

SPATIO-TEMPORAL ANALYSIS OF URBAN EXPANSION AND ITS EFFECTS ON VEGETATION COVER IN NYAMAGABE DISTRICT (2000-2024)

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Abstract: *Urban expansion in Rwanda has intensified over the past two decades, particularly in secondary cities such as Nyamagabe District, where rapid population growth and infrastructural development have transformed the landscape. Despite this expansion, limited empirical research has assessed how urban growth affects vegetation cover, ecological stability, and sustainable land use at the district level. This study examined the spatial and temporal dynamics of urban expansion in Nyamagabe District between 2000 and 2024 and investigated its impacts on vegetation cover. Using a descriptive and analytical research design, Landsat-based satellite imagery for 2000, 2008, 2016, and 2024 was employed to generate Land Use and Land Cover (LULC) maps and Normalized Difference Vegetation Index (NDVI) datasets. Remote sensing and GIS techniques, including supervised classification, post-classification change detection, and NDVI computation, quantified land cover transitions and vegetation health trends. Complementary qualitative data from 18 key informants, including sector land and environmental officers and district planners, provided contextual insights into the drivers and consequences of vegetation change. Structured interviews and focus group discussions identified key drivers of vegetation loss, including housing development, informal settlement expansion, agricultural conversion, and weak enforcement of land use regulations. The results revealed that built-up areas increased from 0.76 km² in 2000 to 50.46 km² in 2024, while forest cover declined by approximately 320.91 km², and grassland expanded dramatically, reflecting widespread land degradation and secondary succession. NDVI analysis showed fluctuating vegetation health, with persistent declines in healthy vegetation, particularly in peri-urban zones. The study concluded that urban expansion is the primary driver of vegetation loss in Nyamagabe District, although national policies such as the National Land Use and Development Master Plan and the National Forest Policy have contributed to partial vegetation recovery. These findings underscore the need for integrated land-use planning, strengthened policy implementation, and community-based restoration programs, providing evidence-based guidance for promoting sustainable urban development while safeguarding ecological integrity in rapidly transforming districts of Rwanda.*

Keywords: *GIS, Land Use Change, Spatio-temporal Analysis, Urban Expansion, Vegetation Cover.*

0. Introduction

Urban expansion is a global phenomenon with significant implications for land use, biodiversity, and ecosystem services. Rapid urbanization worldwide has resulted in the increasing artificialization of land, habitat loss, and rising carbon emissions, raising concerns about the sustainability of urban environments and the need for green infrastructure to mitigate ecological impacts (Cerema, 2020; Czech et al., 2020; Seto et al., 2020). In many regions, urban growth has also caused substantial reductions in vegetation cover, conversion of farmland to built-up areas, and alterations to ecosystem functions, highlighting the interconnectedness of urban development and environmental health (Yao et al., 2017).

In Africa, urbanization is occurring at an unprecedented pace, often outstripping planning capacity and creating environmental challenges. Rapid urban growth has been linked to deforestation, land degradation, and changes in vegetation patterns, leading to the loss of biodiversity and ecosystem services (United Nations Environment Programme, 2020; Gowda et al., 2017). These trends are especially pronounced in East Africa, where cities and secondary towns are experiencing intensive land transformation. The expansion of built-up areas has increasingly converted natural habitats, affecting vegetation cover and ecosystem functionality.

In Rwanda, urban growth has intensified over recent decades, driving changes in land use and vegetation dynamics. This expansion has extended beyond major cities into surrounding districts, creating pressures on natural resources and vegetation cover (Mugabowindekwe & Rwanyiziri, 2020; National Institute of Statistics of Rwanda, 2020). The increasing demand for land and infrastructure has resulted in the conversion of forests, croplands, and grasslands into urban landscapes, with potential consequences for carbon sequestration, biodiversity conservation, and sustainable land management.

Nyamagabe District, located in the Southern Province, is characterized by hilly terrain, diverse ecosystems, and significant biodiversity, including proximity to one of the last remaining tropical rainforests in the region. Population growth and urbanization are exerting pressure on the district's natural resources, resulting in vegetation loss, land degradation, and shifts in land use patterns. Understanding the spatial and temporal dynamics of urban expansion and its effects on vegetation cover in Nyamagabe is therefore

essential for sustainable land use planning and environmental management. This study aims to conduct a spatio-temporal analysis of urban expansion and its impact on vegetation cover in Nyamagabe District between 2000 and 2024.

1. Statement of the problem

Urban expansion in Nyamagabe District has accelerated in recent decades due to rapid population growth, rural-to-urban migration, and increasing infrastructural development, resulting in substantial land use and land cover (LULC) changes, particularly the decline of vegetation cover. This loss of vegetation threatens biodiversity, ecosystem services, and soil stability in the district's hilly terrain, contributing to increased erosion, surface runoff, and sedimentation in rivers and water bodies (Karamage et al., 2016). The reduction of green spaces also diminishes carbon sequestration capacity and exacerbates urban heat effects, negatively affecting both environmental quality and human well-being. Similar patterns have been reported in other districts, including a 22% reduction in vegetation in Runda Sector, Kamonyi, between 2001 and 2022 due to urban growth (Munyaneza et al., 2023).

Despite these environmental and ecological consequences, there is limited empirical research that comprehensively maps the spatial and temporal dynamics of urban expansion and its impacts on vegetation in Nyamagabe District. Previous studies have either focused on single time points or broader national trends, without integrating high-resolution spatio-temporal analyses and vegetation health indicators. What is new in this study is the combined use of Landsat-derived Land Use and Land Cover (LULC) maps, Normalized Difference Vegetation Index (NDVI) analysis, and qualitative insights from key informants to quantify changes from 2000 to 2024. This approach allows for a detailed understanding of how urban growth has reshaped vegetation patterns over time, identifies the drivers of these changes, and provides evidence-based recommendations to guide sustainable urban planning and natural resource management in the district.

2. Empirical Studies

Several studies have examined the impacts of urban expansion on land use, vegetation cover, and ecological dynamics, highlighting patterns and consequences relevant to the current research. Munyaneza et al. (2023) investigated urbanization impacts on agricultural land in Runda Sector, Kamonyi District, using remote sensing and GIS. They found significant agricultural land loss and vegetation decline due to urban growth, emphasizing the need for sustainable planning, but the study did not cover Nyamagabe District. Similarly, Mnyali and Materu (2021) analyzed land use changes in peri-urban areas of Dar es Salaam, Tanzania, predicting future urban expansion and reporting substantial vegetation loss. While methodologically robust, the study is context-specific to Tanzania and does not address Nyamagabe.

Abimbola et al. (2025) explored the urban heat island effect in Lafia, Nigeria, linking increased temperatures to vegetation loss caused by urban development, highlighting ecological consequences of unplanned expansion. Perikamana et al. (2021) applied convolutional neural networks (CNN) for precise urban land cover classification in Indian cities, demonstrating improved mapping of urban and vegetated areas. However, the study did not examine the vegetative responses to urbanization in African rural settings, leaving a methodological and contextual gap for Nyamagabe.

Regional studies also indicate human activities as drivers of vegetation change. Gowda et al. (2017) observed that human presence altered vegetation patterns in the Horn of Africa, while Mumuni et al. (2025) identified urbanization as a major factor driving wetland degradation in Sub-Saharan Africa. In Rwanda, Uwingabire et al. (2016) described soil properties in the Congo Nile Watershed, providing background for understanding land susceptibility to vegetation loss, though without directly linking urban growth to vegetation cover changes.

Locally, Clay (2023) examined agricultural modernization in Nyamagabe, showing how land use changes can indirectly affect vegetation through altered farming practices. Mugiraneza et al. (2017) analyzed urban expansion in Kigali, demonstrating significant vegetation reduction, with approaches transferable to Nyamagabe. Gatwaza et al. (2016) assessed urbanization impacts on hydrology near Nyamagabe, noting increased runoff and reduced groundwater, yet vegetation effects were not addressed. Rwanyiziri et al. (2020) documented wetland loss in Kigali due to urban growth, while Nsangaband and Mupenzi (2020) observed agricultural land decline in Gasabo District linked to urban expansion. Both studies reinforce the broader trends relevant for Nyamagabe but highlight a lack of localized, vegetation-focused research.

Empirical studies underscore the widespread impact of urban expansion on land use and vegetation while revealing a clear research gap: few studies have systematically assessed the spatio-temporal dynamics of urban expansion and its direct effects on vegetation cover in Nyamagabe District, a gap the present study aims to address.

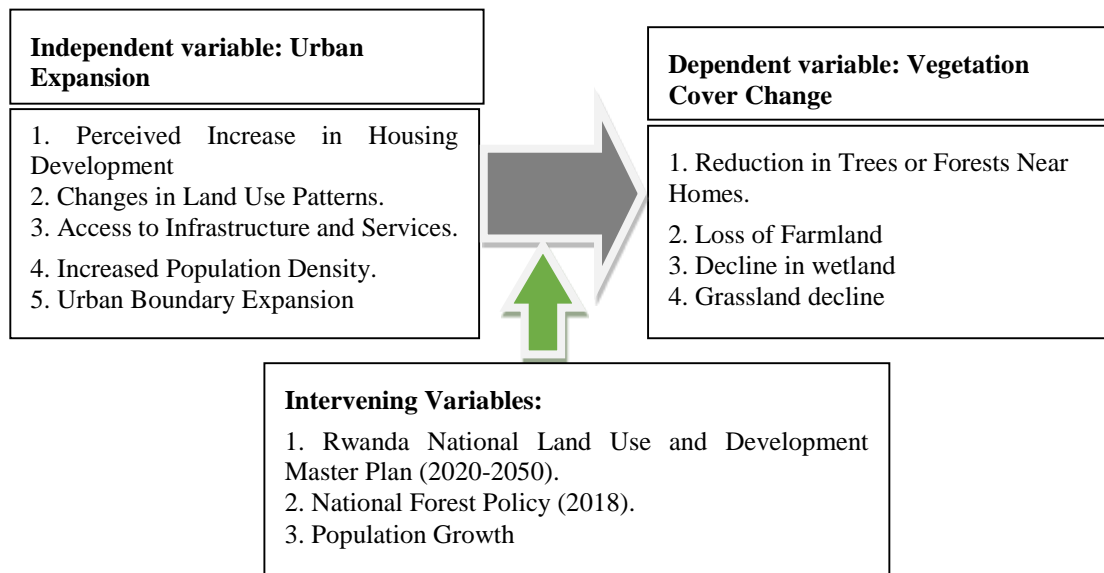
3. Conceptual framework of the study

The ten indicators of urban expansion and vegetation cover are intricately interlinked through the dynamic interaction between human settlement growth and environmental sustainability, with national policies acting as mediating frameworks. As urban expansion intensifies reflected by increased housing development, land use changes, infrastructure growth, and rising population density communities in Nyamagabe District report a noticeable loss of farmland, green spaces, and forest cover, as well as environmental degradation such as soil erosion and reduced biodiversity. These changes highlight the community's direct experience of how unchecked urban growth can threaten vegetation and ecosystem services. However, the impacts of these trends are not occurring in a policy vacuum.

The Rwanda National Land Use and Development Master Plan (2020–2050) is intended to guide orderly urbanization and prevent the encroachment of built environments into ecologically sensitive zones, while the National Forest Policy (2018) aims to restore and preserve vegetation through reforestation and forest protection efforts. Together, these policies serve as critical intervening variables that can either mitigate or exacerbate the environment consequences of urban growth, depending on their implementation and

community alignment. Thus, the indicators and policies are linked through a cause-effect-moderation chain, where the success of sustainable development in Nyamagabe hinges on managing the balance between development needs and ecological preservation.

Figure 1: Conceptual Framework of the Study



Source: Author, (2025)

4. Study Methodology

This section gives in details methods and techniques which are used to achieve study objectives and testing validity of the study objectives and hypotheses. It shows study design, population and sample size, sampling techniques, data collection tools, methods for data processing and data analysis. Here below are details:

4.1 Study objective

The general objective of this study is to assess the impacts of urban expansion on vegetation cover in Nyamagabe District, Rwanda, between 2000 and 2024. Specifically, this study intends to achieve the following objectives:

- To examine the spatial and temporal dynamics of urban expansion.
- To assess the changes in vegetation cover.
- To determine the relationship between urban expansion and vegetation cover changes.

4.2 Study Hypotheses

The above research objectives are based on the following first assumptions (hypotheses):

- H₀₁: There is no significant change in the spatial extent of urban areas in Nyamagabe District between 2000 and 2024.
- H₀₂: There is no significant change in vegetation cover in Nyamagabe District between 2000 and 2024.
- H₀₃: Urban expansion has no significant effect on vegetation cover changes in Nyamagabe District between 2000 and 2024.

4.3 Research Design

This study adopts a descriptive research design, combining Spatio-temporal Analysis of land use and vegetation trends with limited institutional-level qualitative insights. The research is largely grounded in secondary data, particularly satellite imagery and official land use records, to assess the spatial and temporal patterns of urban expansion and vegetation cover change in Nyamagabe District between 2000 and 2024. The descriptive design is suitable for systematically examining historical land cover changes, understanding patterns of urban growth, and linking these to ecological impacts using geospatial tools such as remote sensing and GIS.

Although secondary data provides the primary basis for analysis, a small amount of primary data were collected from key informants comprising 5 sector-level land officers and 2 environmental officers and 11 district staff involved in land use, planning, and environmental management (18 total key informants). Their perspectives offered contextual understanding and validation of the observed changes. These data were collected using a brief instrument combining open- and closed-ended questions, designed to minimize response burden while eliciting relevant insights. The approach allows for a targeted and efficient mixed-methods framework, integrating high-resolution spatial data with grounded institutional knowledge.

4.3 Study Population and Sampling Techniques

The study population consists of institutional stakeholders in Nyamagabe District who have technical expertise and administrative responsibilities related to land use, environmental protection, and infrastructure development. This includes sector-level land and environmental officers and staff from the Nyamagabe District One Stop Center who are directly involved in land management, urban planning, and policy implementation. These individuals provide critical insights into how urban expansion and vegetation changes are managed and monitored on the ground.

For primary data collection, the sample is intentionally limited to 18 key informants, comprising 8 sector-level officers from urbanizing sectors and 10 district-level staff from the One Stop Center. Participants were selected purposively based on their professional roles and relevance to the study objectives. This strategic sample size allows for focused qualitative inquiry, ensuring rich, context-specific data while remaining feasible in terms of data collection, transcription, and thematic analysis. The study uses purposive sampling to identify all 18 respondents. This non-probabilistic method ensures that only individuals with direct involvement in land use and environmental management are included. By targeting experienced professionals and administrative staff, the study ensures that the qualitative data reflects accurate and meaningful institutional perspectives. The combination of purposive sampling and expert-based inquiry strengthens the study's ability to interpret satellite findings considering real-world policy and planning dynamics

Table 1: Population and Sample Size

| Population Groups | Estimated Household Population | Sample Size (Households) | Sampling Technique |
|--|--------------------------------|--------------------------|---------------------------|
| Sector land/environment officers (5 sectors) | 8 | 8 | Purposive sampling |
| Nyamagabe District One Stop Center (Planning, Land, Environment Departments) | 10 | 10 | Purposive sampling |
| Total | 18 | 18 | Purposive sampling |

Source: Author, 2025

4.4 Data Collection Sources, Instruments, and Processing Techniques

This study employed both primary and secondary data sources to investigate the effects of urban expansion on vegetation cover in Nyamagabe District. Secondary data formed the foundation of the research and included Landsat and Sentinel satellite imagery from 2000, 2010, and 2024, as well as shapefiles, topographic maps, population statistics, and policy documents obtained from institutions such as National Institute of Statistics of Rwanda and Rwanda Environment Management Authority. Primary data were collected from 18 key informants through interviews, questionnaires, and focus group discussions using both open- and closed-ended questions to capture institutional perspectives on urban growth, vegetation change, and land use management. Geospatial and analytical tools such as QGIS, ArcGIS, Google Earth Engine, NDVI analysis, and supervised classification were used to process and analyze spatial data, while documentary review supported contextual interpretation. Data processing involved editing, coding, and tabulation of qualitative and spatial information to ensure accuracy, consistency, and meaningful analysis. Qualitative responses were thematically coded using NVivo or Excel, while satellite imagery was classified into land cover categories to enable temporal comparison of vegetation and built-up area changes across the study period.

4.5 Data Analysis

This study employs a combination of quantitative, qualitative, and geospatial analyses to investigate the impacts of urban expansion on vegetation cover in Nyamagabe District between 2000 and 2024. The analysis is organized according to the study's specific objectives, integrating spatial data interpretation with institutional perspectives obtained through interviews and focus group discussions.

4.5.1 Analysis for Objective 1: Investigating the Spatial temporal dynamics of Urban Expansion

To examine the spatial patterns and trends of urban expansion, multi-temporal satellite imagery from Landsat (2000, 2010) and Sentinel-2 (2024) was processed and analyzed using ArcGIS software. Preprocessing included geometric correction, atmospheric correction, cloud masking, and radiometric normalization to ensure comparability across years. Land use and land cover (LULC) maps were generated using a combination of unsupervised (ISODATA clustering) and supervised classification (Maximum Likelihood Classification), enabling the identification of built-up areas, forests, grasslands, and other land cover types.

Post-classification change detection techniques were then applied to quantify the extent, rate, and hotspots of urban growth. Statistical summaries of LULC transitions, including gains and losses of built-up areas, were extracted to highlight Spatial temporal dynamics over the 24-year period.

4.5.2 Analysis for Objective 2: Assessing Changes in Vegetation Cover

Vegetation cover changes were assessed using both LULC data and vegetation indices. NDVI (Normalized Difference Vegetation Index) was calculated from satellite imagery using the formula:

$$NDVI = \frac{(NIR + RED)}{(NIR - RED)}$$

Where NIR is the near-infrared band and RED is the red band of the satellite imagery. NDVI values range from -1 to +1, with higher values indicating denser and healthier vegetation. Comparisons across 2000, 2010, and 2024 enabled the identification of areas experiencing vegetation loss or gain. NDVI differencing was performed as follows:

$$\Delta\text{NDVI} = \text{NDVI}_{2024} - \text{NDVI}_{2000}$$

Positive ΔNDVI values indicated vegetation recovery, while negative values indicated vegetation degradation. These quantitative findings were supplemented with descriptive statistics, summarizing the magnitude and patterns of vegetation change across the district.

4.5.3 Analysis for Objective 3: Determining the Relationship Between Urban Expansion and Vegetation Cover

To examine the relationship between urban expansion and vegetation loss in Nyamagabe District, quantitative data from satellite-derived metrics (e.g., NDVI, LULC statistics) and structured key informant responses were analyzed using SPSS. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were first computed to summarize perceptions regarding urban growth, vegetation reduction, and land use changes.

To assess the strength and direction of associations between urban expansion variables and vegetation cover, bivariate correlation analysis was performed. This analysis identified which urban growth factors such as housing development, land use changes, population density, access to infrastructure, and urban boundary expansion are most strongly associated with reductions in vegetation. Correlation coefficients (Pearson's r) were interpreted to determine the magnitude and direction of these relationships.

Further, multiple regression analysis was conducted to quantify the combined effect of urban expansion drivers on vegetation cover indicators. The regression model is specified as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \varepsilon$$

Where Y represent Vegetation Cover (1. Reduction in Trees or Forests Near Homes; 2. Decline in Green/Open Spaces, 3. Loss of Farmland/Garden Areas, 4. Perceived Increase in Soil Erosion or Dust and related hazards, and 5. Decrease in Biodiversity (e.g., birds, insects, wild plants)

While X_1 represents Perceived Increase in Housing Development, X_2 : Changes in Land Use Patterns; X_3 : Access to Infrastructure and Services; X_4 : Increased Population Density; and X_5 : Urban Boundary Expansion. And β_0 =y-intercept (constant term) and ε =the model's error term (also known as the residuals).

The combination of correlation and regression analyses provides both a preliminary understanding of the bivariate relationships and a more comprehensive assessment of the multivariate drivers of vegetation loss.

4.5.2 Qualitative data analysis

Qualitative data derived from interviews and focus group discussions was analyzed through thematic content analysis. This involved transcription of all recorded sessions, followed by thorough review to identify meaningful phrases and recurring patterns. The data then be organized into thematic codes relating to urban growth drivers, land use decisions, institutional responses, and perceived environmental effects.

The emerging themes were grouped under broader categories such as land policy enforcement, vegetation loss trends, stakeholder capacity, and community adaptation measures. To strengthen the analysis, direct quotes from respondents were used to illustrate key findings and demonstrate contextual understanding. Additionally, responses from sector officers were compared with those from district-level staff to identify any variations in institutional perspectives or priorities. This layered interpretation offered insights not only into what is happening on the ground, but also how it is understood by those directly involved in managing land and environment in Nyamagabe.

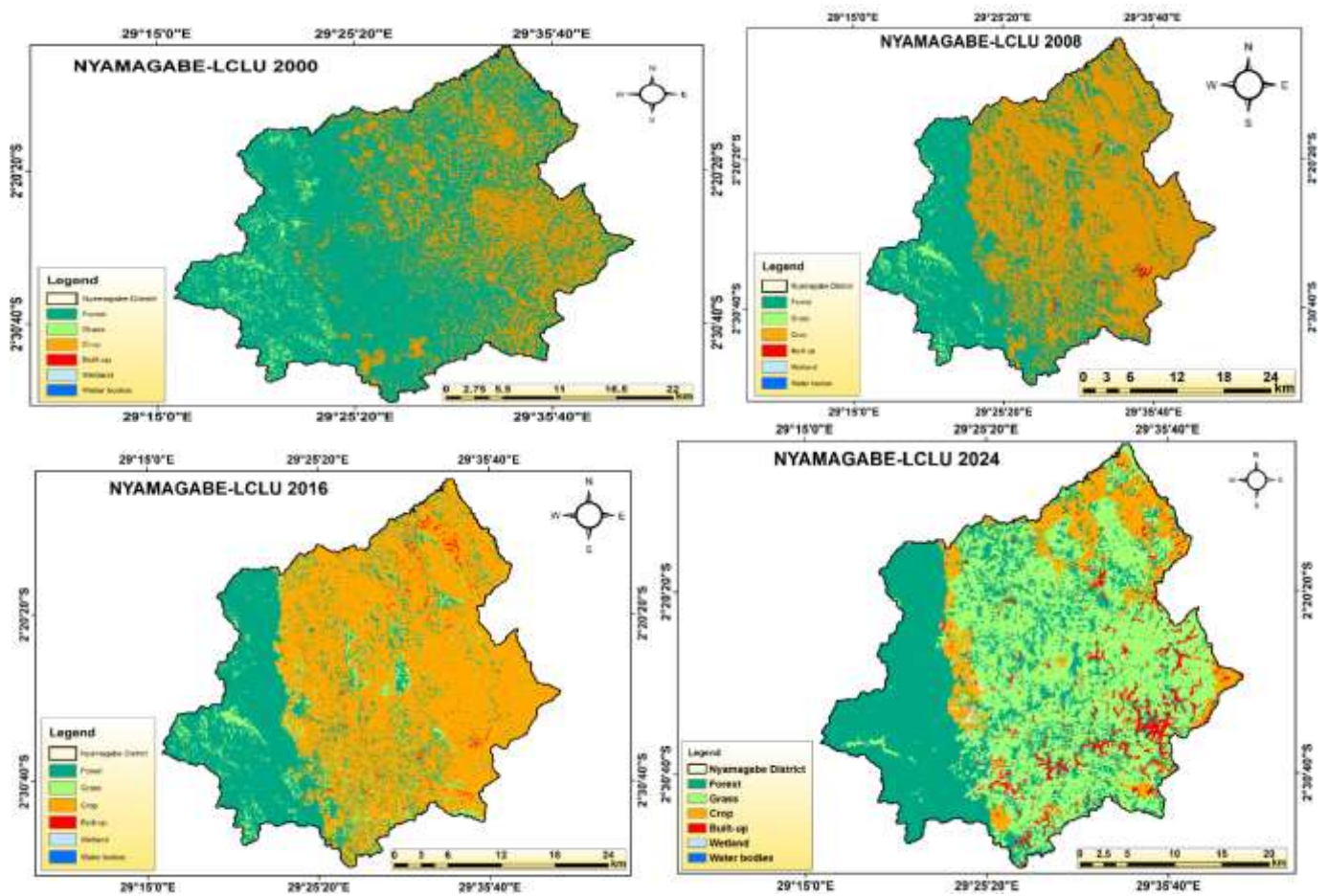
5. Findings

This section presents the findings on the spatial-temporal dynamics of urban expansion and land cover transformation in Nyamagabe District between 2000 and 2024. Using satellite imagery, GIS techniques, and land use classification methods, the analysis examines how different land cover categories including built-up areas, forests, cropland, and grassland have changed over time. The results highlight the magnitude and direction of urban growth, patterns of vegetation change, and the environmental implications associated with increasing settlement expansion and land use conversion across the district:

5.1 To investigate the Spatial temporal dynamics of urban expansion in Nyamagabe District from 2000 to 2024.

The spatial-temporal analysis of land use and land cover (LULC) in Nyamagabe District between 2000 and 2024 revealed major environmental and urban transformation driven by rapid population growth, infrastructure development, and changing land use patterns. Using supervised classification of satellite imagery in ArcGIS, six land cover categories were identified: built-up areas, cropland, forest, grassland, water bodies, and wetlands. The results showed a dramatic increase in built-up areas from 0.76 km² (0.07%) in 2000 to 50.46 km² (4.62%) in 2024, particularly after 2016 in urbanizing sectors such as Gasaka, Kamegeri, and Kitabi. Cropland expanded significantly until 2016 due to intensified agriculture but later declined sharply by 2024, while forest cover reduced considerably between 2000 and 2016 before partially recovering through reforestation initiatives. Grassland recorded the highest increase, expanding from 29.77 km² to 482.50 km², indicating widespread land conversion and degradation processes across the district.

Figure 2: Land Use/Land Cover Map of Nyamagabe District, 2000, 2008, 2016 and 2024



Source: Author, Geospatial Data Analysis (2025)

The land change detection analysis further demonstrated the extent and direction of landscape transformation over the 24-year period. Built-up areas increased by 49.70 km², while grasslands expanded by 452.73 km², reflecting strong urbanization and environmental pressure. In contrast, cropland and forest cover declined by 182.71 km² and 320.91 km² respectively, highlighting the impact of settlement expansion, agricultural intensification, and deforestation. Water bodies and wetlands experienced only minor increases and remained spatially insignificant throughout the study period. Overall, the findings indicate that urban growth has increasingly reshaped the district's land use structure, replacing productive agricultural and forested landscapes with settlements and degraded open land.

Table 2: Land Use/Land Cover Classification Statistics for Nyamagabe District (2000–2024)

| Land Cover Class | 2000 (km ²) | 2008 (km ²) | 2016 (km ²) | 2024 (km ²) | 2000 (%) | 2008 (%) | 2016 (%) | 2024 (%) |
|------------------|-------------------------|-------------------------|-------------------------|-------------------------|------------|------------|------------|------------|
| Built-up Area | 0.76 | 3.50 | 12.67 | 50.46 | 0.07 | 0.32 | 1.16 | 4.62 |
| Crop Land | 310.88 | 599.96 | 672.55 | 128.17 | 28.45 | 54.94 | 61.58 | 11.74 |
| Forest | 751.44 | 448.32 | 332.47 | 430.53 | 68.76 | 41.05 | 30.44 | 39.42 |
| Grassland | 29.77 | 39.71 | 73.81 | 482.50 | 2.72 | 3.64 | 6.76 | 44.18 |
| Water Bodies | 0.007 | 0.16 | 0.17 | 0.40 | 0.0006 | 0.015 | 0.016 | 0.036 |
| Wetland | 0.001 | 0.44 | 0.43 | 0.04 | 0.0001 | 0.040 | 0.039 | 0.003 |
| Total | 1092.10 | 1092.10 | 1092.10 | 1092.10 | 100 | 100 | 100 | 100 |

Source: Author, Geospatial Data Analysis (2025)

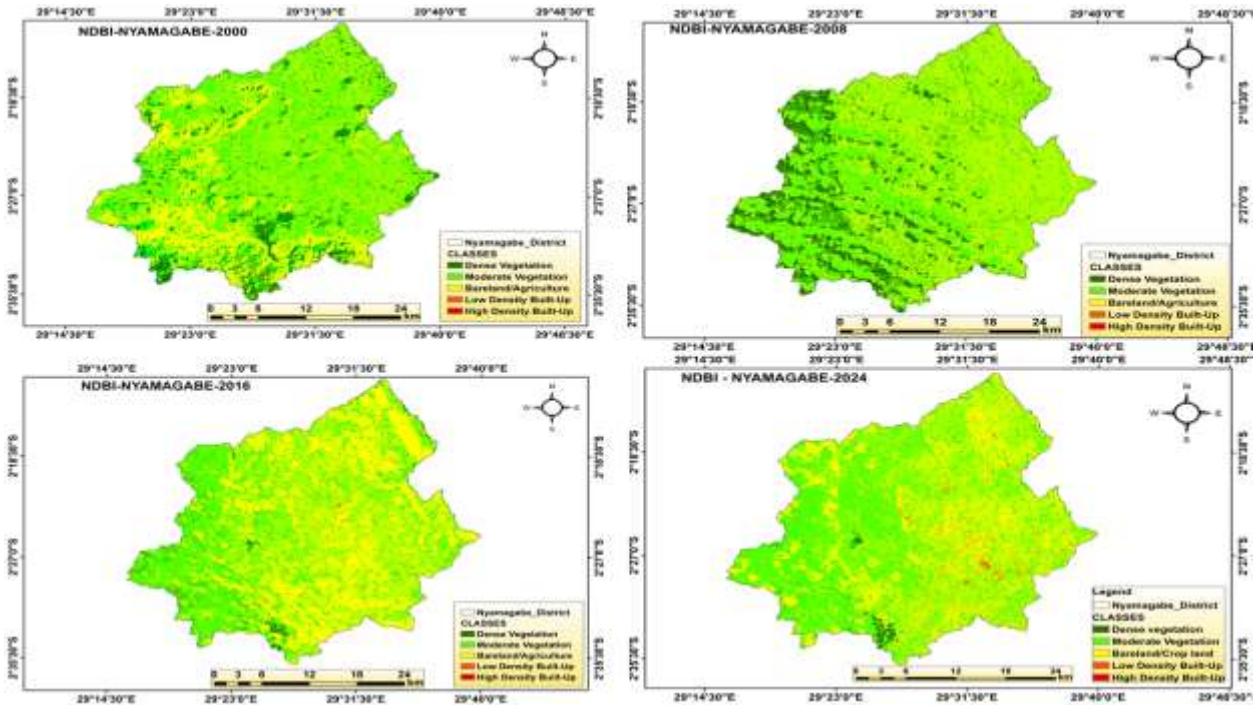
The Normalized Difference Built-Up Index (NDBI) analysis provided additional evidence of rapid urban intensification and vegetation decline in the district. High-density built-up areas increased more than tenfold, from 5.76 km² in 2000 to 60.46 km² in 2024, confirming a shift from dispersed settlements toward denser urban cores. At the same time, dense vegetation cover declined drastically from 50.01 km² to 10.44 km², reflecting severe ecosystem degradation and forest fragmentation. Moderate vegetation areas fluctuated but showed slight recovery due to reforestation and agroforestry programs. The findings collectively demonstrate that urban expansion in Nyamagabe District has been rapid and environmentally significant, contributing to vegetation loss, land degradation, and major alterations in the district's ecological and spatial landscape.

Table 3: Normalized Difference Built-Up index for Nyamagabe District (2000–2024)

| NDBI CLASSES | Area in km | | | |
|----------------------|------------|---------|---------|---------|
| | 2000 | 2008 | 2016 | 2024 |
| Dense Vegetation | 50.008 | 100.6 | 12.6 | 10.44 |
| Moderate Vegetation | 401.44 | 348.32 | 320.47 | 420.53 |
| Bareland/Agriculture | 571.4028 | 567.603 | 631.224 | 540.603 |
| Low dense Built-Up | 63.4892 | 63.067 | 70.136 | 60.067 |
| High Dense Built-Up | 5.76 | 12.51 | 57.67 | 60.46 |
| Total | 1092.1 | 1092.1 | 1092.1 | 1092.1 |

Source: NDBI computation results (2025)

Figure 3: Normalized Difference Built-Up Index

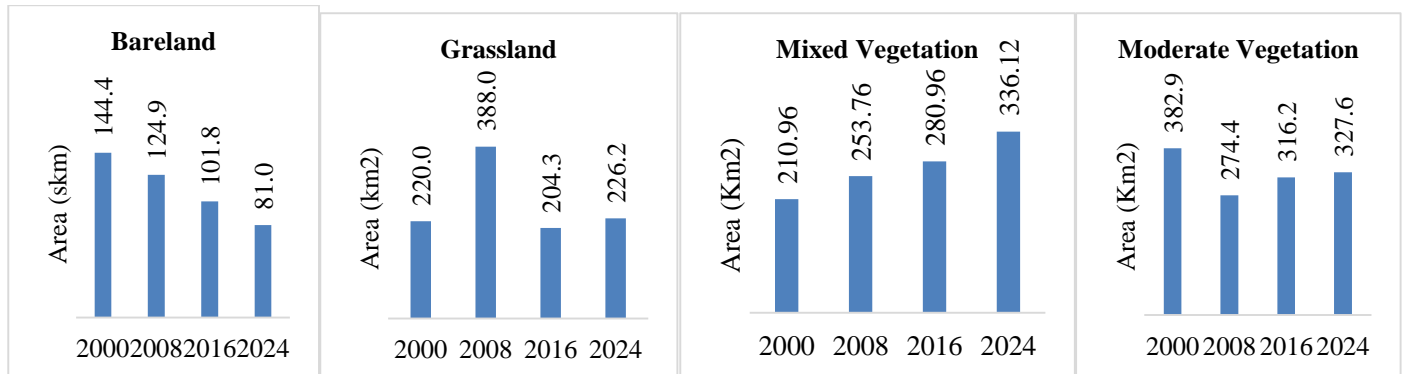


Source: NDBI computation results (2025)

5.2 To analyze the changes in vegetation, cover during the same period of 2000 to 2024

The NDVI analysis revealed that bareland areas steadily declined from 144.39 km² in 2000 to 81.04 km² in 2024, suggesting reduced land degradation and some vegetation recovery. Mixed vegetation increased consistently from 210.96 km² to 336.12 km², while moderate vegetation fluctuated but generally indicated gradual ecological improvement. Grassland coverage showed unstable trends, increasing sharply by 2008, declining in 2016, and rising again in 2024, reflecting cycles of degradation, regeneration, and land conversion. These patterns suggest that some areas experienced recovery through reforestation and improved land management, while others were affected by urban growth and agricultural pressure.

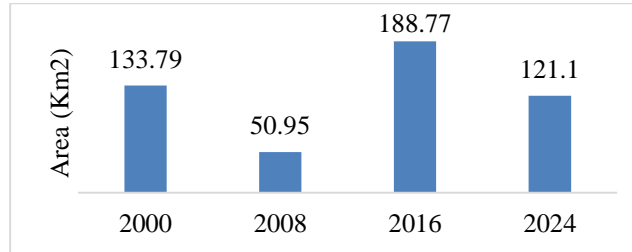
Figure 4: Changes in vegetation cover during the same period of 2000 to 2024



Source: NDVI computation results (2025)

Healthy vegetation exhibited the most fluctuation during the study period, decreasing from 133.79 km² in 2000 to 50.95 km² in 2008, increasing significantly to 188.77 km² in 2016, and declining again to 121.10 km² in 2024. These variations indicate that dense vegetation cover in Nyamagabe District has been highly sensitive to deforestation, agricultural expansion, climatic conditions, and pressures of urbanization. Although reforestation and natural regeneration contributed to temporary recovery, the decline observed by 2024 suggests that continued urban expansion and land conversion remain major threats to long-term vegetation stability and ecosystem health.

Figure 5: Healthy Vegetation Area (km²), 2000–2024



Source: NDVI computation results (2025)

5.3 To determine the relationship between urban expansion and vegetation cover changes from 2000 to 2024

The statistical analysis revealed a significant relationship between urban expansion and vegetation cover changes in Nyamagabe District from 2000 to 2024. Correlation results showed that increased housing development had a significant negative relationship with vegetation cover change ($r = -0.471$, $p = 0.049$), indicating that the expansion of residential areas contributed directly to vegetation loss. Urban expansion was also strongly associated with decreased biodiversity ($r = -0.588$, $p = 0.010$), confirming that rapid urban growth has created ecological stress within the district. Although some variables such as land use change and population density showed weaker or non-significant relationships, the overall findings supported the hypothesis that urbanization negatively affects vegetation cover.

Table 4: Coefficients: Relationship Between Urban Expansion and Vegetation Cover Change

| Model | Coefficients ^a | | | | t | Sig. |
|--|-----------------------------|------------|---------------------------|--|--------|------|
| | Unstandardized Coefficients | | Standardized Coefficients | | | |
| | B | Std. Error | Beta | | | |
| (Constant) | 5.749 | 1.187 | | | 4.845 | .000 |
| 1. Perceived Increase in Housing Development | -.263 | .091 | -.619 | | -2.893 | .013 |
| 2. Changes in Land Use Patterns | .236 | .179 | .291 | | 1.320 | .212 |
| 3. Access to Infrastructure and Services | .008 | .138 | .013 | | .059 | .954 |
| 4. Increased Population Density | -.102 | .145 | -.150 | | -.700 | .497 |
| 5. Urban Boundary Expansion | -.208 | .096 | -.472 | | -2.163 | .051 |

a. Dependent Variable: Vegetation Cover Change

Source: Primary Data, 2025

Regression analysis further demonstrated that urban expansion variables collectively explained 51.2% of the variation in vegetation cover change ($R^2 = 0.512$). Among all predictors, housing development emerged as the strongest and most statistically significant factor influencing vegetation decline ($\beta = -0.619$, $p = 0.013$), while urban boundary expansion also showed a marginally significant negative effect ($\beta = -0.472$, $p = 0.051$). These findings indicate that both densification and outward urban growth contribute to the reduction of forests, farmland, and green spaces. Although the overall regression model was not statistically significant at the 5% level, the individual predictor results strongly reinforced the evidence from the NDVI and land use analyses showing increasing environmental pressure from urban growth.

Qualitative findings from 18 key informants strongly supported the statistical and spatial analyses. Respondents confirmed that urban expansion has intensified through increased housing development, infrastructure growth, population density, and conversion of farmland into built-up areas. Informants also reported substantial vegetation decline, including reductions in trees, green spaces, biodiversity, and increased soil erosion and dust hazards. Additionally, respondents acknowledged that national policies such as the Rwanda National Land Use and Development Master Plan and the National Forest Policy have contributed to awareness and partial vegetation recovery, although implementation challenges remain. Overall, the combined quantitative and qualitative findings demonstrate that urban expansion in Nyamagabe District has had a considerable negative impact on vegetation cover and environmental sustainability between 2000 and 2024.

6. Discussion of findings

The study reveals substantial land use and land cover (LULC) changes in Nyamagabe District between 2000 and 2024, driven primarily by rapid urban expansion and intensified anthropogenic activities. Built-up areas increased dramatically from 0.76 km² to 50.46 km², reflecting accelerated urban growth consistent with national trends and similar findings by Mugabowindekwe & Rwanyiziri (2020), who documented increasing urbanization pressures across secondary Rwandan cities (Mugabowindekwe, 2020). This sharp

increase aligns with Seto et al. (2020), who emphasize that urban growth in developing regions rapidly converts natural landscapes into built environments. Forest cover declined significantly losing about 320.91 km² between 2000 and 2024 mirroring studies in Rwanda and Africa (Seto, 2020). For example, Karamage et al. (2016) and UNEP (2020) reported widespread deforestation linked to agricultural expansion and settlement growth (Karamage, 2016). The partial forest recovery after 2016 corresponds with national reforestation initiatives under the National Forest Policy (2018), similar to Yao et al. (2017), who observed that state-led restoration can reverse forest loss in heavily exploited landscapes (Yao, 2017). Cropland expanded by 2016 but sharply decreased by 2024, a trend echoed in research by Munyaneza et al. (2023), which noted farmland reduction due to settlement expansion in Rwanda's peri-urban zones. This conversion of cropland and forest to grassland evidenced by the dramatic grassland increase from 29.77 km² to 482.50 km² supports regional findings by Gowda et al. (2017), who linked landscape degradation and overuse to grassland dominance in Eastern Africa (Gowda, 2017). Minimal changes in wetlands and water bodies align with previous remote-sensing assessments showing that these categories are relatively stable but sensitive to mapping resolution. Overall, the LULC changes identified in this study are consistent with global and regional empirical literature, reaffirming that rapid urbanization when unaccompanied by strong land management leads to vegetation decline, cropland loss, forest fragmentation, and landscape degradation.

The observed NDVI trends in Nyamagabe with reductions in bareland, fluctuating grassland, and expansion of mixed and moderate vegetation reflect a complex interplay of degradation and recovery under urban pressure, a pattern consistent with recent empirical studies. For instance, Amisi et al. (2024) show that in Rwanda's Great Lakes region, forest fragmentation is accompanied by expansion of grassland and shrub patches, linked to land consolidation and agroforestry interventions, matching our mixed-vegetation recovery trend (Amisi, 2024).

Meanwhile, Munyaneza et al. (2023) document in Kamonyi District (Runda Sector) a sharp decline in NDVI/vegetation health associated with rapid urban expansion, echoing our drop in healthy vegetation by 2008 and again by 2024. In addition, Nkundabose et al. (2021) used remote sensing in Rwanda's Eastern Province to demonstrate that cropland-to-degraded land conversion initially reduces NDVI, but later stabilization can occur as woody regrowth begins, comparable to our moderate vegetation resurgence (Nkundabose, 2021). Together, these studies support the interpretation that while urbanization drives degradation, policy-driven restoration (such as terracing or reforestation) is enabling partial vegetation recovery, though high-quality dense vegetation remains unstable under continued land-use stress.

The perceptions of key informants in Nyamagabe District strongly mirror broader empirical trends of urbanization-driven vegetation loss documented in recent studies. Informants' reports of rampant housing development replacing open land, densification, and shrinking green spaces closely parallel findings in Masaka Sector, Rwanda, where Dufatanye, Mind'Je, and Ngirishuti (2025) observed that rapid urban expansion corresponded with severe forest cover loss demonstrating a strong inverse relationship between built-up growth and vegetation. Similarly, their observations of increased soil erosion and biodiversity decline reflect broader ecosystem service degradation noted in Bugesera District; Dusengimana, Kamuhanda, and Nsabimana (2025) found that land use change, particularly from forest or vegetation to urban use, significantly undermines soil fertility, water quality, and biodiversity (Dusengimana, 2025).

Moreover, informants' mixed views on the effectiveness of national policies resonates with research in Kigali City by Akimana and Didier (2025), who used to deep-learn and remote-sensing to show that although the National Land Use Master Plan has been implemented, urban expansion still encroaches on vegetated zones, suggesting a gap between policy intent and realization (Akimana, 2025). Together, these empirical studies corroborate the key informant insights, reinforcing the conclusion that urban expansion in Nyamagabe is contributing to vegetation degradation, even as policy efforts strive to balance development and ecological concerns.

7. Conclusion

This study concludes that urban expansion in Nyamagabe District between 2000 and 2024 has had a significant and measurable impact on vegetation cover, thereby rejecting all three null hypotheses (H_{01} , H_{02} , and H_{03}) and supporting their corresponding alternative hypotheses (H_1). Specifically, the first null hypothesis (H_{01}) that there is no significant spatial change in urban areas was rejected as LULC analysis revealed a rapid increase in built-up areas from 0.76 km² in 2000 to 50.46 km² in 2024, replacing forested lands, croplands, and mixed vegetation zones. The second null hypothesis (H_{02}) that there is no significant change in vegetation cover was rejected because NDVI results showed persistent declines in healthy vegetation, intermittent forest loss, and expansion of grasslands, indicating widespread land degradation with partial regeneration in some zones. Finally, the third null hypothesis (H_{03}) that urban expansion is not significantly related to vegetation loss was also rejected, as correlation and multiple regression analyses demonstrated strong negative relationships between urban expansion drivers (housing development, land use changes, population density, infrastructure access, and urban boundary expansion) and vegetation indicators.

The findings further highlight that while national policies, including the National Land Use and Development Master Plan and the National Forest Policy, have contributed to partial recovery in mixed and moderately vegetated areas, their effectiveness is limited in high-growth and peri-urban zones. Environmental consequences of urban expansion such as soil erosion, declining biodiversity, and altered microclimates underscore the broader ecological implications of uncontrolled urban growth. Insights from key informants indicate that housing development, informal settlements, and land conversion are primary drivers accelerating vegetation loss, reinforcing the need for integrated land-use planning, stricter policy enforcement, and community engagement. Overall, the study demonstrates that urbanization is the dominant force shaping vegetation dynamics in Nyamagabe District, and despite restoration efforts, comprehensive planning solutions are required to balance development with ecological sustainability.

8. Recommendations

The study recommends that urban planners, local authorities, policymakers, researchers, and communities work collaboratively to manage urban expansion while protecting vegetation cover in Nyamagabe District. Urban and environmental planners should integrate green infrastructure, ecological corridors, and urban green belts into land-use planning, while strengthening monitoring of peri-urban development and promoting reforestation, agroforestry, and natural regeneration. Local authorities are encouraged to enforce national land and forest policies more effectively, expand community-based vegetation management initiatives, and support sustainable livelihood programs that reduce pressure on natural resources. National policymakers should align development policies with sustainable urban growth by encouraging environmentally friendly construction and strengthening the use of remote sensing and NDVI monitoring systems. Researchers are advised to conduct long-term and comparative studies incorporating climate and socio-economic factors, while local communities should actively participate in tree planting, environmental awareness campaigns, and sustainable land management practices to enhance ecological resilience and biodiversity conservation.

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