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Impact Assessment of Land Use Master Plan Implementation on Land Use Land Cover Dynamics, A Case of Muhanga Satellite City (2014-2024)

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Abstract: **Rapid urbanisation in Rwanda's satellite cities is increasing pressure on land resources and raising concerns about the effectiveness of land use master plan implementation. This study assessed the impact of Land Use Master Plan implementation on land use and land cover (LULC) dynamics in Muhanga Satellite City between 2014 and 2024. A longitudinal research design was adopted, integrating geographic information systems (GIS), remote sensing and qualitative data. Multi-temporal satellite imagery was classified using the supervised maximum likelihood algorithm to generate LULC maps, while GIS-based spatial overlay analysis assessed conformity with the Detailed Land Use Plan (DLUP), land use encroachment and development patterns in relation to road networks. Key informant interviews with district planners, National Land Authority staff and community leaders provided additional insights into institutional and governance factors affecting implementation. The findings revealed a substantial increase in built-up areas, from 488 ha (6.3%) in 2014 to 3,437.9 ha (44.4%) in 2024, representing an almost sevenfold increase. This expansion occurred mainly at the expense of cropland and forestland, which declined by 47.9% and 50.3%, respectively. NDVI analysis confirmed considerable vegetation loss, particularly around Nyamabuye and Cyeza sectors. Spatial conformity assessment showed variations across land use categories, with commercial zones recording 76.8% conformity, agriculture/forest approximately 80%, wetlands 78%, and industrial zones 24.4%. Overall encroachment reached 36.2% (945 ha), with wetlands experiencing the highest encroachment at 49.4%. Furthermore, 68% of newly developed built-up areas emerged within 500 metres of road corridors. Qualitative findings identified land tenure insecurity, weak enforcement, delayed expropriation and rapid population growth as major constraints to effective plan implementation. The study concludes that Muhanga Satellite City's land use master plan faces a significant implementation gap, contributing to land conversion that does not fully comply with designated zoning provisions. It recommends strengthening geospatial monitoring, improving land tenure security, enhancing institutional coordination and enforcing land use regulations, particularly in ecologically sensitive and rapidly urbanising areas.**

Keywords: **Land Use Master Plan; Land Use and Land Cover (LULC) Dynamics; Urban Planning; Satellite City Development; Muhanga District.**

1. INTRODUCTION

Land use and land cover (LULC) change is one of the major environmental and developmental challenges worldwide, with significant implications for biodiversity, climate regulation, food security and sustainable livelihoods. These changes are driven by interacting factors, including population growth, agricultural expansion, urbanisation, industrialisation, infrastructure development and natural resource exploitation (Lambin et al., 2001; Foley et al., 2005; Winkler et al., 2021). Globally, approximately 32% of the Earth's land surface experienced land use change between 1960 and 2019, demonstrating the extensive transformation of natural and human-managed landscapes (Winkler et al., 2021). According to

the Food and Agriculture Organization (FAO, 2020), agricultural expansion accounts for nearly 90% of global deforestation, with cropland expansion and livestock grazing representing the principal contributing activities. These transformations affect ecosystem functions, carbon storage, water resources and the availability of productive agricultural land (IPBES, 2019; IPCC, 2022). Consequently, understanding LULC dynamics has become essential for developing effective land management policies and promoting sustainable development.

Across Africa, LULC dynamics reflect the combined influence of demographic pressure, agricultural expansion, urban growth, infrastructure development and changing economic activities. The continent has experienced considerable transformation of forests, grasslands, wetlands and agricultural landscapes, with agricultural expansion remaining one of the major drivers of natural vegetation loss (Brink & Eva, 2009; FAO, 2020). Recent evidence from a meta-analysis of African land use systems also demonstrates that land transformation is influenced by interconnected socioeconomic, political, institutional and environmental factors (Sarfo et al., 2024).

In West Africa, increasing population pressure has been associated with accelerated land cover changes, particularly the conversion of natural vegetation into agricultural and settlement areas (Herrmann et al., 2020). Similarly, land use transformations in East and Southern Africa have been associated with increasing demand for agricultural land, settlement expansion and natural resource exploitation (Winkler et al., 2021; Sarfo et al., 2024). These developments demonstrate that effective land use planning is necessary to balance competing demands for land while protecting ecological resources and supporting socioeconomic development.

In Rwanda, rapid population growth and urbanisation have intensified competition for land, particularly in emerging urban centres and secondary cities. Urban expansion has increased demand for residential housing, commercial facilities, industrial development, transport infrastructure and public services. These competing demands create pressure on agricultural land and environmentally sensitive areas, particularly where settlement development is not adequately coordinated with infrastructure provision and spatial planning regulations (World Bank, 2017; Ministry of Infrastructure [MININFRA], 2025). The Government of Rwanda has therefore prioritised planned urbanisation as an important component of its broader socioeconomic transformation agenda. The National Urbanisation Policy identifies sustainable urban development, institutional coordination, urban densification and environmental protection as essential elements of managing the country's urban transition (MININFRA, 2025). Nevertheless, balancing urban expansion with agricultural productivity, environmental conservation and equitable access to urban services remains a significant planning challenge.

To address these challenges, Rwanda has progressively strengthened its spatial planning and land management frameworks. The National Land Use and Development Master Plan (NLUDMP) 2020–2050 provides a long-term framework for coordinating land allocation, urbanisation, agricultural development, infrastructure investment and environmental conservation (Republic of Rwanda, 2020). At the district and city levels, Detailed Land Use Plans (DLUPs) translate national planning priorities into specific land use allocations and zoning provisions.

These plans identify designated areas for residential, commercial, industrial, agricultural, institutional and environmental conservation activities. The National Land Authority (NLA, n.d.) identifies district land use plans as important implementation instruments for coordinating urban and rural land allocation, infrastructure development and socioeconomic activities. However, the existence of approved planning documents does not necessarily guarantee compliance with designated land use provisions. Effective implementation requires institutional coordination, adequate monitoring capacity, public participation and consistent enforcement of land use regulations (World Bank, 2017; MININFRA, 2025).

Within this national planning framework, Muhanga was designated as one of Rwanda's satellite cities, alongside Bugesera and Rwamagana, to promote balanced urban development and reduce excessive concentration of economic activities and population in Kigali (Republic of Rwanda, 2020). The National Land Use and Development Master Plan identifies Muhanga as an important urban growth centre within the country's proposed urbanisation hierarchy. Its development is intended to strengthen regional economic activities, improve access to urban services and promote more balanced spatial development (Republic of Rwanda, 2020; MININFRA, 2025). The Muhanga Land Use Master Plan provides a spatial framework for directing urban expansion through designated residential, commercial, industrial, agricultural and environmental conservation zones. It also establishes provisions for transport networks, public facilities and green spaces to accommodate future development. These planning interventions are intended to regulate land allocation, coordinate infrastructure investments, protect environmentally sensitive areas and guide the city's long-term physical transformation (MININFRA, 2015; Republic of Rwanda, 2020).

Despite these planning interventions, Rwanda continues to face challenges in ensuring that actual urban development corresponds with approved spatial planning provisions. The World Bank (2017) observed that the relationship between land tenure, zoning regulations and urban development presents important implementation challenges, particularly where planning restrictions affect privately owned land. More recently, the National Urbanisation Policy identified urban sprawl, pressure on agricultural land, unplanned settlements, limited institutional coordination and inadequate urban management capacity among the challenges affecting sustainable urban development in Rwanda (MININFRA, 2025). These challenges demonstrate that successful implementation of land use master plans requires more than the preparation and approval of planning documents. It also depends on the capacity of responsible institutions to monitor development, manage competing land demands and ensure compliance with designated land use regulations. Assessing actual LULC changes against approved master plan provisions is therefore important for determining whether planning objectives are being translated into measurable spatial outcomes.

Muhanga Satellite City provides an important context for examining the relationship between land use master plan implementation and landscape transformation. As urban development expands, increasing demand for residential, commercial and infrastructure development can influence the conversion of agricultural land, changes in vegetation cover and pressure on environmentally sensitive areas. The National Land Use and Development Master Plan recognises Muhanga's strategic role in Rwanda's future urbanisation structure, making effective management of its land resources particularly important (Republic of Rwanda, 2020). Evidence from other urban areas in Rwanda demonstrates that urban expansion is associated with significant changes in land cover and environmental conditions. For example, a recent remote sensing study of Kigali identified substantial changes in built-up areas, vegetation and land surface temperature between 1990 and 2020, illustrating the environmental implications of urban landscape transformation (2024 Kigali LULC and land surface temperature study). Such evidence reinforces the need to investigate whether land development in Muhanga follows designated planning provisions and whether the implementation of its master plan has contributed to sustainable land management. In particular, understanding the extent of conformity and non-conformity between planned and actual land use is essential for evaluating the effectiveness of the city's spatial planning framework.

Advances in geographic information systems (GIS) and remote sensing have significantly improved the capacity to monitor and assess LULC dynamics over time. Satellite platforms such as Landsat, Sentinel and MODIS provide spatially referenced data that enable researchers to identify changes in vegetation, agricultural land, built-up areas, wetlands and other land cover categories. Through supervised image classification, vegetation indices and multi-temporal change detection, these technologies provide quantitative evidence of landscape transformation (Phiri & Morgenroth, 2017; Zhu et al., 2019). GIS further facilitates the integration of satellite-derived land cover information with administrative boundaries, road networks and approved land use plans. Spatial overlay analysis can consequently be used to identify areas of conformity and encroachment, measure the extent of land conversion and examine the spatial relationship between development patterns and planning provisions (Olofsson et al., 2014; Winkler et al., 2021). The reliability of such assessments, however, depends on appropriate image selection, classification procedures and accuracy assessment to ensure that the resulting spatial information provides a credible basis for planning decisions (Olofsson et al., 2014).

2. PROBLEM STATEMENT

In Rwanda, the application of GIS and remote sensing offers opportunities to strengthen evidence-based urban planning, improve land management and monitor compliance with approved spatial development frameworks. The National Land Use and Development Master Plan emphasises integrated land allocation and coordinated development across urban, agricultural, infrastructural and environmental sectors (Republic of Rwanda, 2020). Similarly, the National Urbanisation Policy highlights the importance of reliable spatial information, institutional coordination and effective urban management in achieving sustainable urban development (MININFRA, 2025). By integrating satellite imagery with approved land use zoning documents, researchers can assess not only the extent of landscape transformation but also the relationship between planned development and actual land use patterns. Such assessments provide valuable evidence for identifying implementation challenges, protecting environmentally sensitive areas and strengthening the enforcement of spatial planning regulations.

Against this background, this study assessed the impact of Land Use Master Plan implementation on land use and land cover dynamics in Muhanga Satellite City between 2014 and 2024. Using GIS and remote sensing techniques, the study examined changes in major land cover categories, assessed the extent to which actual land use conformed to the designated

provisions of the Detailed Land Use Plan, and identified areas experiencing land use encroachment. It also examined the spatial relationship between road accessibility and built-up area expansion, alongside institutional and governance factors influencing plan implementation. By comparing observed landscape changes with approved planning provisions, the study provides empirical evidence on the effectiveness of land use master plan implementation and contributes to discussions on sustainable urban development, spatial planning and land resource management in Rwanda's satellite cities.

3. METHODOLOGY

3.1 Research design

This study used a mixed-methods research design combining quantitative remote sensing analysis with qualitative evaluation.

3.2 Study area description

The research was conducted in Muhanga District, which is situated in the Southern Province of Rwanda.

3.3 Data Collection Techniques

Data were collected through remote sensing, key informant interviews, field observations and documentary review. Satellite imagery was analysed and compared with the digitised Land Use Master Plan to assess LULC changes and spatial conformity, while field observations validated the findings. Additionally, interviews were conducted with 12 purposively selected key informants, and relevant planning documents and institutional reports were reviewed to identify factors influencing master plan implementation.

4. RESULTS AND DISCUSSION

4.1 Implementation level of the master plan (2014–2024)

The Muhanga DLUP designates 24 land use zones across a 7,861-ha planning boundary, with residential uses allocated the largest share (2,028.1 ha; 25.9%), followed by forest (1,804.6 ha; 23.0%) and agriculture (1,433.7 ha; 18.2%) (Muhanga District, 2024). Spatial overlay of this zoning layer with the 2024 classified LULC map (7,729 ha after clipping to valid coverage) revealed marked variation in conformity across zone categories (Table 1). Commercial zones recorded the highest conformity (76.8%), followed by agriculture/forest (~80%) and wetland/buffer zones (~78%), while residential zones showed partial conformity (58.7%) and industrial zones the lowest (24.4%) – within planned industrial land, 62.8% remained under informal cropland rather than built-up use.

Table 1. Master plan conformity by zone category, Muhanga Satellite City (2024).

Zone category	Planned area (ha)	Conformity rate (%)	Interpretation
Residential (R1, R1A, R1B, R2, R3, R4)	2,028.1	58.7	Partial conformity
Commercial (C1, C3)	292.9	76.8	High conformity
Industrial (I1, I2)	234.0	24.4	Low conformity
Agriculture / Forest (A1, F1, F3, F5)	3,307.9	~80.0	High conformity
Wetland / Buffer (W1, WB)	870.3	~78.0	Moderate conformity
Public / Infrastructure (PA, PF1–6, T1, U)	1,127.8	~65.0	Moderate conformity

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Figure 1 visualises the zone-level conformity rates summarised in Table 1, highlighting the contrast between the high-conformity commercial and agriculture/forest zones and the low-conformity industrial zone.

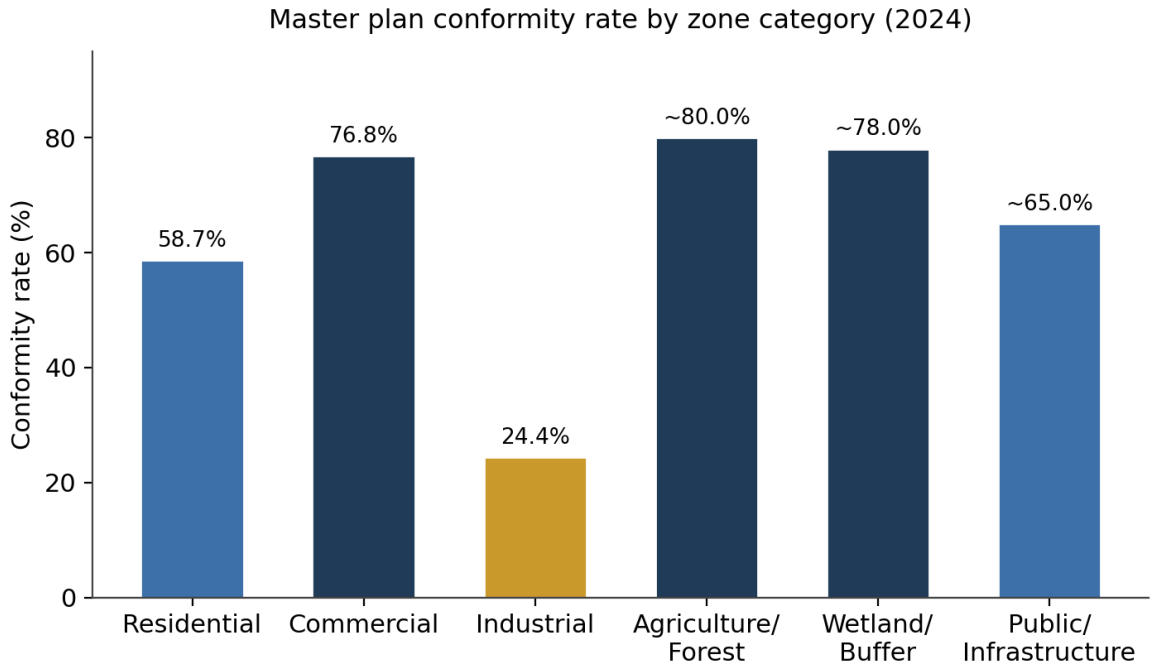


Figure 1. Master plan conformity rate by zone category, Muhanga Satellite City (2024).

Encroachment analysis – defined as development or cultivation within zones reserved for conservation, wetlands, or agriculture – found that 945 ha (36.2%) of the 2,607.6-ha restricted-zone area had been converted to non-conforming uses by 2024. Wetland/conservation buffers were most affected (49.4% encroachment, ~430 ha), followed by industrial reserves (75.6%, though substantially attributable to DLUP-permitted transitional agriculture), green space/urban parks (~35.9%), and the agricultural reserve (21.8%, ~313 ha), concentrated respectively along drainage corridors in Muhanga and Nyamabuye, and along peri-urban fringes of Cyeza. GIS proximity analysis further showed that 68% of new built-up surfaces developed between 2014 and 2024 fell within 500 m of primary or secondary road corridors, with the RN1 corridor a particularly strong attractor of both conforming commercial growth and non-conforming leapfrog development into agricultural and wetland zones. These encroachment patterns by restricted-zone category are summarised in Table 2 and Figure 2.

Table 2: Encroachment within restricted zones by category, Muhanga Satellite City (2024).

Restricted zone category	Encroachment rate (%)	Encroached area (ha)	Notes
Wetland/conservation buffer	49.4	~430	Concentrated along drainage corridors in Muhanga and Nyamabuye
Industrial reserve	75.6	not reported	Substantially attributable to DLUP-permitted transitional agriculture
Green space/urban park	35.9	not reported	—
Agricultural reserve	21.8	~313	Concentrated along peri-urban fringes of Cyeza
Overall (all restricted zones)	36.2	945 (of 2,607.6 ha)	—

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Figure 3 presents the same encroachment rates graphically.

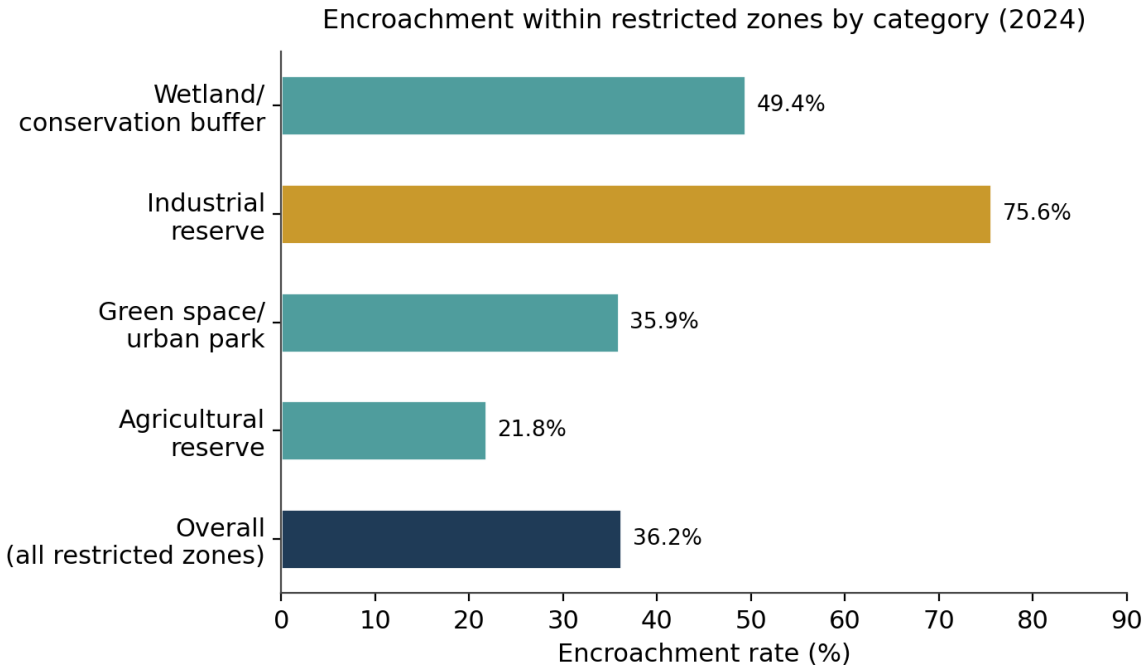


Figure 2. Encroachment within restricted zones by category, Muhanga Satellite City (2024).

4.2 Spatio-temporal LULC dynamics (2014–2024)

Classification of Landsat imagery for 2014 and 2024 identified six LULC classes (Table 3, Figure 4; see also Figure 5). In 2014, cropland dominated the landscape (5,512 ha; 71.3%), followed by forestland (1,045 ha; 13.5%), wetland (660 ha; 8.5%), and built-up area (488 ha; 6.3%). By 2024, built-up area had expanded to 3,437.9 ha (44.5%) – a net gain of 2,949.9 ha (+604.1%) – primarily at the expense of cropland, which fell to 2,869.8 ha (37.1%; −47.9%), and forestland, which declined to 519.1 ha (6.7%; −50.3%). Wetland area increased moderately to 884.8 ha (11.4%; +34.1%), reflecting localised wetland expansion into previously unclassified fringe areas even as encroachment reduced wetland extent elsewhere (Section 3.1); grassland disappeared entirely.

Table 3. LULC class area and change statistics, Muhanga Satellite City, 2014 and 2024.

LULC class	2014 (ha)	2014 (%)	2024 (ha)	2024 (%)	Net change (ha)	% change
Forestland	1,045.00	13.52	519.05	6.71	−525.95	−50.29
Grassland	19.00	0.25	0.00	0.00	−19.00	−100.00
Cropland	5,512.00	71.32	2,869.83	37.14	−2,642.17	−47.94
Built-up	488.00	6.31	3,437.87	44.49	+2,949.87	+604.08
Wetland	660.00	8.54	884.75	11.44	+224.75	+34.05
Water bodies	5.00	0.06	11.52	0.15	+6.52	+130.40
TOTAL	**7,729.00**	**100.00**	**7,729.00**	**100.00**	—	—

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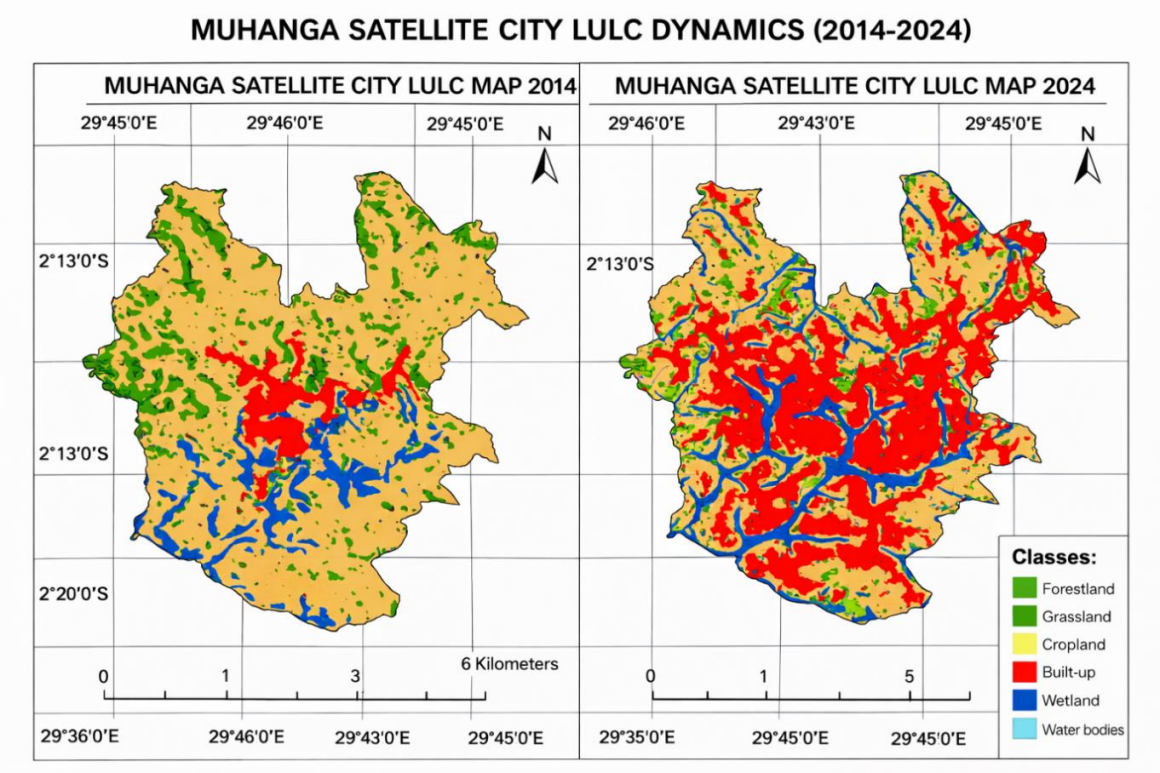


Figure 3. Supervised LULC classification maps of Muhanga Satellite City, 2014 and 2024.

Figure 4 compares total area by LULC class between 2014 and 2024, visualising the transition patterns summarised in Table 4.

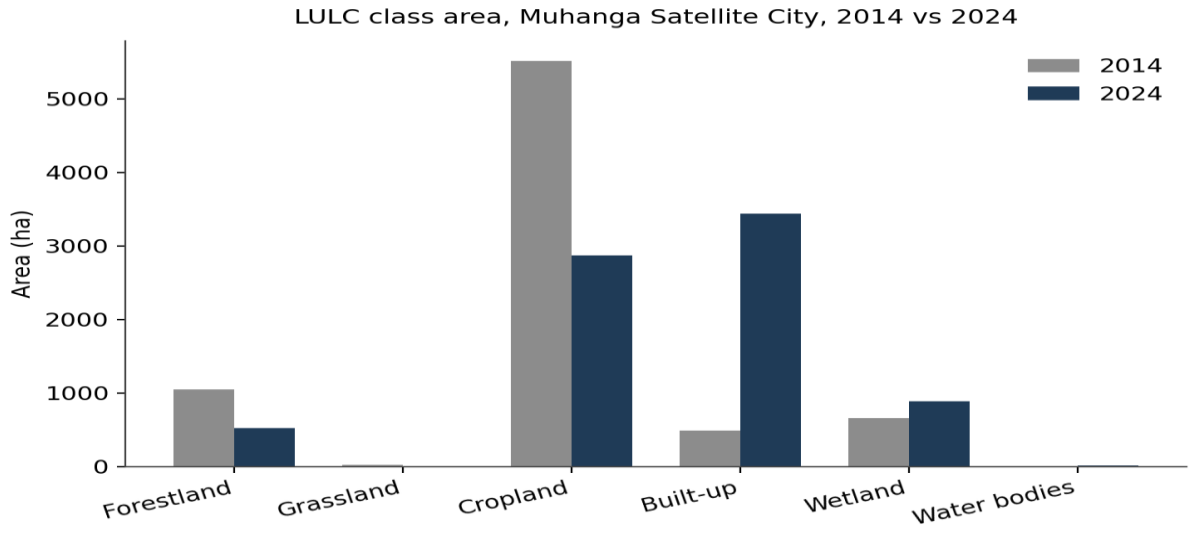


Figure 4. LULC class area, Muhanga Satellite City, 2014 vs 2024.

Transition analysis confirmed cropland-to-built-up conversion as the dominant pathway of change, concentrated along the peri-urban fringe, alongside forest-to-cropland/built-up conversion at the northern and north-eastern city boundary. Spatial pattern analysis of new built-up land identified edge-expansion (52%) as the dominant growth mode, followed by infill (28%) and leapfrog development (20%) in the Cyeza and Shyogwe fringes – the latter typically associated with fragmented, infrastructure-inefficient settlement. NDVI analysis corroborated these transitions: the High-NDVI (dense vegetation) class fell from approximately 35% of the study area in 2014 to 8% in 2024, while Very-Low-NDVI and bare-soil classes together rose to nearly 45% of the area, concentrated in expansion hotspots around Nyamabuye and Cyeza.

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Table 4. Spatial growth pattern typology of new built-up land, Muhanga Satellite City (2014–2024).

Growth pattern	Share of new built-up area (%)	Description
Edge-expansion	52	Contiguous outward growth from the existing built-up perimeter
Infill	28	Development within already partly built-up areas
Leapfrog	20	Detached, non-contiguous development in the Cyeza and Shyogwe fringes; typically fragmented and infrastructure-inefficient

Figure 5: Presents this typology Graphically.

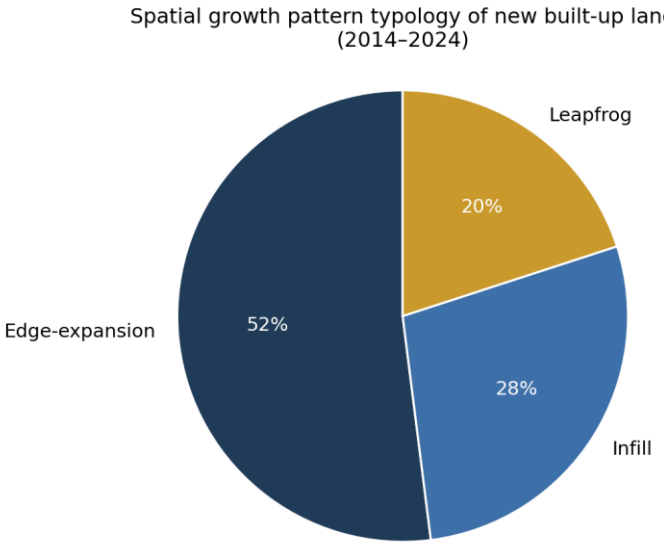


Figure 5. Spatial growth pattern typology of new built-up land, Muhanga Satellite City (2014–2024).

Figure 6 summarizes the corresponding NDVI vegetation-density shift.

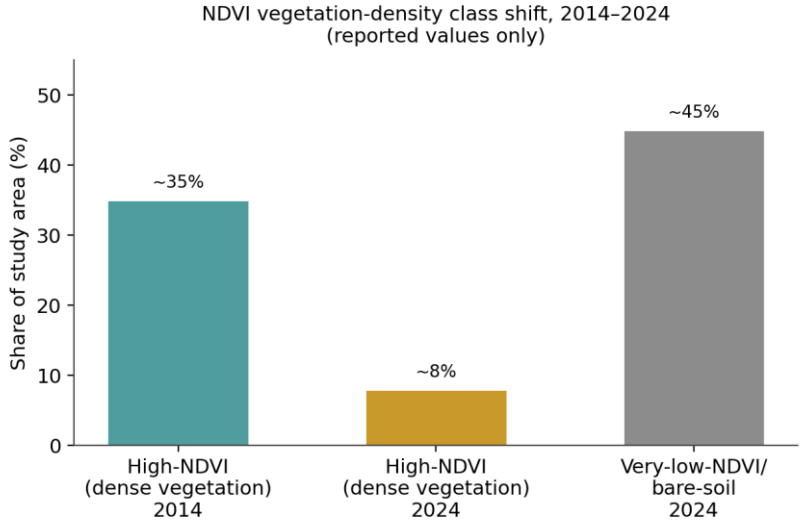


Figure 6. NDVI vegetation-density class shift, Muhanga Satellite City, 2014–2024

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4.3 Relationship between master plan implementation and LULC change

Correlation analysis between zone-level conformity rate and net LULC change yielded a strong positive relationship (R^2 = 0.78, $p < 0.001$): zones with the highest conformity – the commercial core and adjacent high-density residential areas – also recorded the most substantial, largely plan-consistent built-up expansion, whereas low-conformity zones (industrial, peri-urban fringe) exhibited delayed or non-conforming conversion, notably in cropland and wetland encroachment.

Interview triangulation identified four mediating factors underlying this pattern. First, land tenure security: NLA staff reported that approximately 87% of parcels within the city boundary held formal titles by 2024, with the least-titled sectors (Cyeza, peri-urban Shyogwe) showing disproportionately more informal construction. Second, enforcement capacity: district planners uniformly reported insufficient monitoring staff and no real-time surveillance system for a 7,860-ha jurisdiction; as one NLA informant explained, "inspection staff are responsible for a rapidly evolving landscape with limited field mobility and no real-time spatial surveillance infrastructure," allowing unauthorised construction to reach completion before enforcement could act. Third, stalled expropriation for planned public facilities created planning blight that, in several cases, triggered speculative informal settlement. Fourth, population growth outpaced DLUP projections: the city's population grew from roughly 50,608 (2012) to 87,613 (2022), exceeding the growth implied by the plan's 2012 census baseline and generating unmet housing demand that spilled into agricultural and wetland zones. Section 3.4 presents the informant profile and a thematic synthesis of these qualitative findings (Tables 4–5).

4.4 Qualitative insights from key informant interviews

To give the qualitative evidence introduced above a systematic presentation, Table 4 summarises the profile of the twelve key informants and Table 6 synthesises the interview findings by theme, including the drivers underlying the observed non-conformity.

Table 5: Profile of key informants, Muhanga Satellite City (n = 12).

Informant category	Number	Role / vantage point
District planners	2	Oversight of DLUP administration and permitting
Sector land officers	3	Parcel-level land use and titling administration
NLA central-level policy staff	2	National land use policy and enforcement oversight
Community leaders	5	Local knowledge of land use change and informal development
Total	**12**	—

Table 6: Thematic summary of key informant interview findings.

Theme	Key finding	Illustrative evidence
Land tenure security	Formal titling is high overall but uneven across sectors	~87% of parcels within the city boundary held formal titles by 2024; least-titled sectors (Cyeza, peri-urban Shyogwe) showed disproportionately more informal construction
Enforcement capacity	Monitoring capacity is insufficient relative to the size and pace of change in the jurisdiction	"Inspection staff are responsible for a rapidly evolving landscape with limited field mobility and no real-time spatial surveillance infrastructure" (NLA informant)
Stalled expropriation	Delayed compensation for planned public facilities generated planning blight	Stalled expropriation for planned public facilities, in several cases, triggered speculative informal settlement
Population growth	Demographic growth has outpaced the plan's projections	City population grew from roughly 50,608 (2012) to 87,613 (2022), exceeding the growth implied by the plan's 2012 census baseline

Taken together, these four themes indicate that the plan–landscape gap identified in Sections 3.1–3.3 is driven less by deficiencies in the DLUP's technical design than by implementation-side constraints, tenure informality, limited enforcement capacity, delayed expropriation, and demand pressure exceeding planning assumptions, that are examined further in the Discussion.

5. DISCUSSION OF FINDINGS

The findings show that residential and commercial areas generally had higher levels of conformity with the DLUP, while conservation and peri-urban areas experienced greater deviations. This is consistent with Guo et al. (2020), who identified similar implementation challenges in satellite cities. In Muhanga, planned land uses were more likely to be respected in areas with established land tenure, good road access and existing infrastructure, particularly around the central business district. However, conformity was lower in wetland-adjacent and peri-urban areas, where limited infrastructure and land administration challenges made it difficult to control development.

The findings also suggest that planning decisions are influenced by differences in power and influence among stakeholders. Interviews with community leaders and National Land Authority staff pointed to cases where politically connected and economically influential developers may have contributed to development in restricted areas.

This supports Swyngedouw and Heynen's (2003) argument that planning outcomes are shaped not only by technical and institutional capacity but also by relationships of power. The interviews therefore provide useful insights into the governance challenges behind the spatial patterns identified in this study.

The decline in vegetation density and wetland coverage is consistent with Kagabo et al. (2024), who reported vegetation loss associated with urban expansion in Kigali, and Davidson (2014), who documented widespread wetland loss linked to human activities. However, this study goes further by examining these changes in relation to DLUP implementation. The spatial analysis shows that some vegetation loss and wetland encroachment occurred in areas designated for conservation, indicating challenges in enforcing land use restrictions.

The spread of development beyond established urban areas, particularly along the RN1 corridor, also points to growing challenges in managing urban expansion. This pattern is consistent with Seto et al. (2012) and Angel (2023), who highlight the environmental and infrastructure costs of fragmented urban growth. In Muhanga, development along the corridor appears to have encouraged settlement beyond planned areas, reinforcing the need to coordinate infrastructure development with effective land use regulation. Population growth is another important factor affecting the implementation of the DLUP. According to Muhanga District (2024), the population is projected to reach 584,203 by 2035 and 1,026,500 by 2050. This growth is likely to increase demand for housing, infrastructure and other urban services. The findings therefore highlight the need to review planned residential areas, expand the supply of serviced land and regularly update population projections. Without these measures, growing pressure on land may further increase development outside designated zones and make effective implementation of the DLUP more difficult.

6. CONCLUSION

This study assessed the impact of Land Use Master Plan implementation on land use and land cover (LULC) dynamics in Muhanga Satellite City between 2014 and 2024 using GIS and remote sensing techniques. The findings revealed a significant implementation gap between planned land use allocations and actual development patterns. Although the Detailed Land Use Plan (DLUP) has guided development in some designated zones, non-conforming land conversion remains evident, particularly in ecologically sensitive and peri-urban areas. The expansion of built-up areas at the expense of agricultural land, forests and wetlands highlights challenges in enforcing zoning regulations and managing competing land demands. These challenges are associated with institutional weaknesses, land tenure insecurity, delayed expropriation, limited enforcement capacity and rapid population growth. The study concludes that effective implementation of the master plan requires stronger institutional coordination, improved land tenure administration, timely expropriation and continuous GIS-based monitoring of land use changes. These interventions are essential to ensure that actual urban development aligns with approved planning provisions and environmental sustainability objectives. By providing a spatially explicit assessment of land use conformity and landscape transformation, the study contributes empirical evidence to urban planning research and offers a methodological framework that can inform similar assessments in Rwanda's other satellite cities.

7. RECOMMENDATIONS

The Government of Rwanda, through the National Land Authority and the Ministry of Infrastructure, should strengthen master plan implementation through regular GIS-based monitoring, timely expropriation and improved coordination among land administration and urban planning institutions. Muhanga District authorities should integrate GIS monitoring with building permit records, enforce zoning regulations and prioritise the protection of wetlands, agricultural land and other environmentally sensitive areas. Community leaders and residents should also be involved in monitoring land use changes and reporting unauthorised developments.

Future research should extend GIS-based land use conformity assessments to other Rwandan satellite cities to determine whether the challenges identified in Muhanga occur elsewhere. Further studies should examine land use changes beyond 2024, apply advanced classification techniques such as Random Forest, and investigate how land tenure security influences zoning compliance and sustainable urban development.

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