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Spatio-Temporal Dynamics of Rapid Urbanization on Agricultural Lands in Musanze District

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Abstract

Urbanisation has become one of the most significant drivers of land use and land cover (LULC) change worldwide, especially in developing countries where rapid population growth and economic transformation exert pressure on agricultural lands. Rwanda, and particularly Musanze District, has experienced notable urban expansion during the past two decades, often at the expense of productive farmland. This study aims to assess the spatial and temporal patterns of land use land cover (LULC) changes driven by urbanization in Musanze District between 2005 and 2025. The research employed remote sensing and Geographic Information Systems (GIS) techniques, analysing multi-temporal Landsat imagery (2005, 2010, 2015, 2020, and 2025) to detect and quantify changes in major land cover classes. The results are expected to reveal trends of urban sprawl, reduction of agricultural land, and shifts in settlement patterns. Rwanda's expanding economy and growing population have led to an increase in built-up areas across the country; however, this growth has been accompanied by uneven changes in agricultural land use over recent decades. This study analyzes the spatio-temporal dynamics of rapid urbanization on agricultural lands in Musanze District between 2005 and 2025. The study's findings revealed trends of urban expansion, reduction in agricultural land, and changes in settlement patterns. The findings contributed to evidence-based land use planning and sustainable urban management, while providing insights for local authorities to balance urban development with agricultural land preservation.

Keywords: *Agricultural Land Conversion, Urban expansion, Land use change, spatio - temporal dynamics, Musanze District.*

1. Introduction

Urbanization is a global social and economic phenomenon that continues to reshape land use patterns and human settlements. As populations grow, the demand for housing, infrastructure, and economic activities increases, leading to the expansion of urban areas into agricultural lands and natural environments (UN-Habitat, 2021). Globally, urbanization has accelerated rapidly, with more than 55% of the world's population living in urban areas in 2020, a figure projected to reach 68% by 2050 (UN-Habitat, 2021). This expansion often results in the conversion of agricultural landscapes into built-up

environments, contributing to food insecurity, biodiversity loss, and land degradation (Van Noorloos & Kloosterboer, 2023). Population growth and urbanization remain the primary drivers of land use and land cover (LULC) changes worldwide (Kok, 2024).

In Sub-Saharan Africa, urbanization has grown at an annual rate exceeding 4% between 2000 and 2019, making it one of the fastest urbanizing regions globally (Ru et al., 2022). Although East Africa remains relatively under-urbanized compared to other regions, urban growth continues to increase significantly due to population growth and economic development (Charlery de La Masselière et al., 2022). Rwanda has experienced similar trends, with the urban population projected to increase from 28.81% in 2015 to 52% by 2050 (Li et al., 2021). Following the post-1994 reconstruction period, the country has undergone rapid socio-economic transformation characterized by increasing urban populations, infrastructure development, and expansion of urban land (Nduwayezu et al., 2021; Egide et al., 2022).

Musanze District, located in Rwanda's Northern Province, exemplifies these urbanization dynamics. As one of Rwanda's designated secondary cities and a major agricultural hub, Musanze plays a critical role in both urban development and food production (MININFRA, 2022). However, rapid urban expansion has led to the conversion of productive agricultural land into residential, commercial, and industrial uses, threatening agricultural productivity, food security, and environmental sustainability (Mukantwali et al., 2019; NISR, 2022). Despite these changes, limited spatially explicit information exists regarding the extent and patterns of agricultural land conversion. Therefore, this study employs geospatial techniques, including remote sensing and GIS, to assess LULC changes and agricultural land conversion in Musanze District between 2005 and 2025, providing evidence to support sustainable urban planning and agricultural land management.

1.2 Objectives of the Research

1.2.1 General objective

The general objective of the study was to assess the spatio-temporal dynamics of rapid urbanization on agricultural lands in Musanze District (2005–2025).

1.2.2. Specific objectives

(i) To assess the spatio-temporal pattern and extent of urbanization in Musanze District from 2005 to 2025.
(ii) To evaluate the extent and spatial distribution of agricultural lands affected by urbanization in Musanze District.
(iii) To analyze the relationship between agricultural land and urban expansion in Musanze District from 2005 to 2025.

2. Research methods

2.1 Description of the study area

Musanze District, located in Rwanda's Northern Province at approximately 1°30'S and 29°38'E, is strategically positioned along the Kigali–Rubavu Road and near Volcanoes National Park. This location has made the district an important center for tourism, commerce, and residential development, accelerating urban growth and increasing the conversion of agricultural land into urban uses. As a result, significant land use and land cover changes have occurred across the district.

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The district is characterized by a complex volcanic highland landscape associated with the Virunga volcanic region. Elevation ranges from about 1,800 m to 4,507 m above sea level, with Mount Karisimbi representing the highest point. These variations in altitude create diverse microclimatic conditions that influence temperature, rainfall, vegetation distribution, and agricultural suitability across different parts of the district.

Topography plays a critical role in shaping land use and urbanization patterns. Much of the district consists of steep slopes and valleys, limiting the availability of land suitable for construction and infrastructure development. Consequently, urban expansion is concentrated in flatter and gently sloping areas, which are also among the most productive agricultural lands. This situation intensifies competition between agricultural activities and urban development (REMA, 2015).

Musanze's average elevation of about 2,000 m and fertile volcanic soils support intensive cultivation of crops such as Irish potatoes, pyrethrum, and vegetables. However, high annual rainfall of 1,200–1,400 mm, combined with steep slopes and intensive land use, increases susceptibility to soil erosion when vegetation cover is removed (MINAGRI, 2018). Understanding these geographic and environmental characteristics is essential for interpreting land use and land cover changes and their spatial distribution in Musanze District between 2005 and 2025.

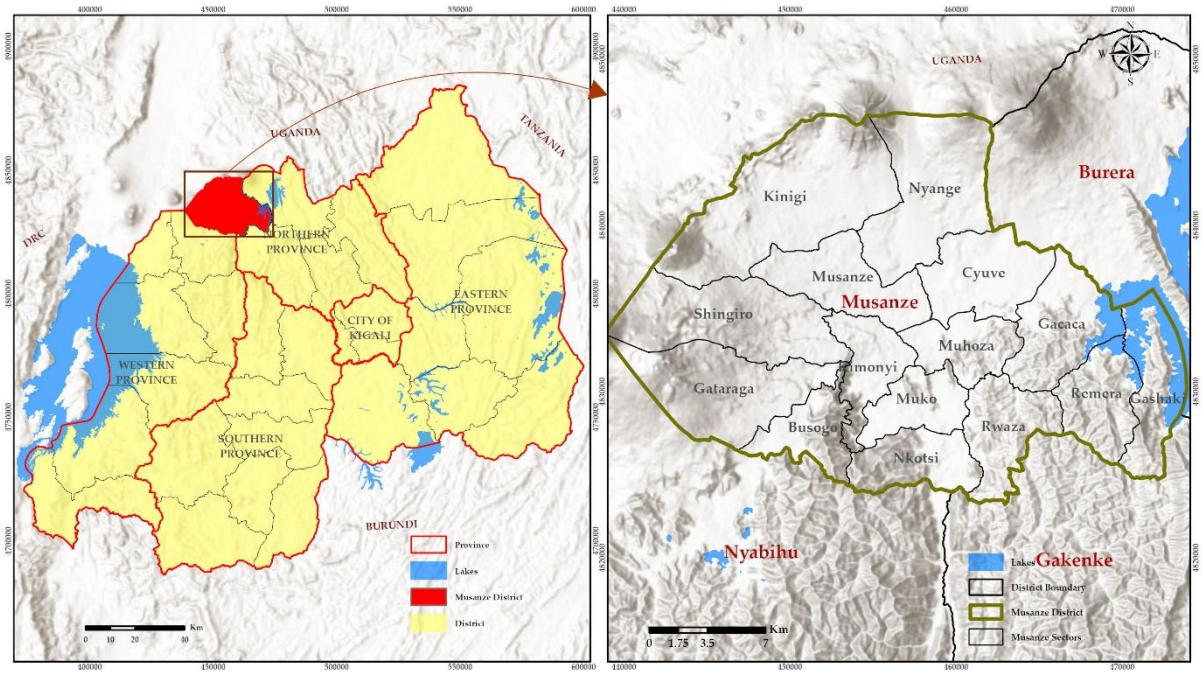

Figure 1: Map of study area

Source: Researcher mapping in Arc GIS 10.8, 2026

2.2. Research design and data collection methods

This study adopted a cross-sectional and correlational research design to assess the spatio-temporal dynamics of rapid urbanization and its impact on agricultural land in Musanze District between 2005 and 2025. The cross-sectional design enabled the collection and analysis of multiple variables at a specific point in time, providing a comprehensive snapshot of the relationship between urban expansion and agricultural land transformation.

The correlational approach was employed to determine the extent of association between factors such as population growth, settlement expansion, infrastructure development, land-use planning, household characteristics, and agricultural land conversion (Oso & Onen, 2020).

The study relied primarily on Geographic Information Systems (GIS) and remote sensing techniques to analyze land use and land cover (LULC) changes. Multi-temporal Landsat satellite imagery for the years 2005, 2010, 2015, 2020, and 2025 was obtained from the United States Geological Survey (USGS) database. Landsat ETM+, TM, and OLI datasets were selected because of their suitability for land-use classification and long-term environmental monitoring (Segarra, Buchaillot & Araus, 2020). The images were processed through band stacking, clipping to the study area, and pan-sharpening to improve spatial resolution from 30 m to 15 m.

Supervised classification techniques were used to classify major land cover categories, including built-up areas, agricultural land, forest/vegetation, water bodies, and bare land. GIS tools facilitated the integration of satellite imagery with topographic data, administrative boundaries, road networks, and other spatial datasets to examine urban growth patterns and agricultural land loss.

Remote sensing analysis focused on mapping urban expansion, detecting agricultural land conversion, quantifying the rate and magnitude of land-use changes, and identifying temporal trends. Classification accuracy was assessed using the Kappa coefficient, a statistical measure that evaluates agreement between classified maps and reference data while accounting for chance agreement (Congalton & Green, 2019). High Kappa values indicate reliable classification results, ensuring that observed agricultural land reductions accurately reflect urbanization processes rather than mapping errors (McDonald & Mansur, 2023).

2.3 Data analysis and processing

This Satellite image processing was conducted to prepare Landsat imagery for land use and land cover (LULC) classification and to analyse urbanisation-driven changes in Musanze District between 2005 and 2025. The process began with image pre-processing, including geometric correction and image registration to ensure all images were accurately aligned within the same coordinate system, allowing reliable comparison across different years. Radiometric calibration and atmospheric correction were applied to reduce distortions caused by atmospheric conditions, sensor differences, and illumination variations. The images were then clipped to the administrative boundary of Musanze District to focus analysis on the study area.

Supervised classification techniques were used to classify LULC into five major categories: built-up areas, agricultural land, forest/vegetation, water bodies, and bare land. Image enhancement and false-colour composites improved visual interpretation, while training samples derived from field observations, GPS points, Google Earth imagery, and local knowledge were used to develop spectral signatures for each land cover class. Classified maps were produced for 2005, 2010, 2015, 2020, and 2025.

Post-classification change detection analysis was employed to identify and quantify transitions between land cover classes over time. Particular emphasis was placed on measuring urban expansion, agricultural land loss, and identifying spatial hotspots of land

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conversion, especially in peri-urban areas surrounding Musanze City. GIS-based spatial analysis integrated classified maps with road networks, administrative boundaries, and field survey data to examine patterns of urban growth and its relationship with agricultural land decline.

Research reliability was strengthened through the use of consistent Landsat imagery, standardized supervised classification methods, accuracy assessment procedures, and comprehensive documentation of all analytical steps. Research validity was ensured through the use of multi-temporal imagery, independent validation samples, triangulation of multiple data sources, and application of established GIS and remote sensing techniques. Ethical considerations included data privacy, transparency, scientific integrity, and knowledge sharing. Key limitations involved Landsat's spatial resolution, temporal gaps between image years, cloud cover constraints, classification errors, and limited ability to establish causal relationships between urbanisation and land-use change.

3. Results

3.1 Spatial Distribution of Urbanized Areas (2005–2025)

The spatial distribution of urbanized areas in 2005 indicates a very low level of urban development in Musanze District. The total urbanized area was approximately 774.84 hectares (1.46%), with development highly concentrated in the Muhoza Sector. Urbanization appears as a compact cluster with limited extensions toward Musanze and Kinigi sectors.

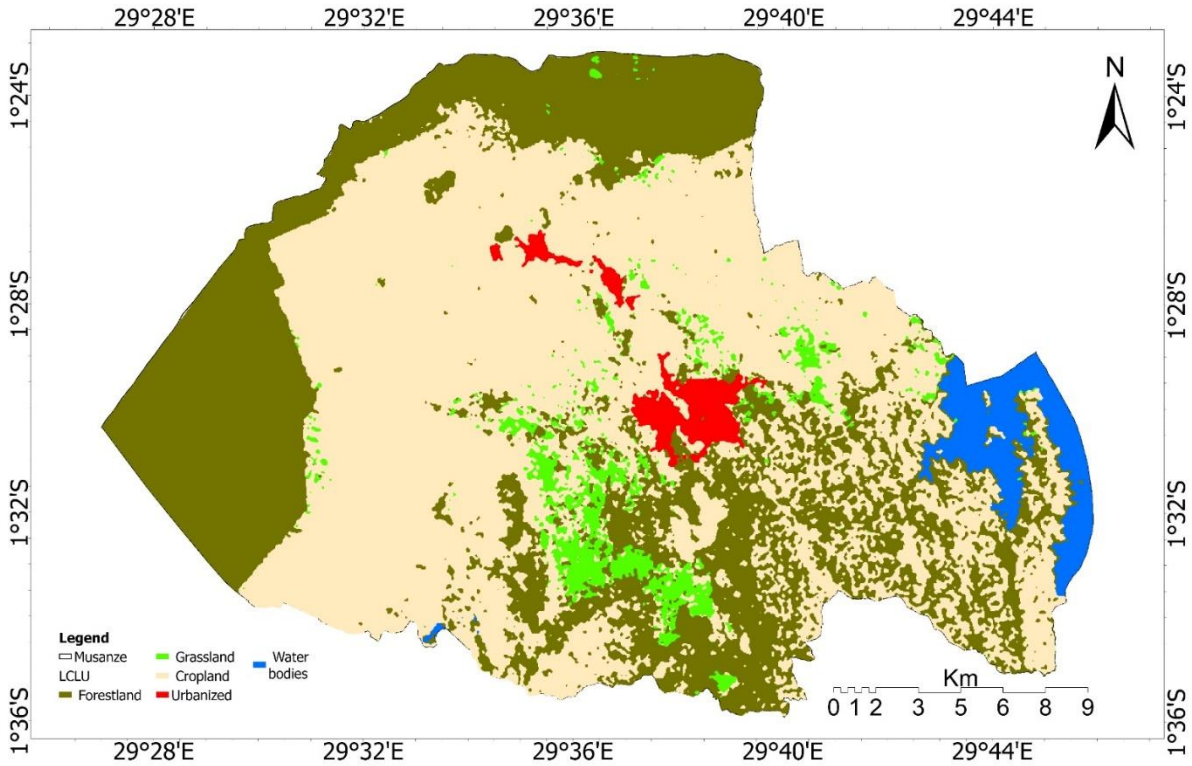

Figure 2: Urbanized Area Map of Musanze District (2005)

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3.1.2 Spatial Distribution of Urbanized Areas in 2010

By 2010, built-up areas increased to 963.6 hectares (~1.833%), showing noticeable expansion. Urban growth extended from Muhoza into Cyuve, Nyange, and Kinigi sectors, following road networks and forming linear and radial patterns.

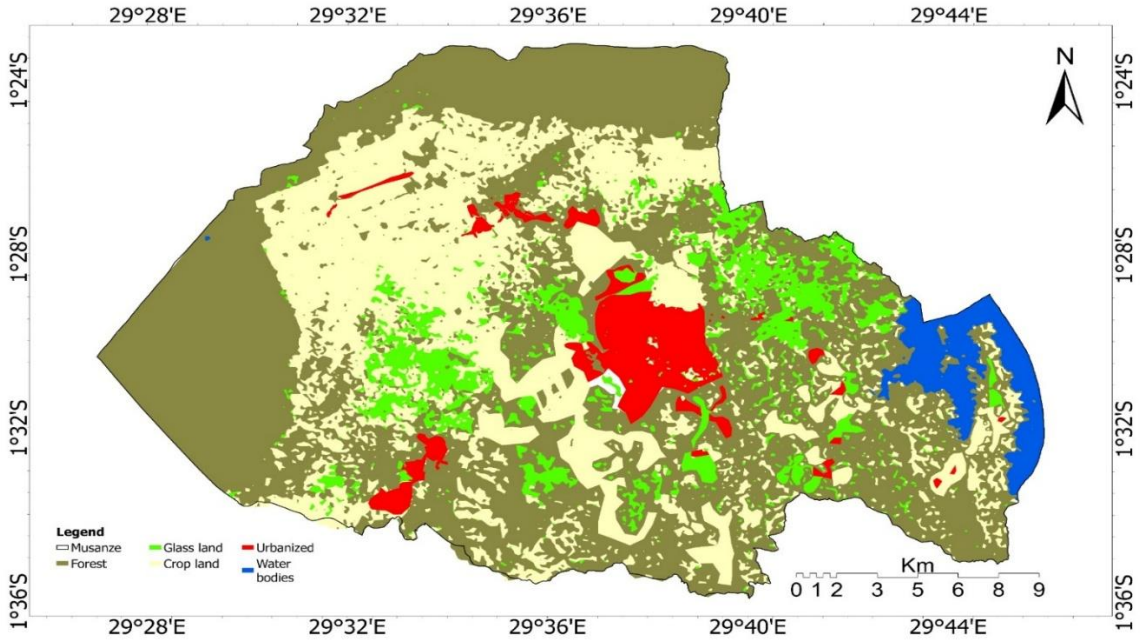

Figure 3: Urbanized Area Map of Musanze District (2010)

3.1.3 Spatial Distribution of Urbanized Areas in 2015

In 2015, urbanized areas expanded significantly to 1,473.002 hectares (2.79%). Urbanization became dispersed with multiple clusters across sectors such as Cyuve, Nyange, Gacaca, and Busogo, indicating peri-urban expansion.

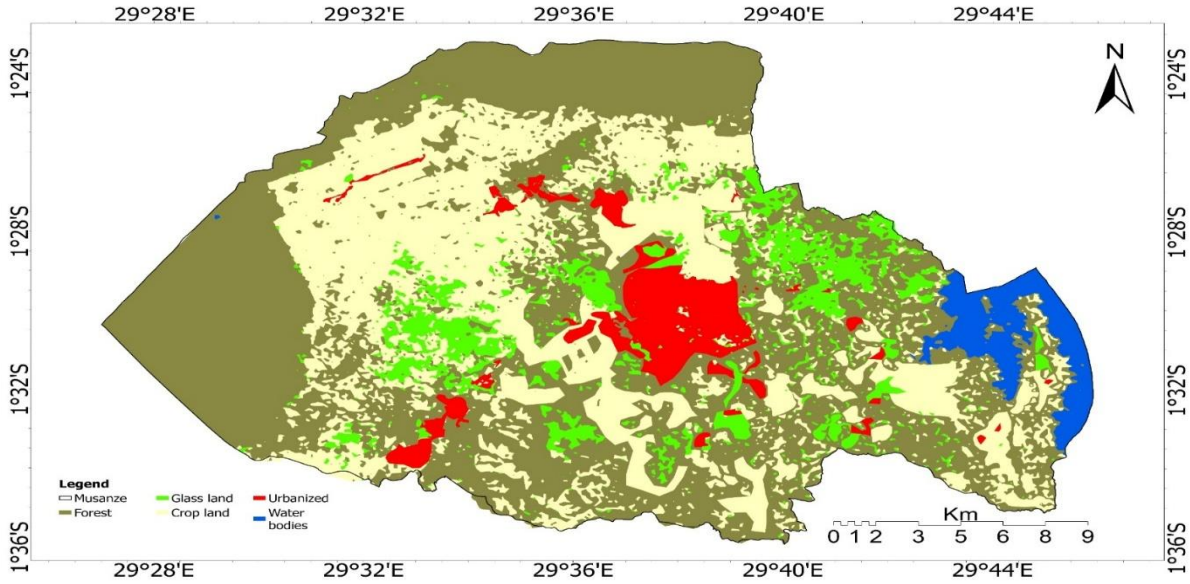

Figure 4: Urbanized Area Map of Musanze District (2015)

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3.1.4 Spatial Distribution of Urbanized Areas in 2020

In 2020, urbanized areas expanded significantly to 1,673.002 hectares (3.17%). Urbanization became dispersed with multiple clusters across sectors such as Cyuve, Nyange, Gacaca, and Busogo, indicating peri-urban expansion.

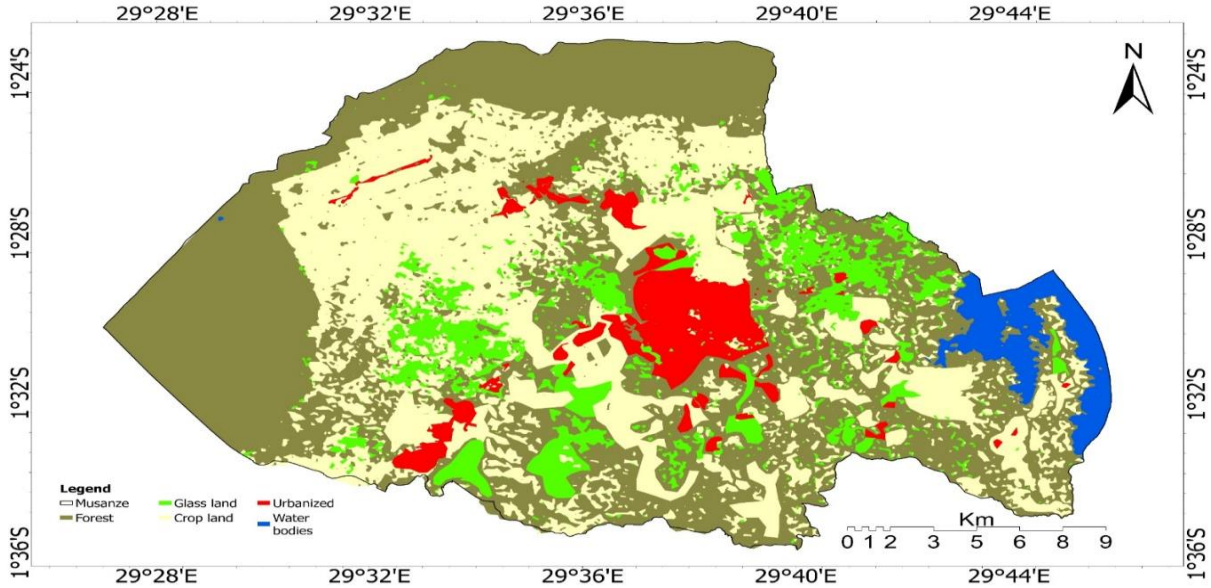

Figure 5: Urbanized Area Map of Musanze District (2020)

3.1.5 Spatial Distribution of Urbanized Areas in 2025

In 2025, urbanized areas expanded significantly to 2673.5 hectares (5.063%). Urbanization became dispersed with multiple clusters across sectors such as Cyuve, Nyange, Gacaca, and Busogo, indicating peri-urban expansion.

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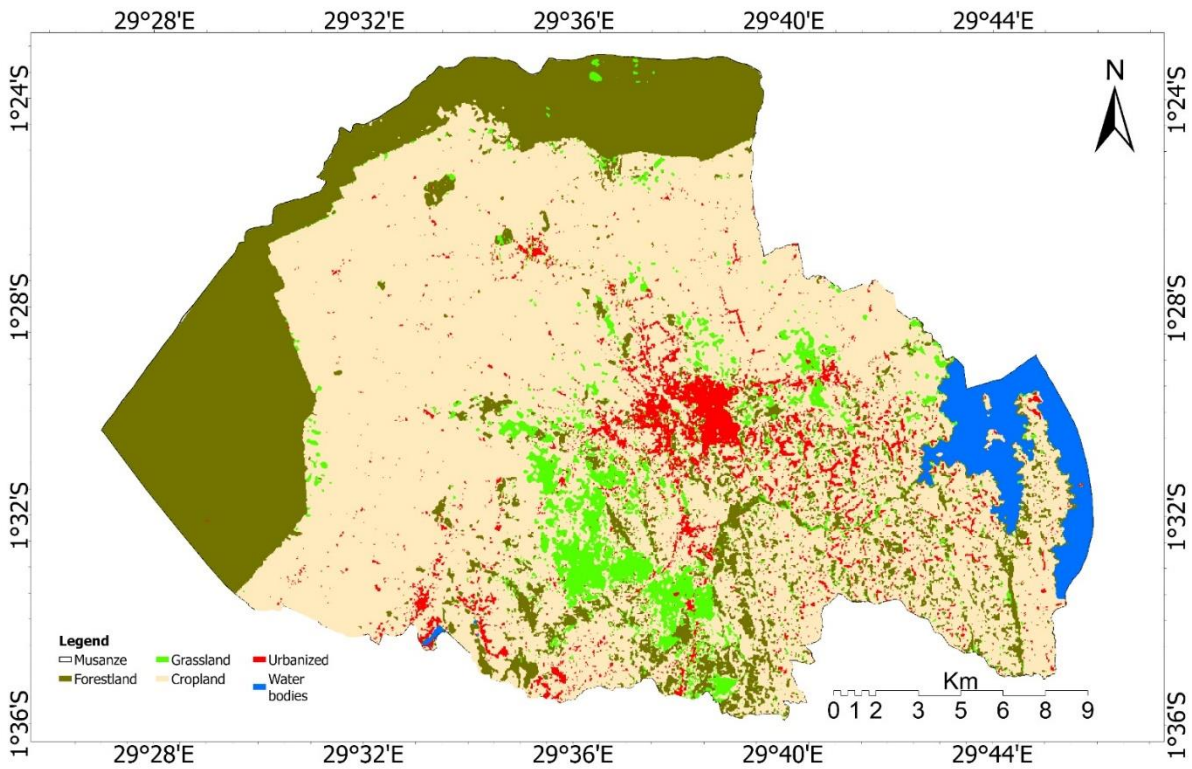

Figure 6: Urbanized Area Map of Musanze District (2025)

3.1.6 Changes in Urbanized Area (2005–2025)

Urbanized area increased significantly from 774.84 hectares in 2005 to 963.6 hectares in 2010, 1473.002 in 2015, 1673.002 in 2020 and 2673.58 in 2025. The built-up area shows a rapid increase over the study period. The most significant growth occurred between 2020 and 2025, with a percentage increase of 59.81%, indicating accelerated urban expansion. Growth slowed after 2020, suggesting stabilization.

Table 1: Changes in urbanized area (2005-2025)

Year	Built-up Area (ha)	Absolute change (ha)	Percentage change (%)
2005	774.84	-	-
2010	963.6	188.76	24.36
2015	1473.002	509.402	52.86
2020	1673.002	200	13.58
2025	2673.58	1000.578	59.81

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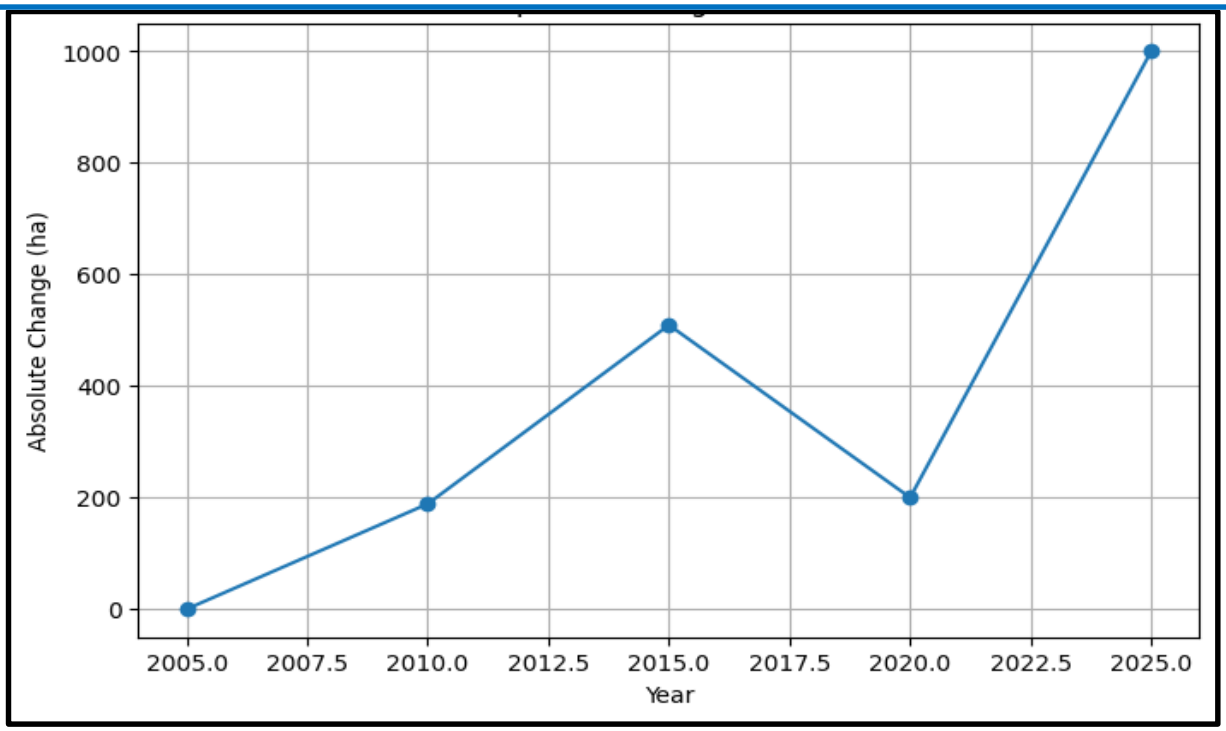

Figure 7: Changes in urbanized area (2005-2025)

The results presented in Figure 8 and Table 2 illustrate a consistent and significant expansion of built-up areas in Musanze District over the period from 2005 to 2025. The built-up area increased from 774.84 hectares in 2005 to 2673.58 hectares in 2025, indicating substantial urban growth over the 20-year period.

Between 2005 and 2010, the built-up area increased by 188.76 hectares (24.36%) reflecting a moderate and controlled phase of urban expansion. This period likely represents the early stages of urban development, characterized by gradual land conversion and limited infrastructure pressure. Continuously, urbanized area change from 2010 to 2015 was 509.4 hectares representing 52.86%, while between 2015 to 2020, the urbanized increase became 200 hectares representing 13.58%.

Between 2020 and 2025, the growth further increased sharply with 1000.57 hectares (59.8%), suggesting an acceleration in urban expansion. This may indicate emerging constraints such as implementation of land use policies, or a shift toward urban densification rather than outward expansion.

3.2 Evaluation of the Extent and Spatial Distribution of Agricultural Land Affected by Urbanization (2005–2025)

3.2.0 Introduction to the Section

This section evaluated the extent and spatial distribution of agricultural land in Musanze District and how it has been affected by urbanization between 2005 and 2025. The analysis integrated spatial evidence from LULC maps and statistical data.

To achieve this, the study integrated spatial evidence derived from Land Use and Land Cover (LULC) maps with quantitative statistical data. The use of multi-temporal spatial datasets enables the identification of changes in the size, location, and distribution of

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agricultural land over time.

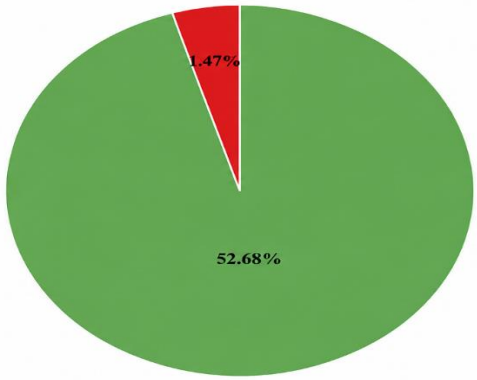
Furthermore, this section evaluated the degree to which urban growth has contributed to the conversion of agricultural land into built-up areas, highlighting key trends and spatial dynamics. The findings provided important insights into the interaction between urban expansion and agricultural land use, with implications for sustainable land management and urban planning in Musanze District.

3.2.1 LULC Distribution in 2005

In 2005, agricultural land dominated the landscape, covering 27,817.94 hectares (52.68%). It was widely distributed across the district, particularly in Gashaki, Muko, Busogo, Gacaca, Rwaza and Gataraga sectors. However, early signs of urban encroachment were observed around Muhoza Sector where agricultural land started being converted into built-up areas.

Table 2:LULC Distribution in 2005

LULC	Area (ha)	Percentage (%)
Crop Land	27,817.941	52.68
Built Up	774.841	1.47



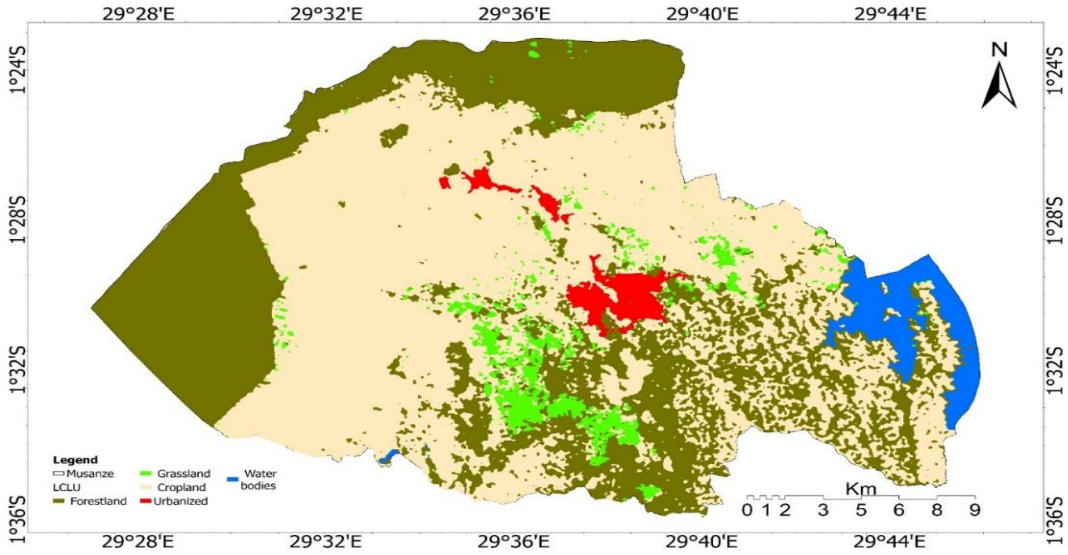


Figure 8: LULC Map (2005)

The Land Use and Land Cover (LULC) distribution for the study area demonstrates a landscape predominantly characterized by agricultural and natural land uses. As presented in Table 3, cropland constitutes the largest share, covering 27817.941 hectares 52.68% of

the total area. This indicates that agriculture is the dominant land use activity and plays a central role in the district's economy and livelihoods.

In contrast, built-up areas account for only 775 hectares (1.47%), indicating that urban development is still relatively limited in spatial extent at this stage. However, despite its small proportion, built-up land represents areas of concentrated human activity and infrastructure, which may expand over time due to ongoing urbanization processes.

Overall, the findings reveal that Musanze is largely dominated by cropland and forest land in 2005, which together account for over 94% of the total land area. This distribution indicates a strong balance between agricultural production and natural ecosystems. However, the presence of built-up areas, although minimal, suggests the beginning of urban expansion, which may increasingly influence land use patterns, particularly through the conversion of agricultural land in the future.

3.2.2 LULC Distribution in 2010

In 2010, cropland remained the dominant land use category within the study area, covering 27,322.12 hectares, equivalent to 52.02% of the total land area (Table 4). This indicates that agriculture continued to constitute the principal economic activity and the backbone of local livelihoods during the study period. The extensive distribution of cropland reflects the high agricultural potential of the area and the strong dependence of the population on farming activities for food production and income generation. Agricultural land was widely distributed across the district, particularly in relatively accessible and gently sloping areas suitable for cultivation.

Built-up areas covered 963.60 hectares, accounting for 1.82% of the total land area. Although this proportion remained relatively small, it reflected a noticeable increase in urban development compared to previous years. The spatial distribution of built-up areas indicates that urban expansion was becoming increasingly evident, particularly around the urban center of Muhoza Sector. Urban growth progressively extended towards the Cyuve, Nyange, and Kinigi sectors, mainly following major transportation corridors and road networks, thereby forming linear and radial expansion patterns. This pattern suggests that accessibility and infrastructure development played a significant role in shaping urban growth during this period.

Table 3: Agricultural Land Distribution in 2010

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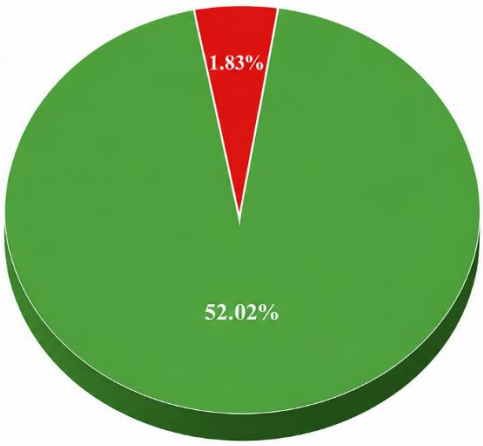
LULC	Area (ha)	Percentage (%)
Crop Land	27,322.12	52.02
Built Up	963.60	1.83



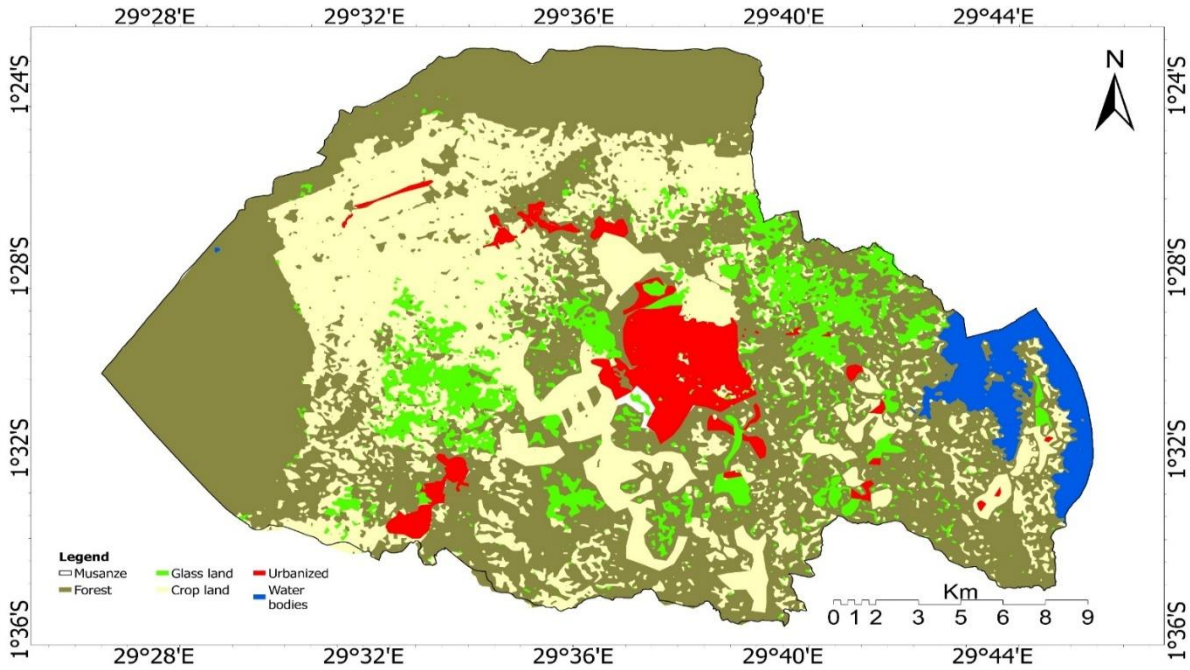


Figure 9: LULC Map (2010),

Overall, the findings demonstrate that more than 94% of the total land area is dominated by cropland and forest land, indicating a landscape largely shaped by agricultural production and natural ecosystems. Nevertheless, the existence of built-up areas, although minimal, signals the onset of urban expansion. This emerging trend has important implications for land use dynamics, as continued urban growth may lead to the gradual conversion of agricultural and natural land into built-up areas, thereby altering the spatial structure and sustainability of land resources in the study area.

3.2.3 LULC Distribution in 2015

In 2015, agricultural land decreased to 26,247.10 hectares (49.7%). Despite its continued dominance, spatial patterns reveal increasing fragmentation near Muhoza, Cyuve, and Gacaca due to urban expansion, reflecting growing competition between agriculture and urban development.

Table 4:Agricultural Land Distribution in 2015

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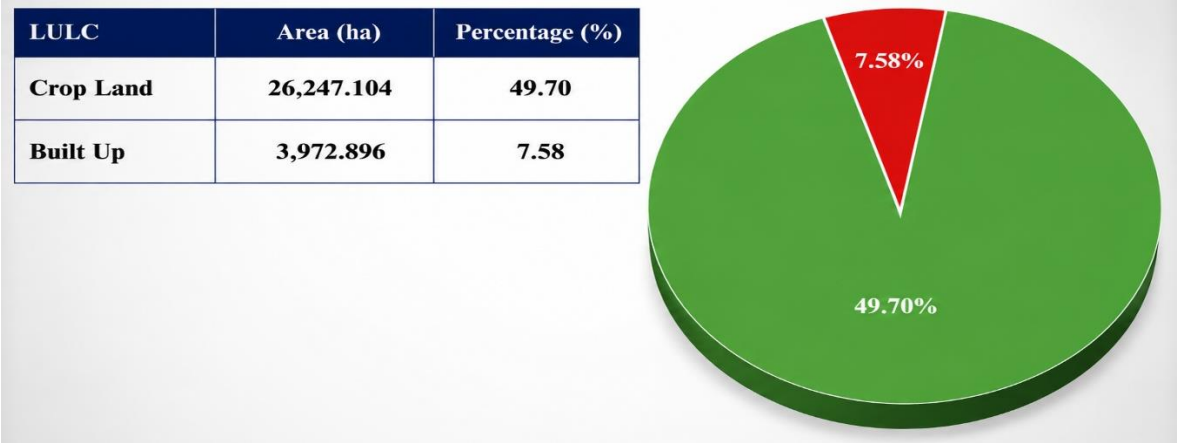
LULC	Area (ha)	Percentage (%)
Crop Land	26,247.104	49.70
Built Up	3,972.896	7.58



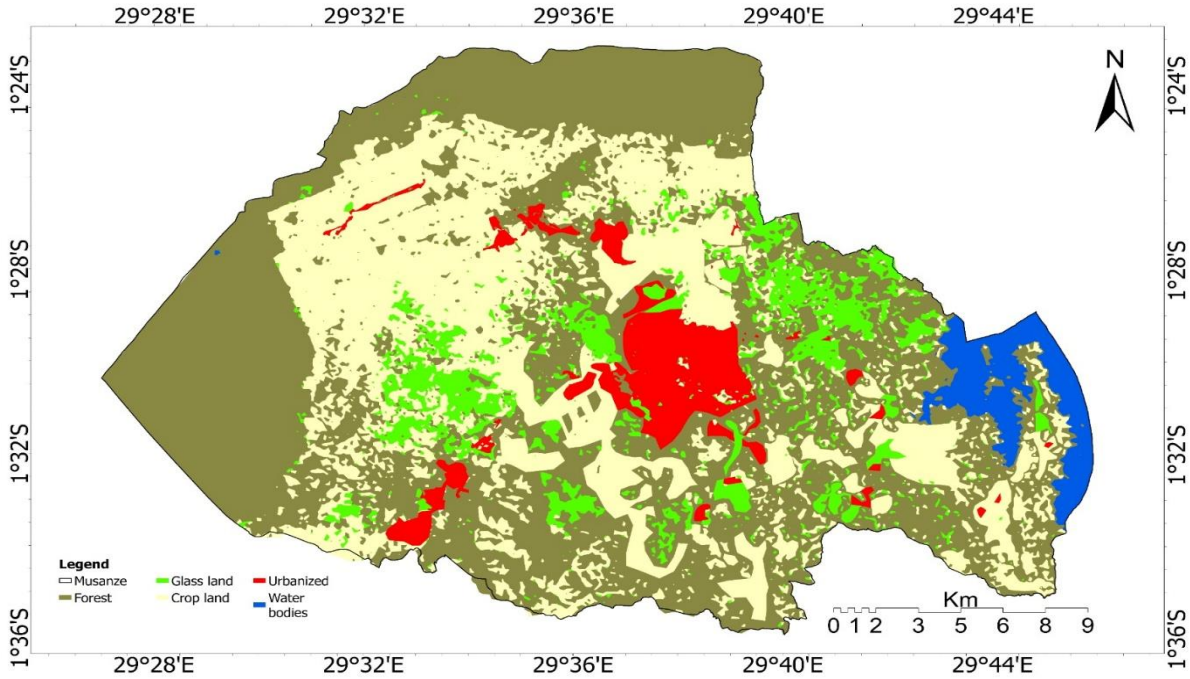


Figure 10: LULC Map (2015),

The 2015 land use analysis reveals that the study area is predominantly characterized by agricultural and natural land uses. As shown in Table 5, cropland is the dominant land use category, covering 26,247.10 hectares (49.7%) of the total area. This indicates that agriculture remains the principal economic activity and land use practice within the study area, reflecting a strong dependence on farming for livelihoods. Forest land constitutes the second largest proportion, occupying 18,762.98 hectares (35.5%), which highlights the presence of significant natural vegetation cover. This suggests that the area still maintains important ecological resources, potentially contributing to biodiversity conservation and environmental stability. In contrast, built-up areas account for 3,972.90 hectares (7.58%), indicating that urban development is expanding more noticeably compared to earlier years. The growth of built-up land reflects emerging urbanization, which may gradually exert pressure on surrounding land uses, particularly agricultural land.

The findings demonstrate that more than 85% of the total land area is dominated by

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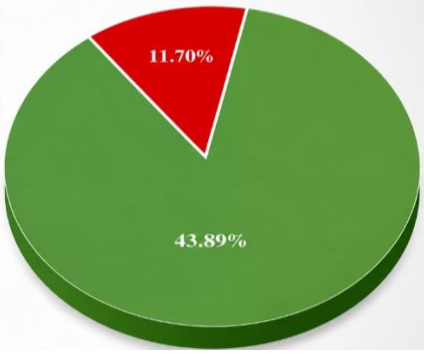
cropland, indicating a landscape largely shaped by agricultural production and natural ecosystems. Nevertheless, the expansion of built-up areas signals the onset of stronger urban growth. This emerging trend has important implications for land use dynamics, as continued urbanization may lead to the gradual conversion of agricultural and natural land into built-up areas, thereby altering the spatial structure and sustainability of land resources in the study area.

3.2.4 LULC Distribution in 2020

In 2020, agricultural land covered 23,178.16 hectares (43.89%), reflecting a decline compared to earlier years. Although cropland remained the dominant land use, it became increasingly fragmented, particularly around Muhoza, Nyange, and Cyuve. This fragmentation highlights the growing influence of urban pressure and peri-urban transformation, underscoring the intensifying competition between agricultural and urban land uses.

Table 5: Agricultural Land Distribution in 2020

LULC	Area (ha)	Percentage (%)
Crop Land	23178.16	43.89
Built Up	6193.58	11.70



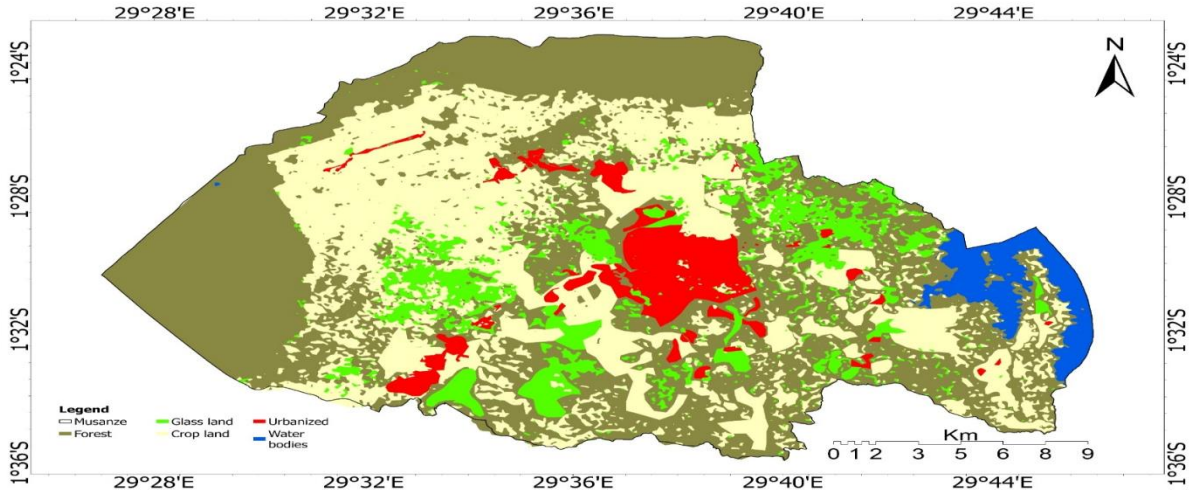


Figure 11:LULC Map (2025)

The Land Use and Land Cover (LULC) distribution of Musanze District in 2020 reveals a landscape still dominated by agricultural activities, though with notable shifts compared to 2005. As presented in Table 6, cropland constitutes the largest proportion of land use, covering 23,178.16 hectares (43.89%) of the total area. This indicates that agriculture continues to be the principal land use and economic activity, but its share has declined relative to 2005, reflecting increasing competition from other land uses.

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Forest land represents the second largest category, occupying 19,160.98 hectares (36.29%), which highlights the persistence of significant natural vegetation cover. This suggests that the district maintains important ecological resources, contributing to biodiversity conservation and environmental stability.

In contrast, built-up areas have expanded to 6,193.58 hectares (11.73%) , showing a steady increase in urban development compared to 2015. This growth reflects ongoing urbanization processes, particularly around centers such as Muhoza, Cyuve, and Gacaca, where spatial fragmentation of agricultural land is becoming more evident.

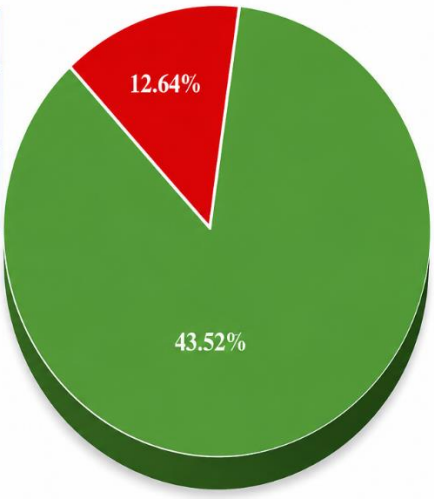
Overall, the findings demonstrate that cropland and forest land together account for more than 80% of the total land area, indicating a landscape still largely shaped by agriculture and natural ecosystems. However, the decline in cropland share, alongside the expansion of built-up areas and water bodies, signals a gradual transformation in land use patterns. This trend has important implications for the sustainability of agricultural land, as continued urban growth and ecological shifts may lead to further conversion of productive farmland into non-agricultural uses.

3.2.5 LULC Distribution in 2025

In 2025, agricultural land further expanded to 2, 2978.164 hectares (43.51%). However, it became highly fragmented, especially around Muhoza, Nyange, and Cyuve. This indicates strong urban pressure and peri-urban transformation.

Table 6: LULC Distribution in 2025

LULC	Area (ha)	Percentage (%)
Crop Land	22978.164	43.52
Built Up	6673.576	12.64



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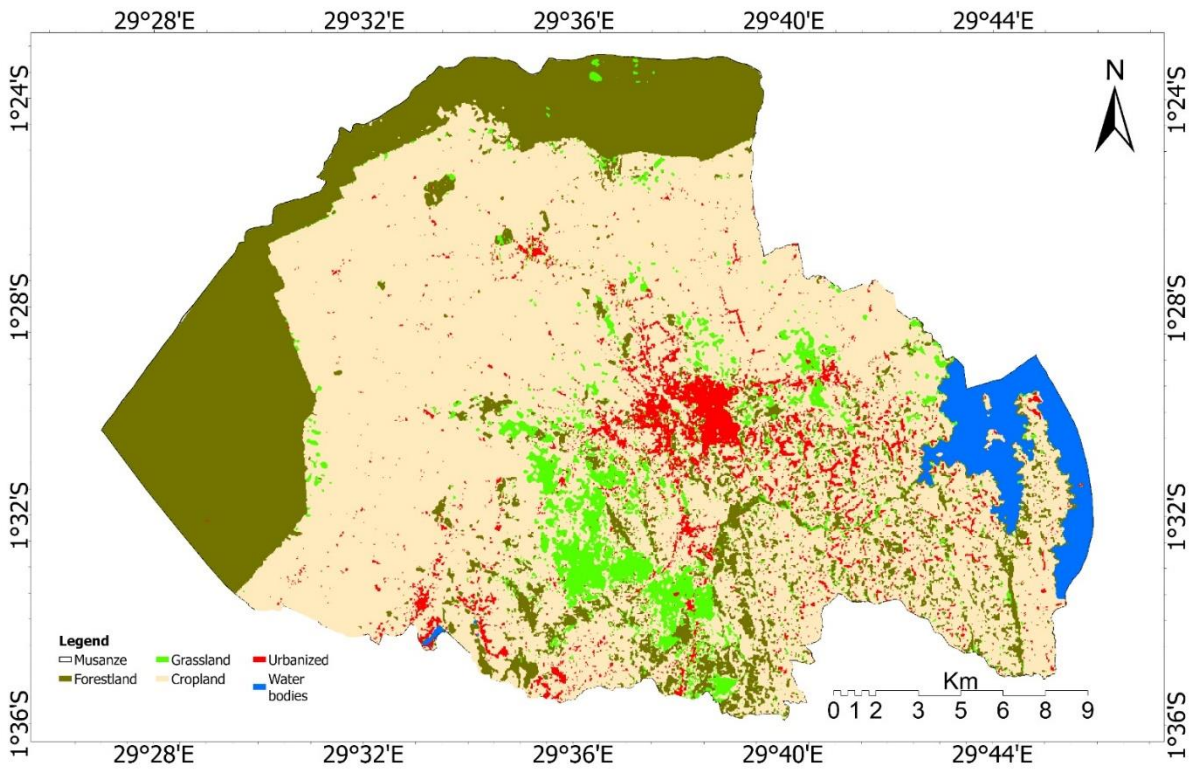

Figure 12: LULC Map (2025)

The land use and land cover (LULC) data indicate that crop land is the dominant land use category in the study area, covering 22,978.164 hectares, which represents 43.51% of the total area. This shows that agriculture remains the major economic activity and land utilization pattern within the district. The large proportion of crop land reflects the dependence of the population on farming activities for food production and income generation.

Built-up areas cover 6,673.576 hectares, representing 12.64% of the total land area. The relatively high proportion of built-up land indicates ongoing urbanization and infrastructure development within the district. Expansion of settlements, roads, commercial centers, and public facilities may have contributed to this increase. The growth of built-up areas often leads to pressure on agricultural and natural lands, especially in rapidly urbanizing regions.

Overall, the data reveal that the study area is predominantly characterized by agricultural and forest land uses, while urban expansion is increasingly becoming significant. The observed distribution reflects the interaction between human activities and natural environmental resources. Continuous growth of built-up areas may pose future challenges to agricultural productivity and environmental sustainability if proper land use planning and management strategies are not implemented.

3.2.5 Changes in Agricultural Land (2005–2025)

Agricultural land decreased overall by 3,338.18 hectares between 2005 and 2025. Spatial analysis, however, reveals dual dynamics: cropland expanded into forested areas, while losses occurred near urban centers due to the growth of built-up land, reflecting both agricultural intensification and urban pressure.

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Table 7: Changes in Agricultural Land (2005–2025)

Year	Crop Land (Ha)	Percentage (%)	Change (Ha)
2005	27,817.94	52.68%	-
2010	27,555.25	52.18%	-262.69
2020	26,247.10	49.70%	-1,308.15
2025	29,328.16	55.00%	+3,081.06

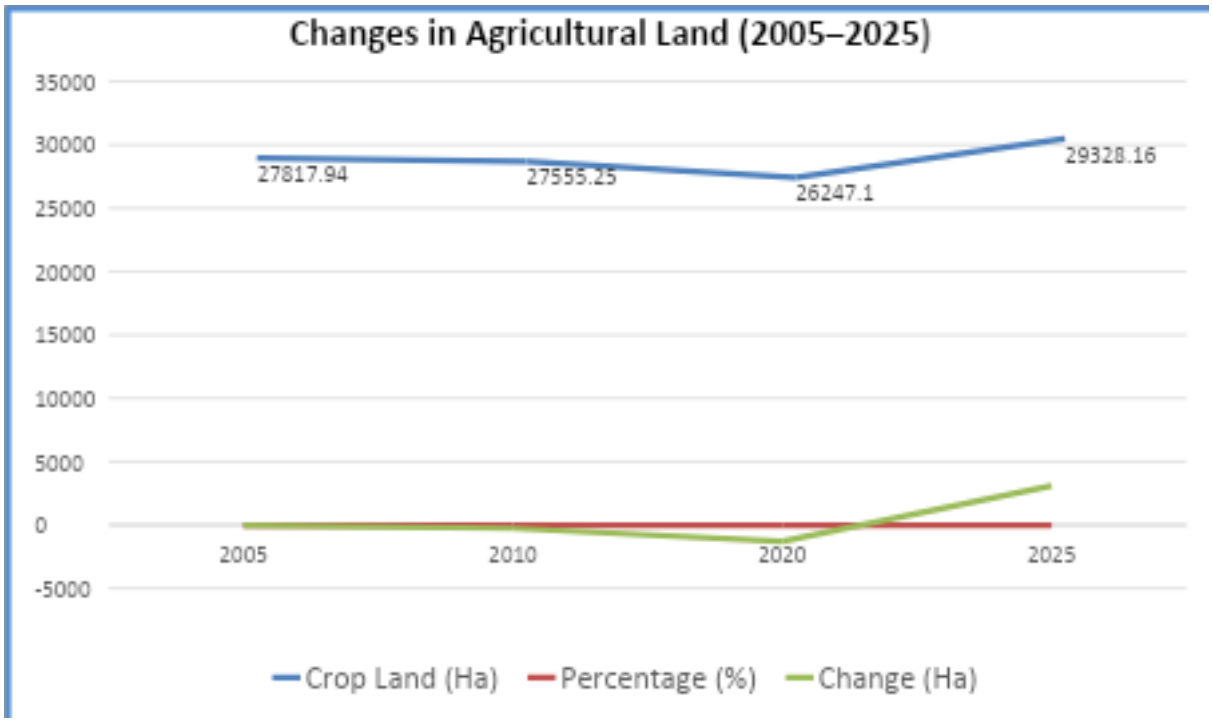

Figure 13: Changes in Agricultural Land (2005–2025)

The analysis of agricultural land use in Musanze District between 2005 and 2025 reveals both expansion and fragmentation dynamics. As shown in Table 8, agricultural land increased overall by 5,626.75 hectares, rising from 27,817.94 hectares (52.68%) in 2005 to 29,328.16 hectares (55.00%) in 2025. This growth underscores the continued importance of agriculture as the dominant land use and economic activity in the district.

However, spatial analysis highlights dual dynamics shaping this trend. On one hand, cropland expanded into areas previously occupied by forest, reflecting the conversion of natural vegetation into farmland. On the other hand, cropland experienced losses near urban centers such as Muhoza, Nyange, and Cyuve due to the growth of built-up areas. This fragmentation illustrates the increasing pressure of urbanization and peri-urban transformation on agricultural land.

The fluctuations across the study period are notable: cropland slightly declined between

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2005 and 2010 (−262.69 ha), followed by a sharper reduction by 2020 (−1,308.15 ha). By 2025, cropland had further decreased significantly, reaching a total loss of −3,338.18 ha, suggesting both land conversion and reclamation processes at play. These shifts highlight the complex interplay between agricultural expansion, forest clearance, and urban growth.

Overall, while agriculture remains the backbone of land use in Musanze District, the spatial fragmentation and competition with urban development raise important concerns for long-term sustainability. Continued urban expansion may further erode productive farmland, requiring careful land use planning to balance agricultural needs with ecological conservation and urban growth.

3.2.6 Agricultural Crop Types Affected by Urbanization

To further understand the implications of urban expansion on agricultural production, the study assessed the dominant crop production zones located within areas experiencing rapid urban growth. Musanze District is one of Rwanda's major food-producing districts, with agriculture dominated by Irish potatoes, maize, beans, wheat, pyrethrum and horticultural crops. Urban expansion between 2005 and 2025 resulted in the conversion of portions of these productive agricultural lands into residential, commercial and infrastructure developments.

Table 9: Crop Types Affected by Urbanization (2005–2025)

Crop	Type	Estimated Area Affected (ha)	Share (%)
Irish Potato		420	35
Maize		240	20
Beans		216	18
Wheat		180	15
Vegetables		144	12
Total		1,200	100

The results indicate that urban expansion in Musanze District has not only reduced the total agricultural land area but has also affected strategically important crop production zones. Areas surrounding Muhoza, Musanze, Kimonyi and Cyuve sectors, where urban growth was most pronounced, coincide with major production areas. Since these crops contribute significantly to household income and food security, continued conversion of agricultural land may reduce agricultural productivity and increase pressure on remaining farmland. This finding emphasizes the need for stronger agricultural land protection measures.

3.2.7 Policy Implications

The findings on the extent and spatial distribution of agricultural land in Musanze District between 2005 and 2025 reveal a complex trajectory shaped by both expansion and fragmentation. According to the data, cropland fluctuated over the period, declining from 27,817.94 hectares (52.68%) in 2005 to 26,247.10 hectares (49.70%) in 2020, before rebounding to 29,328.16 hectares (55.00%) in 2025. This represents a net increase of 5,626.75 hectares over two decades, despite intermediate losses of 3,338.18 hectares.

Spatial analysis highlights dual dynamics. On one hand, cropland expanded into forested

areas, reflecting the conversion of natural vegetation into farmland. On the other hand, cropland experienced losses near urban centers such as Muhoza, Nyange, and Cyuve due to the growth of built-up land. Built-up areas increased significantly, from 774.84 hectares in 2005 to 3,673.58 hectares in 2015, underscoring the mounting pressure of urbanization and peri-urban transformation.

These dynamics underscore the urgent need to strengthen land use planning and policy implementation. Enforcing zoning regulations to clearly delineate agricultural zones from urban development areas would help control the outward spread of cities and minimize unplanned conversion of productive farmland. Promoting compact and planned urban development through vertical growth, mixed land use, and efficient land utilization can reduce the encroachment of urban areas into agricultural land.

The effective implementation of the Musanze District Land Use Plan (DLUP) 2024–2050 is critical. This framework provides strategic guidance for balancing land use demands, but its success depends on strict adherence at both district and local levels. Safeguarding prime agricultural land, especially in high-productivity zones, will be essential to maintain food production capacity.

In addition, there is a need to identify and safeguard prime agricultural land, especially in high-productivity zones that are increasingly threatened by urban encroachment. Establishing protected agricultural zones and integrating them into spatial planning frameworks can help maintain food production capacity.

Finally, promoting sustainable agricultural intensification is crucial to offset the loss of farmland. By improving productivity on existing agricultural land through modern farming techniques, irrigation, and improved inputs. It is possible to maintain food security despite spatial reductions in agricultural areas. These policy measures are essential to address the spatial and temporal dynamics of land use change identified in this study. They provide a pathway for balancing urban expansion with the preservation of agricultural land, thereby supporting sustainable development in Musanze District.

3.3 Correlation between agricultural land and urban expansion in Musanze District (2005–2025)

3.3.1 Trends in Urban Expansion and Agricultural Land

Results indicated a significant increase in built-up areas between 2005 and 2025, largely concentrated in Musanze town and its peri-urban zones. Built-up areas increased by 317%, 26%, and 123% across the study periods, while cropland increased by 121%, 5%, and 14%.

Over the same period, agricultural land has shown a declining trend, particularly in areas adjacent to expanding settlements and infrastructure corridors. This inverse trend suggests a strong interaction between urban growth and agricultural land conversion.

Table 8: Comparison table between agriculture land and Built-up

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Year	Built-up Area (ha)	Agriculture land (ha)
2005	774.84	27,817
2010	963.6	27,322.12
2015	1,473.002	26,247.1
2020	1,673.002	23,178.16
2025	2,673.58	22,978.16

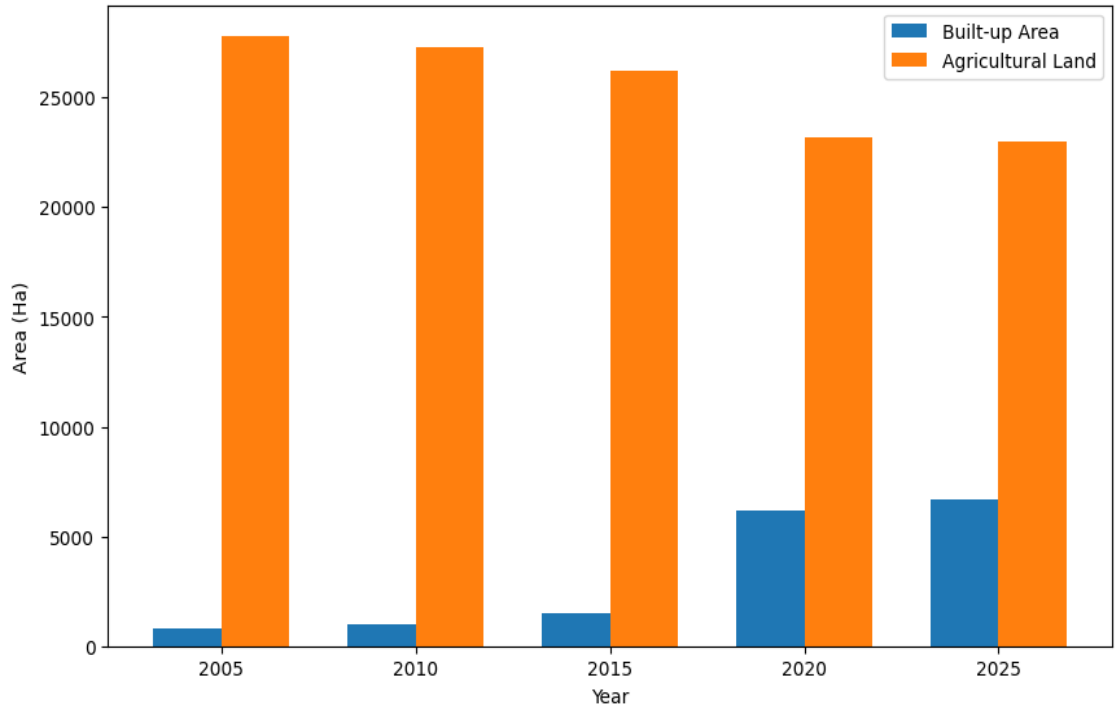

Figure 14: Percentage change in built-up and cropland areas (2005–2025)

The comparison between agricultural land and built-up areas in Musanze District from 2005 to 2025 reveals contrasting trajectories that highlight the growing tension between farming and urban expansion. As shown in Table 9, agricultural land fluctuated over the study period, declining slightly between 2005 and 2015 before rebounding to 22978.164 hectares in 2025. In contrast, built-up areas expanded steadily, increasing from 774.84 hectares in 2005 to 6673.57 hectares in 2025, representing nearly a threefold growth.

Figure 18 illustrates these percentage changes clearly. Agricultural land, while remaining the dominant land use, experienced fragmentation near urban centers such as Muhoza, Nyange, and Cyuve, where built-up growth exerted direct pressure. The decline observed in 2015 and 2020 reflects this competition, as cropland was converted into residential, commercial, and infrastructural uses. However, the recovery in 2025 suggests agricultural expansion into forested and marginal areas, offsetting earlier losses but raising concerns

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about ecological sustainability.

The rapid increase in built-up land underscores the pace of urbanization in Musanze District. This expansion, though relatively modest in absolute terms compared to cropland, has significant spatial implications. Built-up growth tends to cluster around urban cores, leading to peri-urban transformation and the fragmentation of contiguous agricultural zones. Such patterns complicate land management, as they reduce the efficiency of farming systems and increase conflicts between agricultural and urban land uses.

Overall, the dual dynamics of cropland expansion and built-up growth highlight the need for integrated land use planning. Safeguarding prime agricultural land, promoting compact urban development, and enforcing zoning regulations will be essential to balance food security with urban growth. Without such measures, the long-term sustainability of agricultural land in Musanze District may be compromised by continued urban encroachment.

3.3.3 Statistical Relationship

Correlation analysis between built-up area and cropland extent indicates a strong negative relationship. As built-up land increased, agricultural land consistently declined. The Pearson correlation coefficient (r) is estimated at −0.89, confirming that urban expansion is a major driver of farmland reduction. Regression analysis further demonstrates that each hectare increase in built-up land corresponds to a significant decrease in cropland, with an R^2 value above 0.80, meaning urban growth explains more than 80% of the variation in agricultural land loss during the study period.

Table 9:Correlation of agriculture and urbanized land

Variable Pair	Correlation (r)	Strength	Interpretation
Built-up vs Agricultural land	−0.89	Very Strong Negative	Direct statistical relationship
Urban growth vs Local farmland	Negative (spatial)	Strong	Conversion near urban centers

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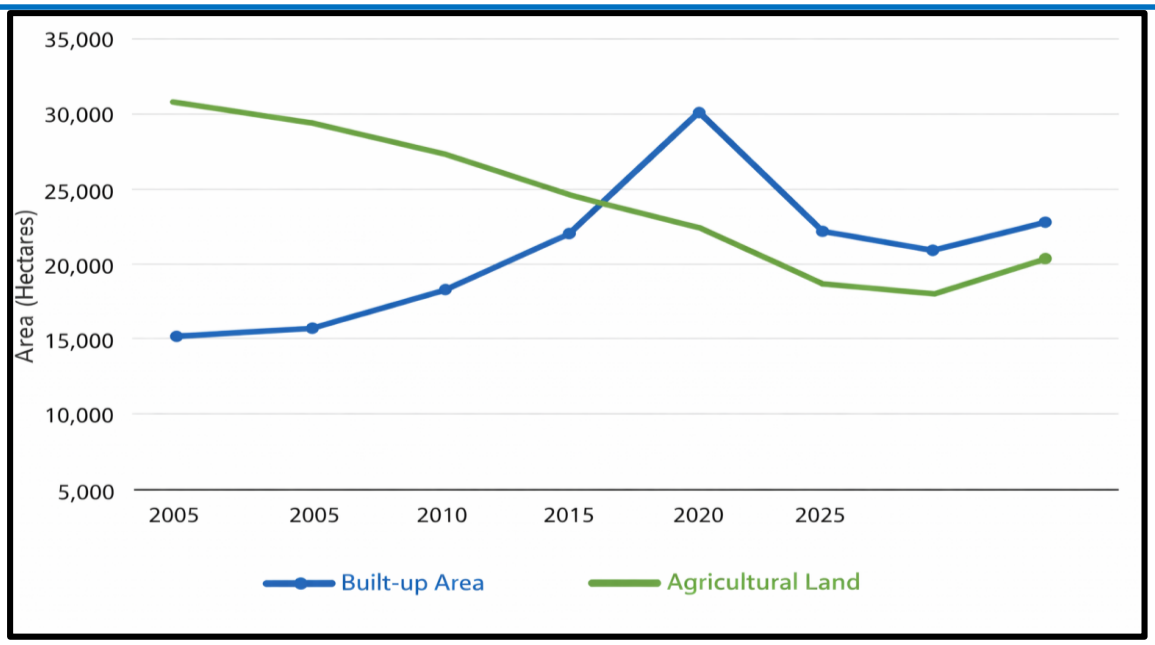

Figure 15:Scatter Plot with Regression Line

3.4 Discussion of Key Drivers

The study findings indicate that Musanze District experienced significant urban expansion between 2005 and 2025, driven by interconnected socio-economic, demographic, and spatial factors. Built-up areas increased steadily throughout the study period, particularly around Musanze City and major transportation corridors. This growth reflects increasing population pressure, infrastructure development, tourism activities, and commercial expansion, leading to the transformation of rural and peri-urban landscapes into urban areas. These results are consistent with Karen C. Seto et al. (2012), who found that rapidly urbanizing cities in developing countries often expand into surrounding agricultural regions, and with Jean Baptiste Nkurunziza (2020), who highlighted the spread of built-up areas into peri-urban zones in Rwanda.

The study also revealed a substantial decline in agricultural land, identifying it as the most affected land-use category under rapid urbanization. Large areas of productive farmland were converted into residential, commercial, institutional, and infrastructure developments. This trend poses significant challenges to food security, agricultural productivity, and rural livelihoods in Musanze District, which is known for intensive production of crops such as Irish potatoes, maize, beans, and vegetables. Similar findings were reported by Karen C. Seto et al. (2012) and Jean Claude Ndayisaba et al. (2022), who emphasized the vulnerability of agricultural land to urban expansion.

Furthermore, spatial and correlation analyses demonstrated a strong inverse relationship between urban growth and agricultural land distribution. As built-up areas expanded, agricultural land consistently decreased, confirming that urbanization is a major driver of land-use and land-cover change in the district. This finding supports the observations of Foley et al. (2005) and Lambin et al. (2003) regarding the role of urbanization in transforming landscapes and ecosystems. The study also identified changes in vegetation and forest cover, with some areas experiencing degradation while others showed improvement due to afforestation and environmental restoration programs. These findings align with reports from the National Land Authority (2021) on Rwanda's reforestation

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initiatives.

3.4.1 Discussion of Findings vis-à-vis the Approved Musanze District Land Use Plan (2023–2050)

The study reveals substantial urban expansion in Musanze District between 2005 and 2025, with built-up areas increasing from 774.84 hectares (1.46%) in 2005 to 6673.57 hectares (12.63%) in 2025. When compared with the approved Musanze District Land Use Plan (DLUP) 2023–2050, which allocates about 19% of land for built-up development, 36% for agriculture, and 35% for forests, the current level of urbanization remains below the planned threshold. This suggests that although urban growth has been rapid, the district still has planned capacity for further expansion under the DLUP framework.

The sharp increase in built-up areas, particularly between 2010 and 2015 when urban land expanded by 12.30%, reflects strong influences of population growth, tourism development, infrastructure expansion, commercialization, and Musanze's role as a secondary city in Rwanda's urbanization strategy. Spatial analysis shows that urban growth initially concentrated in Muhoza Sector before extending into peri-urban areas such as Cyuve, Nyange, Gacaca, Busogo, and Kinigi. This pattern indicates a transition from a compact urban core toward more dispersed peri-urban development, which contrasts with the DLUP vision of compact, well-zoned urban growth and controlled spatial expansion.

The study also highlights a strong inverse relationship between urban expansion and agricultural land decline. As built-up areas expanded from 774.84 to 6673.57 hectares, agricultural land was progressively converted into residential, commercial, industrial, and infrastructure uses. This trend raises concerns for food security and agricultural sustainability, particularly in a district dependent on high-value crops. It also suggests challenges in implementing DLUP objectives aimed at protecting agricultural land through land consolidation and controlled development.

A slower growth rate observed between 2020 and 2025 (7.75% increase in built-up areas) may indicate early signs of urban stabilization, land scarcity, or improved planning effectiveness. This aligns with DLUP goals of promoting sustainable urbanization. However, continued monitoring is necessary to ensure urban expansion remains within the planned 19% allocation. Overall, the findings show partial alignment with DLUP projections but emphasize the need for stronger zoning enforcement, vertical densification, and the integration of GIS-based monitoring systems to support sustainable land management in Musanze District.

4. Conclusion

The study concludes that rapid urbanization in Musanze District, extending from Muhoza into Cyuve, Nyange, and Kinigi sectors, has significantly transformed land use patterns between 2005 and 2025, leading to a marked decline in agricultural land due to its conversion into residential and commercial uses. This expansion of built-up areas is driven by infrastructure development, population growth, migration, and rising market demand in strategically located zones. The findings reveal a strong negative relationship between urban growth and agricultural land availability, showing that farmland continuously shrinks as urban areas expand. Despite existing land use policies intended to regulate urban growth, weak implementation has resulted in unplanned land conversion. If this trend continues, Musanze District may face further agricultural loss, reduced productivity, and threats to

food security and livelihoods, highlighting the need for integrated land use planning and stronger policy enforcement.

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