influence in eastern Côte d'Ivoire and Benin respectively. Thalès de Haulleville *et al.* (2018) and Sikuzani *et al.* (2018) also observed forest fragmentation in the Katanga landscape and the Arivonimamo forest in Madagascar, respectively.

Landscape Anthropization

This study shows the high conversion of dense forests into degraded forest/fallow lands and agricultural lands, and the conversion of agricultural lands and dense forests into buildings. This confirms the observed decrease in dense forests and degraded forest/fallow lands and indicates the instability of land-use classes in the Butembo landscape over the study period. Several other authors have reported similar trends in Central Africa, notably in Kinshasa (Sambieni, 2019) and Lubumbashi (Sikuzani *et al.*, 2018). Indeed, according to Akpoyètè *et al.* (2018), forest/savanna formations are increasingly being replaced by anthropogenic formations (agricultural lands/fallows, settlements) in tropical zones. Furthermore, the reduction in the values of the fractal dimension index of land use classes is a consequence of the increase in the landscape disturbance index values. This means that the more the Butembo landscape is anthropized, the more the patches of natural formations take on a regular shape.

This study, while methodologically robust, presents certain limitations and notable findings with significant theoretical and practical implications. First, the reliance on Landsat images with a spatial resolution of 30 meters may overlook fine-scale land-use changes, particularly in densely urbanized or fragmented landscapes. Furthermore, the temporal resolution of the data, limited to 2003, 2013, and 2023, may fail to capture annual or seasonal variations in land cover dynamics. Some anomalies were also identified in the results, such as irregular trends in the stability indices of land-use classes, which could be influenced by external factors like unplanned construction or political events. Additionally, the aggregation of built-up areas between 2003 and 2013, followed by rapid patch creation from 2013 to 2023, reveals varying urbanization processes that require further investigation.

Theoretically, this study reinforces the theory of anthropization by demonstrating how urbanization systematically replaces natural landscapes with anthropogenic structures. It also contributes to landscape ecology by quantifying the impacts of anthropogenic pressures on ecological degradation and offering insights into patterns of landscape fragmentation and land-use transformations over time. Practically, the findings have direct applications for urban planning and natural resource management in Butembo. By identifying high-risk zones for ecological degradation, the study provides guidance for targeted interventions such as reforestation initiatives and the creation of urban green spaces. Furthermore, the spatial and temporal data form a critical foundation for the development of a comprehensive urban and cadastral plan, aimed at mitigating unplanned urban expansion and promoting sustainable development.

To address the limitations and enhance the robustness of future studies, several suggestions are proposed. First, the use of higher-resolution imagery, such as Sentinel-2, is recommended to improve spatial accuracy and detect fine-scale land-use changes, particularly in densely urbanized or fragmented areas. Second, increasing the temporal frequency of data

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collection would allow for the analysis of annual or seasonal variations in land cover dynamics, providing a more detailed understanding of urbanization trends. Third, integrating socio-economic surveys into the research framework could help correlate land-use changes with demographic and economic drivers, offering deeper insights into the underlying causes of urbanization. Finally, examining the ecological impacts of these land-use transformations, such as biodiversity loss and alterations in ecosystem services, would provide a more holistic view of the consequences of rapid urbanization.

CONCLUSION

The aim of this paper was to analyze the dynamics of land use in the urban landscape of Butembo from 2003 and 2023. The evolution of land use showed a sharp decrease in dense forest, degraded forest and wasteland, and an increase in built-up areas and bare soil. This increase indicates anthropization and needs to be considered in the city's development. Quantifying changes in land-use classes in urban landscapes is essential to understanding the challenges and opportunities associated with rapid urbanization. By integrating interdisciplinary data and methods, researchers can contribute to more efficient resource management and the creation of more resilient, sustainable cities. These results suggest the need for an integrated land-use plan for the sustainable management of Butembo and its natural resources.

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Declaration of Competing Interest

The authors declare that they have no conflicts of interest that might appear to influence the outcome of this paper.

AUTHOR'S CONTRIBUTIONS

Kalambulwa, N.A. drafted the article, Kakule M.S. collected the data, Mbavumoja S.T. and Teteli S.C. processed the data and drafted the methodology, Ahouandjinou S.D.I.T., Bitagirwa N.A., Mumba T.U., Lobho L.J. and Mumbere S.E. read the draft and made corrections and Cabala K.S. made the final revision.

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