

Impact of Land Use and Land Cover Change on Vegetation Cover Loss in Rwanda: Evidence from Muhoza Sector, Musanze District (2015–2025)

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Abstract: This study analyzed the impact of land use and land cover (LULC) change on vegetation cover loss in Muhoza Sector, Musanze District, Rwanda, between 2015 and 2025. A quantitative geospatial research design was adopted using multi-temporal Landsat and Sentinel-2 satellite imagery, field-based GPS validation, Geographic Information Systems, and Normalized Difference Vegetation Index (NDVI) analysis. Six land-cover classes—forestland, grassland, cropland, urbanized land, wetland, and water bodies—were mapped using supervised classification and post-classification change detection. Forestland declined from 7.58 km² in 2015 to 4.42 km² in 2025, a net loss of 41.69%, while urbanized land expanded from 5.10 km² to 9.60 km², an increase of 88.24%. Cropland declined by 26.60% over the decade, whereas grassland increased by 113.46%. Mean NDVI fell from 0.60 in 2015 to 0.55 in 2020 before partially recovering to 0.57 in 2025. Forestland showed a very strong positive relationship with mean NDVI ($R = .96$), while urbanized land showed a strong negative relationship ($R = -.93$); cropland showed a moderate negative relationship ($R = -.52$). The findings identify forest conversion and urban expansion as the principal structural drivers of vegetation decline. The study recommends stronger zoning enforcement, forest conservation and restoration, green infrastructure, and routine integration of LULC and NDVI monitoring into local land-use planning.

Keywords: Land Use and Land Cover; Vegetation Cover Loss; NDVI; Remote Sensing; GIS; Urbanization; Muhoza Sector; Musanze District; Rwanda.

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I. INTRODUCTION

Land use and land cover change is a major driver of environmental transformation because the conversion of forests, grasslands, croplands, wetlands, and other natural surfaces alters ecosystem functioning, biodiversity, soil stability, hydrological processes, and local climate regulation. These changes are particularly significant in rapidly urbanizing highland environments, where population pressure and infrastructure expansion compete with agriculture and ecologically sensitive vegetation.

In Rwanda, high population density, urban growth, agricultural intensification, and infrastructure development have increased pressure on land resources. Muhoza Sector is the administrative and commercial core of Musanze District and lies within a sensitive highland landscape near the Virunga mountain system. The sector's expanding urban footprint and surrounding agricultural land create a strong

need for fine-scale, temporally consistent monitoring of landscape change.

Remote sensing and GIS provide a practical means of detecting such change. Multi-temporal Landsat and Sentinel-2 imagery can be classified into land-cover categories, while NDVI provides a complementary measure of vegetation greenness, density, and condition. Combining LULC change detection with NDVI therefore enables direct assessment of how landscape transformation corresponds with vegetation loss or recovery.

➤ Problem Statement

Despite evidence of rapid urbanization and vegetation pressure in Musanze, sector-level information linking specific LULC transitions to vegetation-cover change has remained limited. Existing studies frequently operate at spatial scales too coarse for decisions such as zoning enforcement, construction permitting, green-infrastructure

planning, and localized restoration. Without fine-resolution temporal evidence, planners and environmental managers cannot easily identify where urban growth, forest conversion, and agricultural dynamics are most strongly affecting vegetation condition. This study addressed that gap through a decade-long analysis of Muhoza Sector using satellite-derived LULC maps and NDVI.

➤ *Study Objectives*

- To analyze the spatio-temporal dynamics of land use and land cover change in Muhoza Sector.
- To analyze the level and temporal pattern of vegetation cover loss in Muhoza Sector.
- To determine the relationship between land use and land cover change and vegetation cover loss in Muhoza Sector.

II. LITERATURE REVIEW

➤ *Theoretical Foundation*

The study was informed by Land Change Science, Human–Environment Interaction Theory, and Landscape Ecology Theory. Land Change Science explains LULC transformation through proximate human actions such as urban expansion, agricultural conversion, and infrastructure development, together with broader structural drivers. Human–Environment Interaction Theory emphasizes the reciprocal relationship between land-use decisions and environmental consequences. Landscape Ecology Theory adds a spatial perspective by showing how the size, connectivity, and arrangement of land-cover patches affect ecological processes and vegetation integrity.

➤ *LULC Change and Vegetation Dynamics*

Urban expansion typically converts vegetated and agricultural surfaces into impervious land, lowering landscape greenness and fragmenting ecological cover. Forest loss has particularly strong effects because closed-canopy vegetation produces high NDVI values and provides

important ecological functions. Cropland presents a more variable signal because seasonal crops maintain temporary greenness but usually provide lower and less stable vegetation cover than forests. Grassland can provide an intermediate stabilizing function, while changes in wetland and water-body extent can indicate broader hydrological modification.

➤ *Remote Sensing, GIS and NDVI*

Supervised classification of multi-temporal satellite imagery provides spatially explicit estimates of land-cover extent and transition. NDVI, calculated from near-infrared and red reflectance, is widely used as an indicator of vegetation density and health, with higher positive values representing denser photosynthetically active vegetation. Integrating change detection and NDVI is particularly useful because it links structural changes in land-cover composition with corresponding changes in vegetation condition.

➤ *Research Gap*

Although international and East African studies document strong relationships between urbanization, forest loss, agricultural change, and vegetation degradation, relatively little fine-resolution evidence exists at sector level in Rwanda. The lack of temporally consistent LULC and NDVI analysis for Muhoza Sector limited the evidence available for local land-management decisions. This study filled that gap by using three time steps—2015, 2020, and 2025—to quantify land-cover transitions and vegetation responses.

➤ *Conceptual Framework*

The conceptual framework treats LULC change as the independent variable and vegetation cover loss as the dependent variable. LULC change is represented through urban growth, forest change, grassland dynamics, cropland dynamics, and wetland/water-body change. Vegetation cover loss is assessed through forest loss, vegetation health, and NDVI-based indicators.

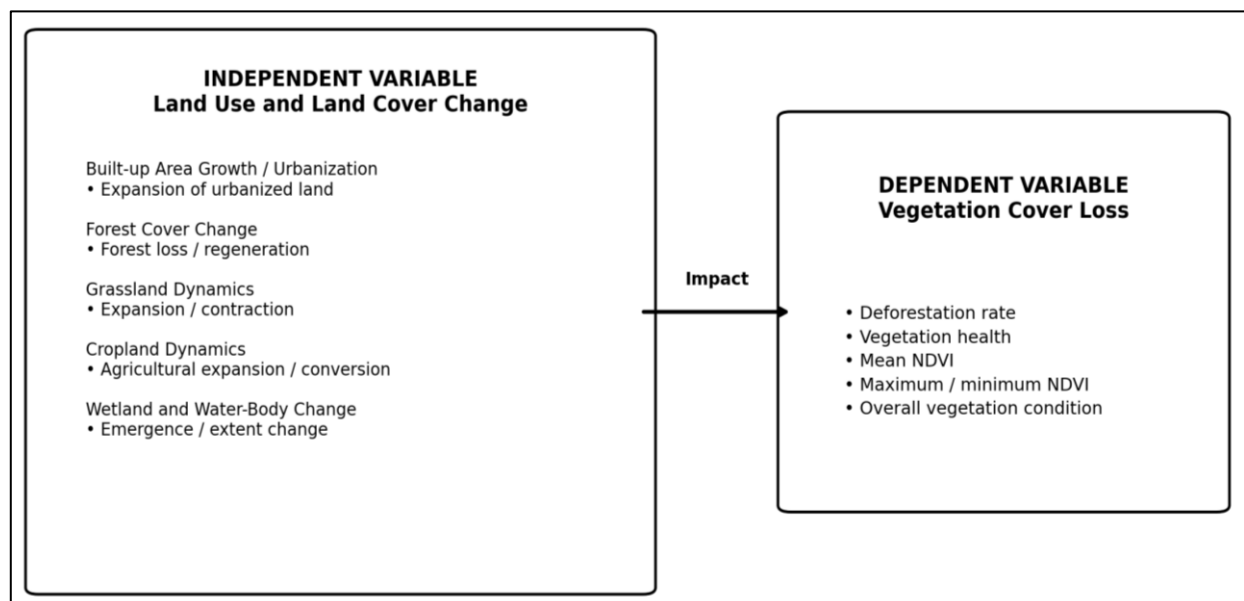


Fig 1 Simplified Conceptual Framework

III. METHODOLOGY

The study adopted a quantitative geospatial research design focused on Muhoza Sector, Musanze District, Northern Province of Rwanda. The temporal scope covered 2015, 2020, and 2025. Remote sensing was the primary data source, complemented by field observation, GPS ground-truth points, administrative boundaries, existing land-use information, and documentary review.

Satellite imagery was accessed through Google Earth Engine. Sentinel-2 imagery at 10 m resolution was prioritized for fine-scale interpretation, while Landsat imagery was used for temporal analysis and cross-validation. Images were filtered for dry-season and low-cloud conditions, atmospherically and geometrically standardized, cloud masked, mosaicked where necessary, and clipped to the Muhoza Sector boundary.

A supervised classification procedure was applied to identify six classes: forestland, grassland, cropland, urbanized land, wetland, and water bodies. Training samples were informed by high-resolution imagery, field observations, and existing maps. Classification reliability was assessed using independent validation points and confusion-matrix statistics. Change detection then quantified net area change and percentage change across 2015–2020, 2020–2025, and 2015–2025.

NDVI was calculated in ArcGIS 10.8.2 from near-infrared and red reflectance. Maximum, minimum, mean, and standard deviation values were extracted for each year. The relationship between LULC and vegetation condition was evaluated by comparing temporal trajectories and correlation coefficients between major land-cover classes and mean NDVI.

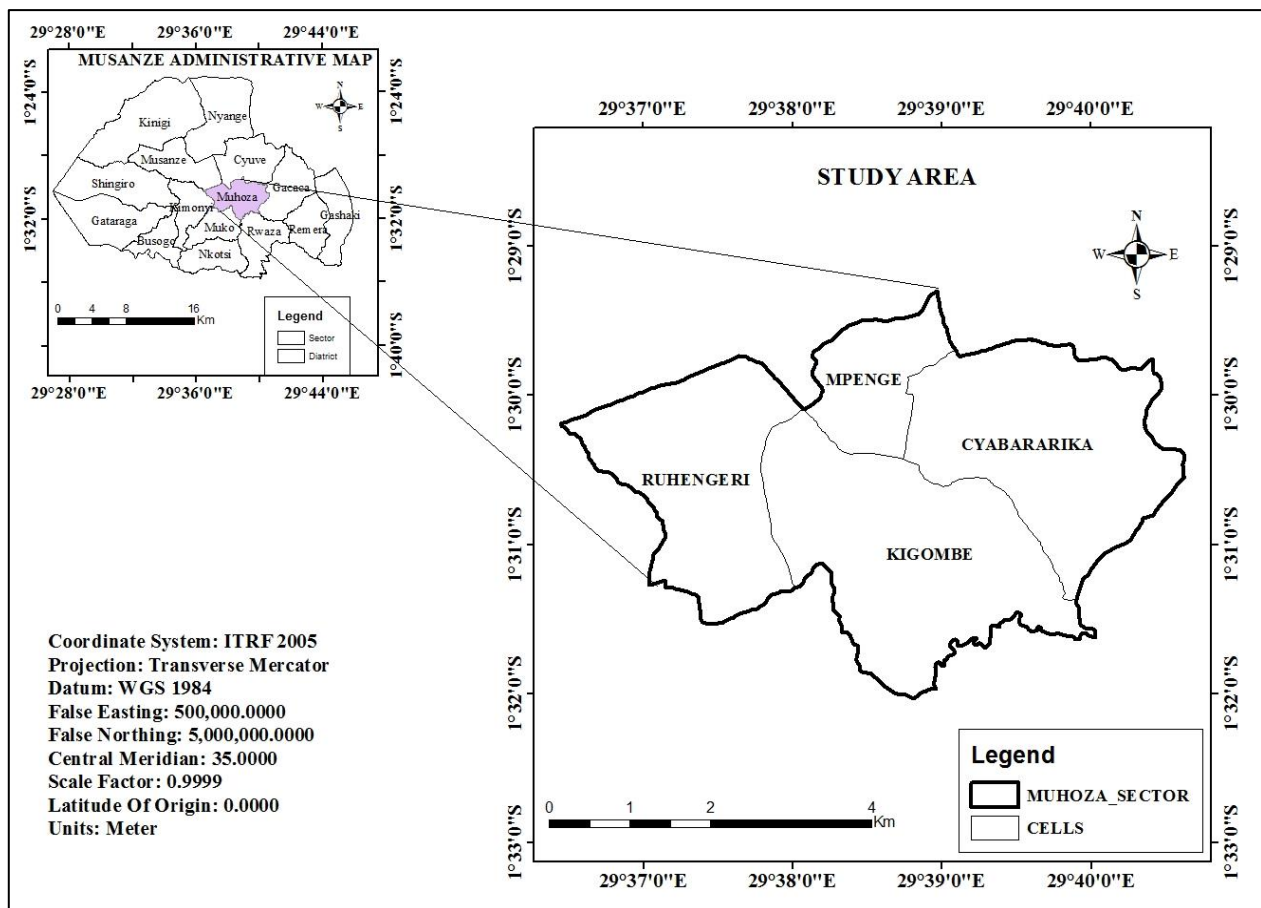


Fig 2 Study area: Muhoza Sector, Musanze District

IV. FINDINGS AND DISCUSSION

➤ Land Use and Land Cover Dynamics

The decade from 2015 to 2025 was characterized by substantial landscape transformation. Forestland declined from 7.58 km² in 2015 to 2.22 km² in 2020, before recovering partially to 4.42 km² in 2025. This represented a net decadal reduction of 3.16 km² or 41.69%. Urbanized land increased continuously from 5.10 km² to 6.45 km² and then to 9.60 km²,

producing the largest absolute gain of 4.50 km² and an 88.24% increase.

Cropland increased from 7.97 km² in 2015 to 11.23 km² in 2020 before contracting sharply to 5.85 km² in 2025, resulting in a net decline of 26.60%. Grassland increased from 0.52 km² to 1.11 km² over the decade, a 113.46% gain, although it remained a relatively small component of the landscape. Wetland and water-body classes appeared in 2025 at 0.0035 km² and 0.19 km² respectively.

Table 1 Land Use and Land Cover Dynamics

LULC Class	2015 (km ²)	2020 (km ²)	2025 (km ²)	2015–2025 Change (km ²)	% Change
Forestland	7.58	2.22	4.42	-3.16	-41.69
Grassland	0.52	1.25	1.11	+0.59	+113.46
Cropland	7.97	11.23	5.85	-2.12	-26.60
Urbanized land	5.10	6.45	9.60	+4.50	+88.24
Wetland	0	0	0.0035	+0.0035	New class
Water bodies	0	0	0.19	+0.19	New class

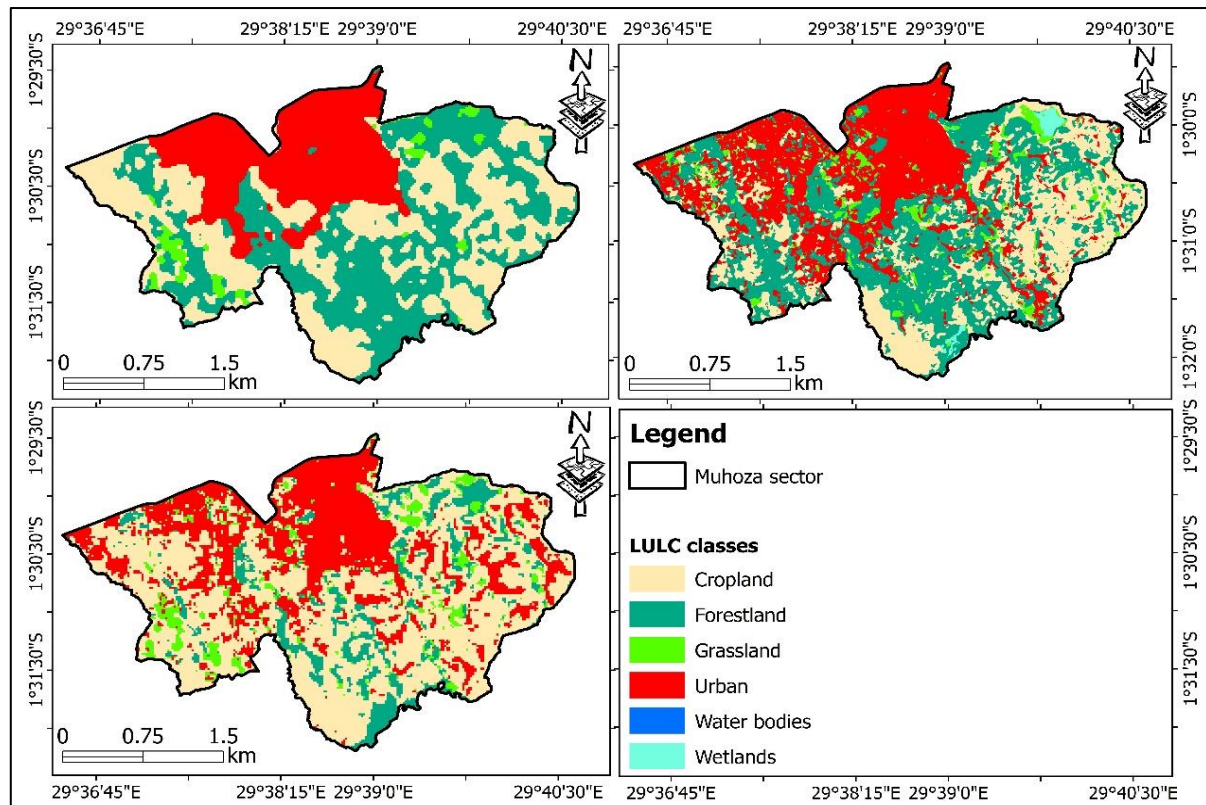


Fig 3 Land Use and Land Cover Dynamics in Muhoza Sector, 2015–2025

➤ Classification Accuracy

Validation results showed that the land-cover maps were sufficiently reliable for change analysis. Overall validation accuracy was 83.6% in 2015, 92.2% in 2020, and 91.3% in 2025, with Kappa coefficients of 0.770, 0.893, and

0.881 respectively. The lower 2015 accuracy reflects differences in imagery quality relative to later observations, while the 2020 and 2025 classifications achieved high agreement with validation data.

Table 2 Classification Accuracy

Year	Overall Validation Accuracy (%)	Kappa Coefficient	Validation Points
2015	83.6	0.770	150
2020	92.2	0.893	150
2025	91.3	0.881	150

➤ Vegetation Cover and NDVI Dynamics

Vegetation condition deteriorated most strongly between 2015 and 2020. Mean NDVI declined from 0.60 to 0.55, while maximum NDVI declined from 0.72 to 0.67. By

2025, a modest recovery was visible; mean NDVI increased to 0.57 and maximum NDVI to 0.69. The recovery remained incomplete because mean NDVI was still 0.03 below the 2015 baseline.

Table 3 Vegetation Cover and NDVI Dynamics

NDVI Statistic	2015	2020	2025	2015–2025 Change
Maximum	0.72	0.67	0.69	-0.03
Minimum	0.28	0.29	0.27	-0.01
Mean	0.60	0.55	0.57	-0.03
Standard deviation	0.09	0.08	0.09	0.00

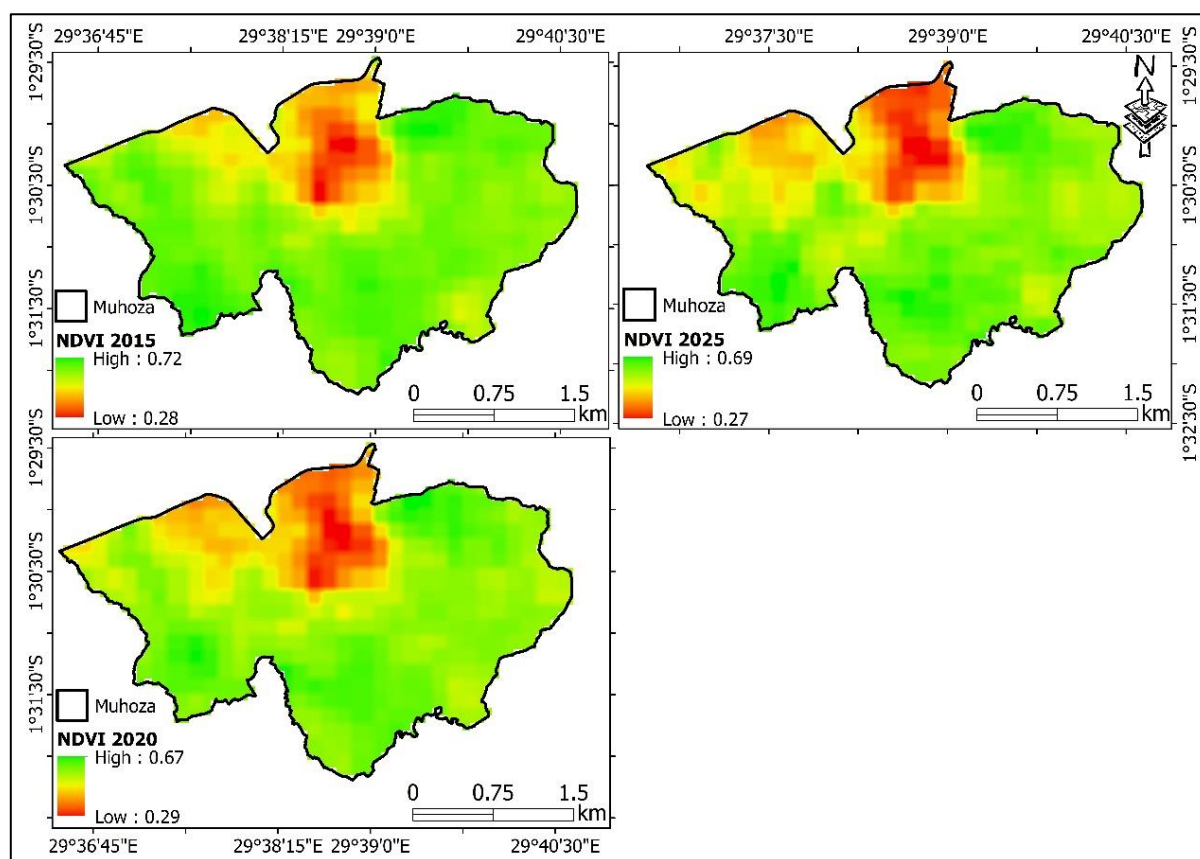


Fig 4 Spatio-Temporal Vegetation Condition (NDVI), 2015–2025

➤ Relationship between LULC Change and Vegetation Cover

The integrated LULC–NDVI analysis demonstrated strong directional coupling. Forestland and mean NDVI had a very strong positive correlation ($R=.96$), confirming that forest loss was closely associated with reduced vegetation health and that partial forest recovery contributed to NDVI rebound. Urbanized land and mean NDVI had a strong negative correlation ($R=-.93$), indicating that the expansion

of built-up surfaces progressively suppressed the landscape vegetation signal.

Cropland had a moderate negative relationship with mean NDVI ($R=-.52$), reflecting the seasonal and fluctuating vegetation signal of cultivated land. The combined evidence therefore identifies forest conversion and urban growth as the dominant drivers of vegetation-cover change, while grassland and partial forest regeneration contributed to the limited recovery observed after 2020.

Table 4 Relationship between LULC Change and Vegetation Cover

Land-cover Variable	Relationship with Mean NDVI	Interpretation
Forestland	$R = .96$	Very strong positive
Urbanized land	$R = -.93$	Strong negative
Cropland	$R = -.52$	Moderate negative

➤ Discussion

The steep forest decline between 2015 and 2020 coincided with the largest reduction in mean NDVI, supporting Land Change Science and the wider literature linking vegetation conversion with reduced ecological condition. The simultaneous increase in cropland and urbanized land suggests that forested surfaces were subjected to strong pressure from both agricultural and settlement expansion.

The partial recovery of forestland after 2020 and the corresponding increase in mean NDVI demonstrate that vegetation restoration can produce a detectable ecological response. However, continued urban growth to 9.60 km²

offset part of this recovery. The results therefore illustrate the human–environment interaction described in the study's theoretical framework: land-use decisions reshape vegetation condition, while the resulting environmental consequences create increasing pressure for improved planning and restoration.

The very strong positive forest–NDVI relationship and strong negative urban–NDVI relationship also demonstrate the usefulness of NDVI as a monitoring indicator. The results show that routine geospatial monitoring can provide local authorities with timely evidence of where land-cover conversion is producing ecological decline.

V. CONCLUSION AND RECOMMENDATIONS

➤ Conclusion

The study concludes that Muhoza Sector underwent substantial LULC transformation between 2015 and 2025 and that these changes had a measurable impact on vegetation condition. Forestland declined by 41.69%, while urbanized land expanded by 88.24%. Mean NDVI fell sharply during the period of greatest forest loss and recovered only partially after 2020. The correlation results confirm that vegetation health is highly sensitive to forest cover and negatively affected by urban expansion. LULC change is therefore a primary structural driver of vegetation-cover dynamics in Muhoza Sector.

➤ Recommendations

- Government and local authorities should strengthen enforcement of land-use zoning and master-plan provisions in areas experiencing rapid urban expansion.
- Forest conservation and reforestation programs should prioritize locations where forest-to-urban or forest-to-cropland conversion is most pronounced.
- Urban planners should integrate green corridors, buffer zones, urban greening, and sustainable drainage into new development areas.
- Muhoza Sector and Musanze District should institutionalize periodic LULC and NDVI monitoring using satellite imagery to detect vegetation decline before it becomes irreversible.
- Communities should be supported to adopt agroforestry, soil-conservation practices, and responsible hillside cultivation that reduces pressure on forestland.
- Future studies should use longer time series and higher-resolution imagery and incorporate socioeconomic drivers, hydrological impacts, biodiversity indicators, and field-based biomass validation.

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