**Understanding the impact of deforestation on Land Use Land Cover Change (LULC) in Kalonge, South-Kivu village over the past 33 years.**

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The study delves into the dynamics of land use and land cover change (LULC) in Kalonge, South Kivu province, DRC, amidst pressing challenges posed by deforestation driven by factors like agricultural expansion and urban development. Utilizing Landsat imagery spanning three decades (1990, 1998, and 2023) and remote sensing techniques, particularly supervised classification and post-classification change detection analysis, LULC trends were examined. Between 1990 and 2023, forest cover in Kalonge decreased from 66.5% to 61.4%, while savanna increased from 32.5% to 34.3%. Fallow fields saw a notable increase from 0.9% to 3.5%, along with a rise in the rural agricultural complex from 0.02% to 0.6%. The overall accuracy (Kappa) of 83.5% confirms the reliability of these findings. Interestingly, the shift towards agricultural land predates 1990, suggesting a nuanced relationship between deforestation and advancing agricultural frontiers. Moreover, an evident increase in forest cover near urban areas implies the effectiveness of local reforestation initiatives. These findings underscore the intricate interplay between human activities and environmental changes in Kalonge, emphasizing the need for holistic strategies to address deforestation and promote sustainable land management practices. Future research could delve deeper into the specific drivers of LULC and their implications for ecosystem services and local livelihoods in the region. By understanding these underlying dynamics, policymakers and stakeholders can formulate targeted interventions to conserve remaining forested areas and enhance the resilience of Kalonge's ecosystems.

**Keywords**: Deforestation, Ecosystem services, Land use, and land cover change.

## 1. Introduction

Tropical forests play a pivotal role in global environmental equilibrium and support the livelihoods of local communities (FAO, 2018). However, the escalating threat of deforestation, exacerbated by diverse human activities, imperils these crucial ecosystems, resulting in substantial losses of forested areas and compromising associated ecosystem services (Zakari et al., 2021). This study focuses specifically on the Kalonge region, situated in the South Kivu province of the Democratic Republic of the Congo (DRC). Between 1990 and 2020, global forest cover witnessed a reduction of 420 million hectares, with the DRC experiencing a particularly pronounced impact, losing 1.22 million hectares of natural forest in 2022 (Global Forest Watch, 2022). This extensive deforestation, primarily attributed to activities such as commercial agriculture, subsistence farming, urban expansion, infrastructure development, mining, and logging (FAO, 2018), poses a severe threat to biodiversity and the well-being of local communities heavily reliant on forest resources for their sustenance (Kabwanga et al., 2020). The Kalonge area, in particular, confronts significant challenges associated with the demand for wood energy from the city of Bukavu, exerting considerable pressure on local forests and resulting in alterations in land use, rapid deforestation, and a concurrent decline in ecosystem services (Mudarhi, 2019). However, the initiation of this study stems from a dearth of comprehensive analyses concerning the impact of land cover and land use changes in rural areas within the specific context of South Kivu. The study's objective is to map the evolution of land use and land cover changes over 33 years. To achieve this, a robust methodology was employed, involving the analysis of Landsat satellite images from 1990, 1998, and 2023. The supervised classification methodology, utilizing the Support Vector Machine (SVM) algorithm in ArcGIS Pro, was employed to delineate changes in land use. Post-classification analysis facilitated the evaluation of classification accuracy and the generation of visual maps illustrating the dynamic evolution of land use in Kalonge over time.

## 2. Study Area and Methodology

### *2.1. Study Area*

This study was conducted in the mountainous region of the eastern Democratic Republic of Congo (DRC), specifically in the South Kivu province, Kalehe territory, and the municipality of Kalonge, around the Kahuzi-Biega National Park (PNKB).

#### *2.1.1. Geographic Location of KALONGE*

Figure 1 illustrates the location of Kalonge, starting from the Democratic Republic of Congo, the South Kivu province, and the Kalehe territory, reaching the Kalonge area.

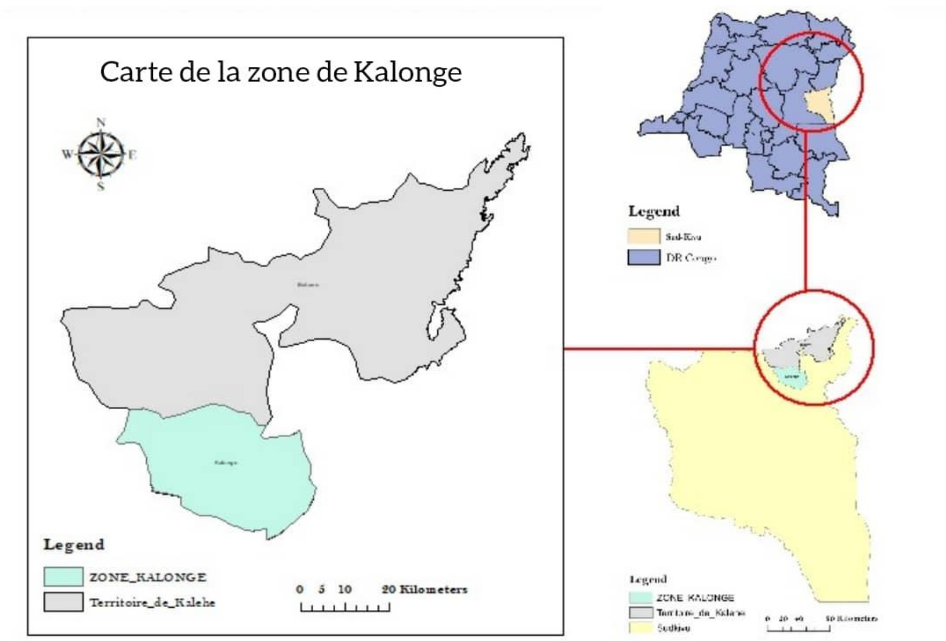



**Fig. 1**: Map of the study area

Kalonge encompasses an expanse of 750 km² and is geographically demarcated to the north by the Buholo community and the municipality of Kalima, to the south by the Kabare territory, to the west by the Kahumba and Biapoka rivers, along with the Nyamusenge massif acting as a natural boundary from the Shabunda area, and to the east by the Kahuzi-Biega National Park (PNKB) in South Kivu, Democratic Republic of the Congo (DRC). The region is characterized by a mountainous climate, situated along the Tumba mountain range. The annual precipitation in Kalonge fluctuates between 1300 and 1680 mm, accompanied by an average annual temperature of 17.5ºC. Absolute maximum temperatures range from 25.5ºC to 28ºC. The climatic seasons are predominantly categorized into a rainy period, spanning around 9 months from September to May, and a dry season, extending for approximately 3 months from June to August (Mugisho et al., 2022).

### 2.2. Methodology

*2.2.1. Land use land cover (LULC Mapping)*

*2.2.1.1 Pre-classification analysis*

- *Data collection and Preprocessing*

Landsat satellite images (5, 5, and 9) from the years 1990, 1998, and 2023 were selected to study the evolution of land use and land cover in Kalonge. The 1990 image provides insights into the state of the forest before the civil war in Kivu, the 1998 image captures the initial impacts post-conflict, and the 2023 image reflects the current state.

- *Characteristics of images used for temporal land use Analysis*

Table 2 summarizes the characteristics of the satellite images used for the temporal analysis of land use, including bands, acquisition dates, and spatial resolution.

**Table 1: Characteristics of satellite images**

| Image | Spectral bands | Acquisition period | Spatial resolution |
|---|---|---|---|
| 1990 (Landsat 5) | B1, B2, B3, B4, B5, B7 | 07-10/1990 | 30m |
| 1998 (Landsat 5) | B1, B2, B3, B4, B5, B7 | 07-09/1998 | 30m |
| 2023(Landsat 9) | B2, B3, B4, B5, B6, B7 | 07-09/2023 | 30m |

- *Identification of Land Use Classes*

In the scope of this study, the mapping of land cover and land use involved considering four distinct types: forest, savanna, fallow field mosaics, and rural agricultural areas. These choices were justified by the diversity of historical landscapes, encompassing wooded areas, semi-open savannah spaces, temporary agricultural plots, and complex agricultural zones, reflecting the complexity of past land uses and landscapes (Mudarhi, 2019).

*2.2.1.2. Classification*

- *Classification Method*

The pixel-by-pixel supervised classification method involves using an algorithm that analyzes each pixel individually to determine its category based on spectral characteristics using the Support Vector Machine (SVM) algorithm. A set of training samples was utilized, including pixels previously identified and classified to teach the algorithm to recognize specific features of different classes (in this case: forest, savanna, fallow field mosaics, and rural agricultural areas). The algorithm then applied this knowledge to classify each pixel in the image based on its spectral properties, allowing for precise identification of land use and land cover. This approach aims to minimize overall errors by treating each pixel individually, enhancing the accuracy of classification (Imorou, 2018).

- *Classification Algorithm*

The Support Vector Machine algorithm in ArcGIS Pro, version 2.8, was chosen for its efficiency in classifying small-scale data, handling missing data, and demonstrating good performance in classification (Bax, 2018). Training data was crucial to train this algorithm, ensuring reliable classification results. 1000 training points were taken for each class. By using these data for the training process, the algorithm learned to recognize specific patterns associated with land use and land cover, guaranteeing accurate and robust classification of satellite images.

*2.2.1.3 Post-classification analysis*

- *Accuracy Assessment*

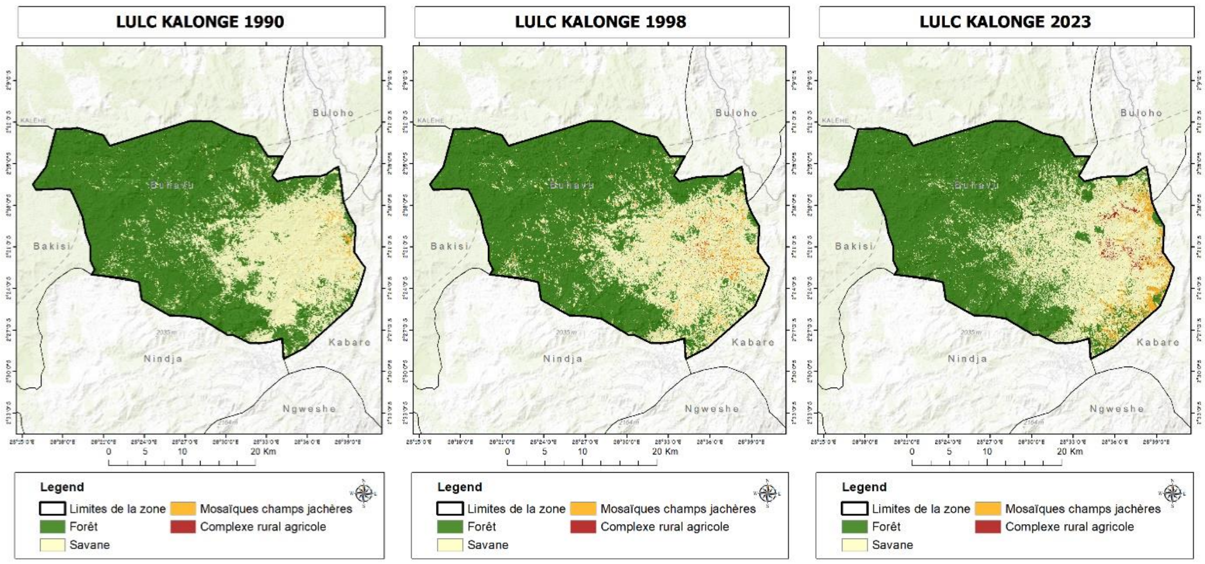
The accuracy of the classification was assessed using the confusion matrix method, allowing measurement of the algorithm's performance through the Kappa coefficient (Imorou, 2018). The Kappa coefficient precisely quantified the percentage of exact classification. In addition to the confusion matrix, a transition matrix was generated to represent changes or transitions between different land use classes. This approach provided a detailed perspective on variations and trends in classification, enriching the analysis of the obtained results.

- *Mapping and Visualization*

Three land use and land cover maps were created to visually illustrate the results. ArcGIS Pro, version 2.8, was the selected software for this mapping. These maps detailed the changes in land use and land cover, highlighting areas affected by deforestation over time. The use of ArcGIS Pro facilitated data manipulation and visualization, providing accurate and informative maps for a better understanding of deforestation trends in the study area.

## 3. Results

*3.1.1. LULC mapping*




According to the above results, there have been noticeable changes in land cover and land use in the village of Kalonge over the past 33 years. The maps illustrate that fallow field mosaics and the rural agricultural complex have increased over time, leading to a reduction in forested areas. This is attributed to an increase in other land use classes (savanna and fallow field mosaics), as indicated by the transition matrix (Table 4).

*3.1.2. Spatial evolution of land use in Kalonge (1990-2023)*

*Table 2 Confusion matrix*

| Classes | 1990 | | 1998 | | 2023 | |
|---|---|---|---|---|---|---|
| | Km² | % | Km² | % | Km² | % |
| **Forest** | 591,6 | 66,5 | 563,4 | 63,3 | 546,5 | 61,4 |
| **Savanna** | 289,5 | 32,5 | 299,7 | 33,7 | 305,1 | 34,3 |
| **Fallow field mosaics(FFM)** | 8,1 | 0,9 | 22,9 | 2,5 | 31,7 | 3,5 |
| **Agricultural land (AL)** | 0,2 | 0,02 | 3,4 | 0,3 | 5,9 | 0,6 |
| **Kappa** | 78,6 | | 76,2 | | 83,5 | |

Between 1990 and 2023, the forest in Kalonge decreased from 66.5% to 61.4%, while the savanna increased from 32.5% to 34.3%. Fallow fields significantly increased, from 0.9% to 3.5%, as did the rural agricultural complex, from 0.02% to 0.6%. The reliability of this result is evidenced by the overall accuracy (Kappa) of 83.5%.

*3.1.3 Evolution of Expansion Rates (ER) of Land Types in Kalonge (1990-2023)*

| | | ER % (1990-1998) | ER% (1998-2023) |
|---|---|---|---|
| **Forest** | | -4.77 | -2.99 |
| **Savanna** | | 3.52 | 1.82 |
| **Fallow field mosaics (FFM)** | | 182.72 | 38.47 |
| **Agricultural land (AL)** | | 1574.45 | 74.66 |

This table illustrates the Expansion Rates (ER) of different land cover categories in Kalonge between 1990-1998 and 1998-2023. A decrease in the forest is observed, with an expansion rate of -4.77% (1990-1998) and -2.99% (1998-2023). The savanna experiences moderate growth, with rates of 3.52% and 1.82%, respectively. Fallow field mosaics show significant expansion, with remarkable expansion rates of 182.72% (1990-1998) and 38.47% (1998-2023). The rural agricultural complex displays substantial growth, covering 1574.45% and 74.66%.

*3.1.4. Analysis of Changes in Land Use/Land Cover Classes*

*Table 3 Transition matrix*

| | | 2023 | | | | |
|---|---|---|---|---|---|---|
| | | **Forest** | **Savanna** | **FFM** | **AL** | **Grand Total** |
| **1990** | **Forest** | 500,52 | 80,93 | 8,53 | 0,05 | 590,03 |
| | **Savanna** | 41,98 | 219,79 | 19,90 | 5,22 | 286,88 |
| | **FFM** | 0,81 | 4,79 | 1,24 | 0,12 | 6,96 |
| | **AL** | 0,00 | 0,11 | 0,02 | 0,03 | 0,15 |
| | **Grand Total** | 543,31 | 305,61 | 29,69 | 5,41 | 884,02 |

Between 1990 and 2023, Kalonge's forest area decreased from 543.31 km² to 500.5 km², with a notable shift towards savanna (80.9 km² to 219.7 km²) and an increase in fallow field mosaics (8.5 km² to 19.9 km²). Marginal changes were observed in rural agricultural complexes. The decline in forest cover and growth in savanna may stem from deforestation, increased agriculture, or urbanization. Fallow field mosaic expansion and rural agricultural complex growth may indicate intensified farming or altered land use to meet population demands.

## 4. Discussion

### *4.1. Land Use and Land Cover Mapping*

This study has revealed a substantial shift in land use and cover, transitioning from forests and savannas to agricultural zones. This trend aligns with global concerns, underscoring the pressing need to conserve natural ecosystems and the vital services furnished by forests. Imorou et al. (2018) and FAO (2022) emphasize the urgency of conservation amidst agricultural expansion. Jackson et al.'s (2020) research on agricultural expansion's impact on biodiversity aligns with these findings, demonstrating a significant decline in species richness and abundance across diverse forests, including tropical, temperate, and boreal regions. Their analysis identifies influencing factors such as cultivation type, climate, and forest patch size, contributing valuable insights into biodiversity changes following agricultural expansion.

### *4.2. Expansion Rates*

Observations spanning from 1990 to 2023 revealed an initial reduction in forested areas followed by a deceleration, aligning with FAO (2020) trends. Imorou (2018), FAO (2020), Gibbs et al. (2010), DeFries et al. (2020), and Hansen (2013) collectively emphasize the alarming global trend of diminishing forests due to agricultural expansion. High Kappa scores affirm consistent land use change classification over time. These findings align with Imorou (2018) and FAO (2020), highlighting the ongoing decrease in land cover concurrent with agricultural expansion. Gibbs et al. (2010) and DeFries et al. (2020) stress the consequential conversion of forests to agriculture, in harmony with the Kalonge study. These convergent insights underscore the persistent detrimental impacts of agricultural expansion on forest ecosystems. Recommendations across studies emphasize the urgent need to strike a balance between agricultural requirements and forest preservation, which is crucial for global biodiversity and ecosystem services.

### *4.3. Transition Matrix*

The transition matrix has elucidated specific changes in the conversion of various land cover categories over the years, illustrating the evolution of lands in the studied region between 1990 and 2023. Notably, there was a substantial shift from forest to savanna, accompanied by moderate increases in savanna and fallow field mosaics. Minimal conversions were observed from rural agricultural complexes to other categories during this period. Zoderer et al.'s (2019) research aligns with these findings, reporting significant conversions from forest to agricultural and savanna areas over comparable time frames. Similarly, the studies by Imorou (2018) and Nyangoko et al. (2022) corroborate these observations, supporting the trends identified in the transition matrix and enhancing the comprehension of land cover changes in the studied region.

## 5. Conclusion

This study highlights the significant impact of land use and land cover change on ecosystem services in Kalonge forest over the past three decades. A noticeable decline in forest cover, primarily driven by agricultural expansion, has significant implications for biodiversity and ecosystem stability. While the observed deceleration in forest loss hints at a potential shift in deforestation trends, it occurs amidst ongoing global challenges. The escalating expansion rates underscore the urgent need for a balanced approach that reconciles agricultural demands with forest preservation to ensure ecological equilibrium. Recommendations for forest ecosystem restoration are crucial to mitigate the adverse effects of deforestation and safeguard global biodiversity. Sustainable land management practices, including reforestation initiatives and community-based conservation efforts, hold promise for enhancing forest resilience. Future research should explore the underlying drivers of agricultural expansion and their implications for land use dynamics and ecosystem health. Additionally, assessing the effectiveness of conservation policies and integrating land-use planning strategies can inform evidence-based decision-making and support long-term conservation efforts in Kalonge and similar regions.

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