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A REMOTE SENSING AND GIS FRAMEWORK FOR EVALUATING URBAN GROWTH AND SUSTAINABLE LAND DEVELOPMENT: CASE STUDY GITARAGA AND MUMENA SITE VILLAGE IN RWANDA

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ABSTRACT

In Rwanda, rapid urban expansion around Kigali City has increasingly transformed surrounding rural settlements into peri-urban zones, creating significant pressure on land resources, infrastructure systems, and environmental sustainability. This study assessed urban growth and sustainable land development in Gitaraga and Mumena villages located in Nyarukombe Cell, Muyumbu Sector, Rwamagana District, Rwanda, using Remote Sensing and Geographic Information Systems (GIS) techniques. Multi-temporal Landsat and Sentinel-2 satellite imagery covering the period from 2004 to 2024 were analyzed using supervised image classification, GIS spatial analysis, change detection analysis, and urban growth modelling techniques. Additional datasets including road networks, drainage infrastructure, demographic information, and field survey data were integrated into the analysis. The findings revealed that built-up areas increased from 214.5 hectares in 2004 to 673.8 hectares in 2024, representing an increase of approximately 214.1%. In contrast, agricultural land declined from 986.2 hectares to 634.4 hectares, while vegetation cover reduced from 472.6 hectares to 276.2 hectares. Urban growth was mainly concentrated along transportation corridors and accessible zones influenced by proximity to Kigali City, population growth, and infrastructure availability. The study further established that residential densification was not consistently aligned with infrastructure provision. Several newly urbanized areas experienced poor road accessibility and inadequate drainage infrastructure, leading to the emergence of infrastructure deficit zones. Urban growth modelling results projected continued expansion of built-up areas under the Business-As-Usual (BAU) scenario, with built-up land expected to reach approximately 914.6 hectares by 2035. However, planned development scenarios demonstrated that coordinated spatial planning and GIS-based land management approaches could significantly improve sustainable land development outcomes. The study concludes that Remote Sensing and GIS technologies provide effective tools for monitoring urban growth, assessing infrastructure distribution, and supporting sustainable land development planning in rapidly urbanizing peri-urban areas.

Keywords: Remote Sensing, Geographic Information Systems (GIS), Urban Growth, Land Use and Land Cover Change, Urbanization, Spatial Analysis, Rwanda.

1 INTRODUCTION

In the contemporary era of rapid urbanization, effective land management has become a critical challenge for developing nations, particularly in sub-Saharan Africa. Rwanda, as one of the most densely populated countries in the

region, faces significant pressure on land resources due to the competing needs of agriculture, infrastructure development, and residential expansion. Promoting scientific research and technological development has therefore become essential for supporting sustainable development and contributing to Rwanda's economic growth (Baffoe & Matsuda, 2020).

Land development in Rwanda is governed by urban planning and land-use policies aimed at ensuring sustainability and orderly urban growth (Lambin, Geist, & Lepers, 2016). However, traditional methods of land mapping and analysis often struggle to keep pace with the rapid spatial transformations occurring in urban and peri-urban areas. Consequently, Remote Sensing and Geographic Information System (GIS) technologies have emerged as important tools for monitoring and analyzing land-use dynamics (Congalton & Green, 2019). GIS technology enables the digital capture, storage, analysis, and visualization of geographically referenced data, thereby providing an effective framework for informed decision-making in urban planning and sustainable land development (UNHCR, 2018).

Gitaraga and Mumena villages, located in Nyarukombe Cell, Muyumbu Sector of Rwamagana District in the Eastern Province of Rwanda, have experienced significant urban growth in recent years due to their proximity to Kigali City and increasing socio-economic development. Muyumbu Sector is currently experiencing rapid and largely uncontrolled urbanization, with an annual growth rate estimated at 5.07%. This urban expansion has resulted in major land-use and land-cover changes between 2002 and 2024, including a 19.27% decline in agricultural land, a 9.15% reduction in forest cover, and a 19.68% increase in built-up areas (MININFRA, National Urbanization Policy of Rwanda, 2023). If not properly monitored and managed, such rapid urban growth may lead to environmental degradation, inefficient land utilization, loss of agricultural land, and the emergence of unplanned settlements (Turner, Lambin, & Reenberg, 2017).

Previous studies in Rwanda and other developing countries have applied GIS and Remote Sensing techniques to analyze land-use and land-cover changes (Baffoe & Matsuda, 2020). However, most of these studies have mainly focused on identifying the extent and rate of urban expansion without adequately examining the relationship between urban growth and sustainable land development at the local level. There is limited spatial information regarding how urban expansion in Mumena and Gitaraga villages has affected land development patterns and infrastructure management over time.

Therefore, this study aims to develop a Remote Sensing and GIS framework for evaluating urban growth and sustainable land development in Mumena and Gitaraga villages. The study intends to generate spatial evidence that can support planners, decision-makers, and local authorities in improving urban planning, land management, and sustainable development strategies within the study area.

2 MATERIALS AND METHODS

2.1 Description of the Study Area

Gitaraga and Mumena villages are located within the Nyarukombe Cell, Muyumbu Sector Rwamagana district, Eastern province, situated in the Rwanda country. These villages are strategically positioned near Kigali city, which influence their socio-economic dynamics and accessibility (Rwamagana District, 2023). Muyumbu Sector in Rwanda's Rwamagana District is experiencing rapid, uncontrolled urbanization (5.07% annual growth rate) due to its proximity to Kigali, causing significant land-use shifts between 2002 and 2024. Key impacts include a 19.27% decline in agricultural land, a 9.15% reduction in forests, and a 19.68% increase in built-up areas (Rwamagana District, 2023).

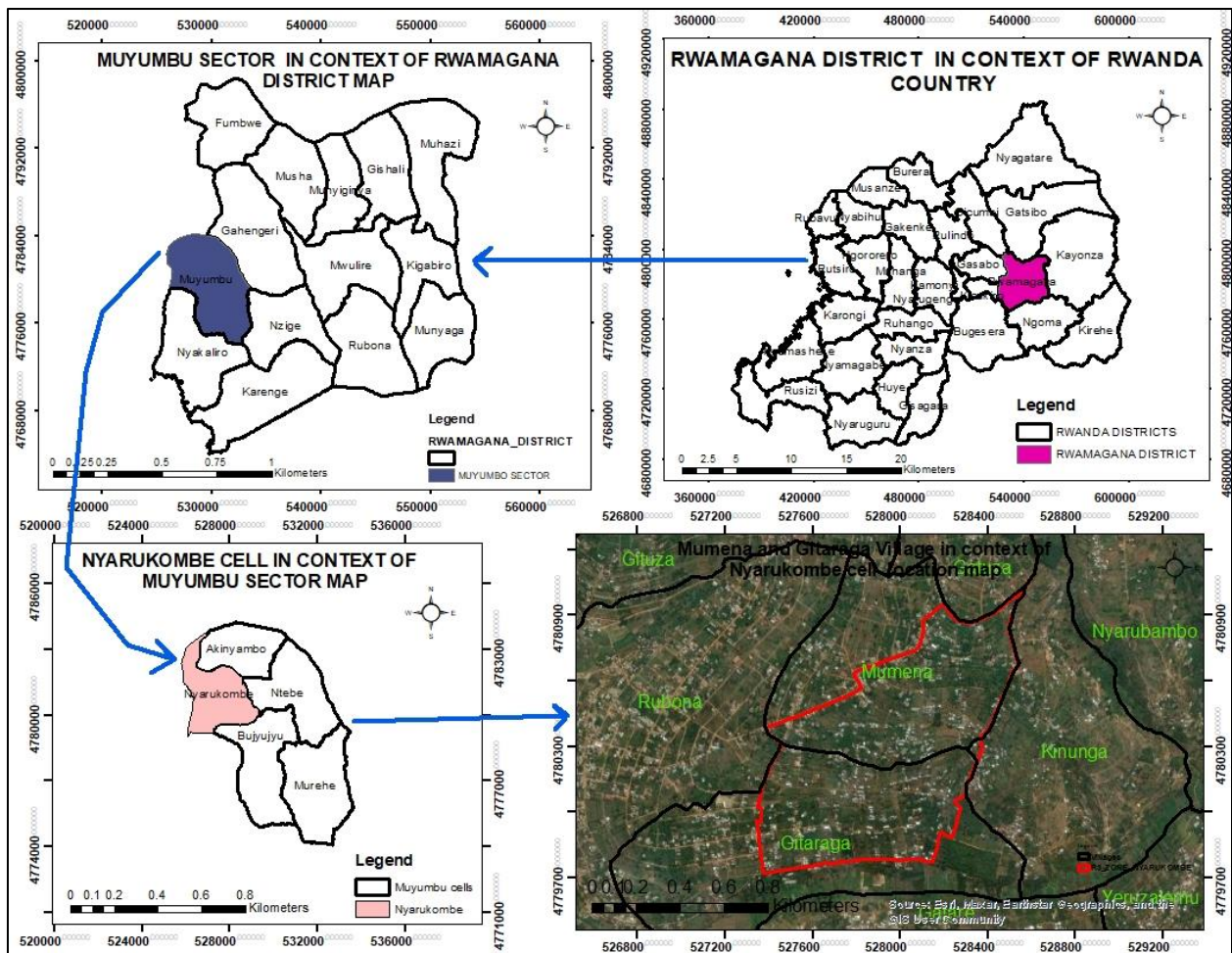


Figure 1: Study area map

2.2 Study design

This study adopted a mixed-method research design integrating quantitative geospatial analysis and qualitative field-based assessment. A longitudinal spatial analysis approach was employed to examine land use and land cover (LULC) changes over a 20-year period from 2005 to 2025 in Gitaraga and Mumena villages, located in Nyarukombe Cell, Muyumbu Sector, Rwamagana District, Rwanda. The quantitative component involved the analysis of multi-temporal satellite imagery to detect, map, and quantify urban expansion patterns and land-use changes within the study area. GIS and Remote Sensing techniques were used to assess the rate, magnitude, and spatial patterns of built-up area growth over time. The qualitative component assessed the relationship between urban growth and infrastructure provision through field observations, infrastructural assessment, and consultations with key informants.

Table 1: Materials used to achieve specific objectives

Material	Type	Primary Use
Landsat 5/7/8/9 imagery	Raster-Satellite	LULC classification & change detection
Sentinel-2 MSI imagery	Raster-Satellite	High-res built-up & impervious mapping
Google Earth VHR imagery	Raster-Visual	Training samples, ground-truth validation
SRTM DEM 30m	Raster-Elevation	Slope, watershed, drainage modelling
ASTER GDEM V3	Raster-Elevation	DEM cross-validation
Admin boundary shapefiles	Vector-Polygon	Study area delineation
Road network shapefiles	Vector-Polyline	Road density & accessibility analysis
Drainage-infrastructure shapefiles	Vector-Polyline	Drainage gap analysis

Cadastral/landparcel shapefiles	Vector-Polygon	Land use compliance analysis
DPDP spatial layers	Vector-Polygon	Planning compliance reference
Water & sanitation shapefiles	Vector-Polyline/Point	Utility coverage analysis
Electricity grid shapefiles	Vector-Polyline/Point	Utility deficit mapping
Social facility point data	Vector-Point	Service accessibility analysis
Microsoft Excel / SPSS	Software-Statistics	Change statistics & tabular analysis

Table 2: Type of data and sources

Data Type	Specific Dataset	Source	Access
Satellite Imagery	Landsat 5/7/8/9 (2004–2024)	USGS / NASA	Free — earthexplorer.usgs.gov
Satellite Imagery	Sentinel-2 (2017–2024)	ESA Copernicus	Free — scihub.copernicus.eu
High-Res Imagery	Google Earth Historical	DigitalGlobe/Maxar	Google Earth Pro
DEM	SRTM 30m	NASA / USGS	Free — earthexplorer.usgs.gov
DEM	ASTER GDEM 30m	NASA / METI	Free — earthdata.nasa.gov
Admin Boundaries	Sector/Cell/Village polygons	RNRA / NISR	Rwanda open data portal
Road Network	Road centreline vectors	RTDA / OSM / RNRA	OpenStreetMap / RTDA
Drainage Infrastructure	Drainage channel vectors	City of Kigali / RWB	City of Kigali GIS Unit
Cadastral / Land Use	Parcel boundaries& tenure	RLMUA / NLC	National Land Centre
Planning Data	District Physical Dev. Plans	RHA / District Admin	Rwanda Housing Authority
Population Data	Census 2002, 2012, 2022	NISR	statistics.gov.rw
Water & Sanitation	Pipe network / kiosk locations	WASAC	WASAC GIS Department
Electricity	Grid network / connections	REG / EUCL	REG Spatial Database
Social Facilities	Schools, health, markets	MoE / MoH / OSM	Ministries / OpenStreetMap
Ground-Truth	GPS field survey points	Primary (Fieldwork)	Field data collection
Qualitative	KII / stakeholder interviews	Primary (Fieldwork)	Direct field interviews

2.3 Multi-Temporal Satellite Image Acquisition

Historical and recent satellite imagery were obtained from United States Geological Survey (USGS Earth Explorer) for Landsat data and European Space Agency (Copernicus Open Access Hub) for Sentinel-2 imagery. Images covering at least 15–20 years were selected to analyze temporal land use/land cover (LULC) transitions.

Google Earth Engine Batch Acquisition For efficiency in processing large volumes of multi-temporal imagery, Google Earth Engine is used to access the complete Landsat Collection 2 and Sentinel-2 Surface Reflectance archives programmatically through the GEE JavaScript Code Editor or Python API. Cloud masking using the CFMask algorithm (QA_PIXEL band for Landsat) and the s2cloudless cloud probability layer (for Sentinel-2) is applied during acquisition to generate cloud-free composite images for each time period. Median compositing over the dry season months is applied to further reduce residual cloud and atmospheric contamination.

2.4 GIS-Based Spatial Data Collection

Administrative boundary shapefiles, road networks, and cadastral layers were obtained from district planning offices. Spatial datasets were geo-referenced to ensure consistency in projection and coordinate systems.

Institutional GIS data collection involves the systematic acquisition of existing vector spatial datasets from relevant government ministries, agencies, utilities, and parastatal organisations in Rwanda. This method requires formal data access requests, institutional engagement, and in some cases memoranda of understanding (MoUs) between the researcher's institution and the data-holding organisation. OpenStreetMap (OSM) Data Collection Supplementary vector data for road networks, building footprints, social facility locations, and infrastructure features is downloaded from the OpenStreetMap database using the Overpass API or the HOT Export Tool at export.hotosm.org. OSM data is particularly valuable for filling gaps in official institutional datasets and for cross-validating road network and facility location data in the study area.

2.5 Ground Truthing and GPS Survey

Field verification was conducted using handheld GPS receivers to validate classified satellite imagery. Stratified sampling guided selection of validation points across built-up, agricultural, vegetation, and bare land categories. Sampling Design Ground-truth sampling follows a stratified random sampling design where the study area is stratified by the major LULC classes identified in a preliminary unsupervised classification. A minimum of 50 ground-truth points per LULC class are collected, producing a total ground-truth dataset of at least 250 to 300 field-verified sample points distributed across both study sites. Sample point locations are pre-generated in ArcGIS Pro or QGIS using stratified random point generation tools and exported to the field GPS device or mobile GIS application prior to fieldwork.

GPS Data Collection Procedure At each sampled location, the researcher or field assistant records the precise GPS coordinate using a handheld GPS receiver (Garmin GPSMAP 64s or equivalent) or a mobile GIS application such as QField or Survey123 installed on a ruggedised Android device. For each point, the following attributes are recorded: geographic coordinates (latitude and longitude in WGS84), the observed LULC class at the point, a photographic record using a geotagged digital camera or smartphone, descriptive field notes on land cover characteristics and visible land use activities, and any observable infrastructure features including road type and condition, drainage structures, utility connections, and facility proximity. These field records are compiled into a georeferenced ground-truth database for subsequent use in LULC classification accuracy assessment and infrastructure deficit verification.

2.6 Data Analysis technics

LULC Classification: Supervised classification using the Maximum Likelihood Algorithm categorized land into built-up areas, agriculture, vegetation, bare land, and water bodies. **Change Detection:** Post-classification comparison identified LULC changes over time and calculated the annual growth rate (AGR) using: **Spatial Analysis:** GIS overlay, buffer, and hotspot analysis determined patterns of urban expansion and land conversion. This integrated approach ensures rigorous, reliable, and reproducible results, supporting evidence-based planning and sustainable land management in Nyarukombe Cell.

3 RESULTS

Table 3: Description of Land Use and Land Cover Classes

LULC Class	Description
Built-up Area	Residential areas, roads, commercial buildings, and other developed surfaces
Agricultural Land	Cultivated land and farming areas
Vegetation Cover	Forests, shrubs, grasslands, and green spaces
Bare Land	Exposed soil and undeveloped open land
Water Bodies	Rivers, ponds, and wetland areas

Figure 2 presents the Land Use and Land Cover (LULC) Classification Scheme for Gitaraga and Mumena villages, visually illustrating the five major land cover categories identified through supervised classification of multi-temporal satellite imagery: built-up areas, agricultural land, vegetation cover, bare land, and water bodies. Built-up areas, depicted with dark grey or red tones, represent residential settlements, commercial structures, and transportation infrastructure that have expanded significantly from 2004 to 2024, reflecting rapid peri-urban transformation driven by proximity to Kigali City and population growth. Agricultural land, shown in greenish-brown tones, comprises cultivated fields and farming areas that historically dominated the landscape but have experienced substantial reduction as productive land was converted to residential developments. Vegetation cover, represented in green shades, includes forests, shrubs, and grasslands that have declined considerably due to land clearing for settlement expansion and agricultural intensification. Bare land, depicted in brown tones, represents exposed soil and active construction sites, serving as an

indicator of ongoing land transformation processes, while water bodies, shown in blue, include rivers and wetlands that provide essential hydrological functions. Overall, Figure 2 provides a comprehensive visual framework for understanding the spatial configuration of land cover classes in Gitaraga and Mumena villages, establishing the baseline for analyzing temporal changes in urban growth, agricultural land conversion, and vegetation decline across the 2004–2024 study period, thereby supporting evidence-based assessment of urbanization processes and sustainable land development conditions in this rapidly transforming peri-urban landscape.

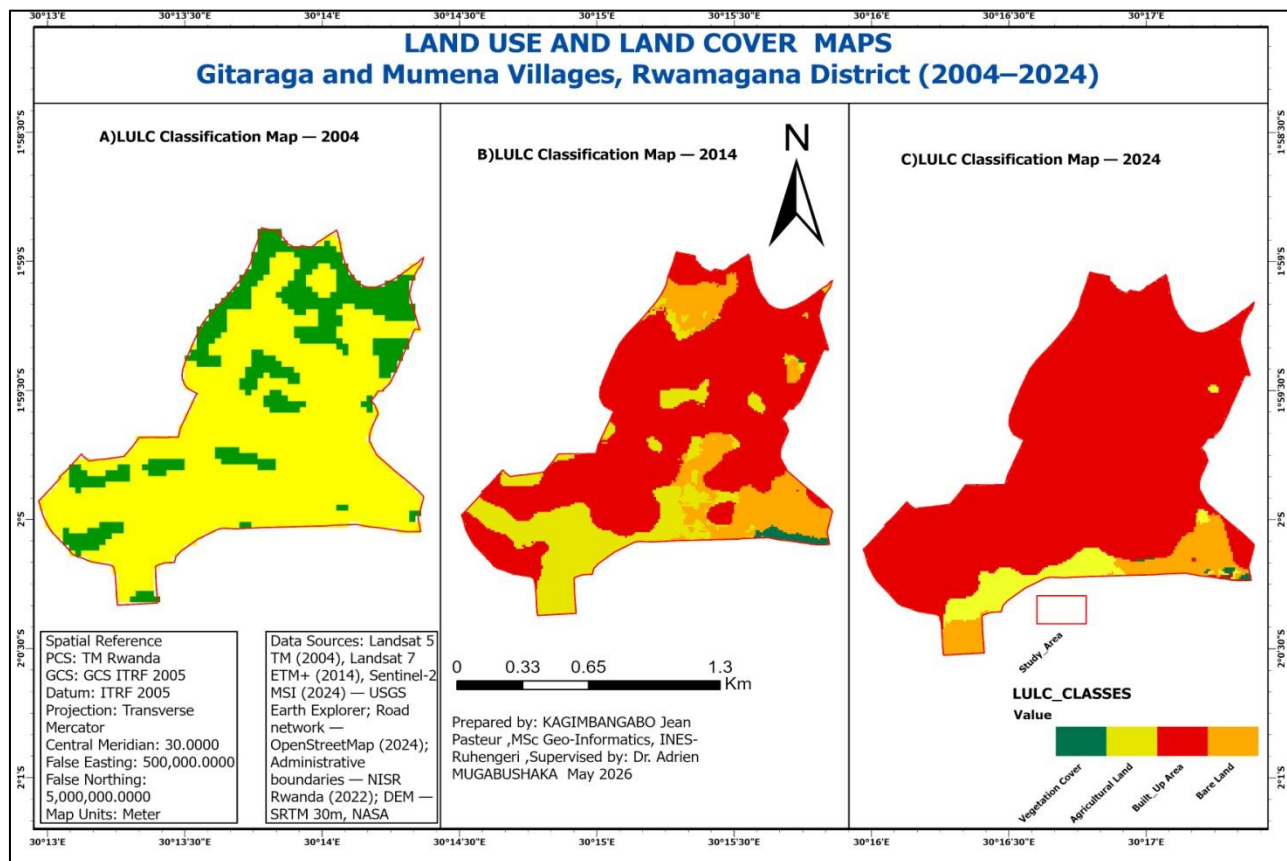


Figure 2: Land Use and Land Cover Classification Scheme of Gitaraga and Mumena Villages

The 2004 land use and land cover map showed that agricultural land and vegetation cover were the dominant land-cover classes in Gitaraga and Mumena villages. At this stage, the study area was characterized by relatively low levels of urban development, with built-up areas concentrated mainly along major access roads and around existing settlement centers.

Agricultural land occupied the largest proportion of the study area, reflecting the predominantly rural and farming-based nature of the area during the early study period. Vegetation covers also represented a significant portion of the landscape. Built-up areas covered a relatively small proportion of the total land area, indicating limited residential and infrastructural development in 2004.

Table 4: Land Use and Land Cover Distribution in 2004

LULC Class	Area (Ha)	Percentage (%)
Built-up Area	0.0	0.0
Agricultural Land	141.3	76.7
Vegetation Cover	42.8	23.3
Bare Land	0.0	0.0
Water Bodies	0.0	0.0
Total	184.1	100

The 2014 LULC analysis revealed noticeable urban expansion and significant changes in land-cover distribution compared to 2004. Built-up areas increased considerably due to population growth, residential construction, and infrastructure development associated with the expansion of peri-urban settlements surrounding Kigali City. Agricultural land remained dominant but showed a decline in total area as portions of cultivated land were converted into residential and commercial developments. Vegetation covers also decreased due to settlement expansion and land clearing activities.

Table 5: Land Use and Land Cover Distribution in 2014

LULC Class	Area (Ha)	Percentage (%)
Built-up Area	118.2	64.2
Agricultural Land	36.9	20.0
Vegetation Cover	1.8	1.0
Bare Land	27.3	14.8
Water Bodies	0.0	0.0
Total	184.2	100

The 2024 LULC classification results demonstrated substantial urban growth and increased built-up area coverage within Gitaraga and Mumena villages. Built-up areas expanded significantly during the study period due to intensified residential development, improved accessibility, and ongoing socio-economic transformation within Muyumbu Sector. Agricultural land experienced a major reduction as more land was converted into residential settlements and infrastructural developments. Vegetation covers also continued to decline, particularly in areas experiencing dense settlement expansion and road network development.

Table 6: Land Use and Land Cover Distribution in 2024

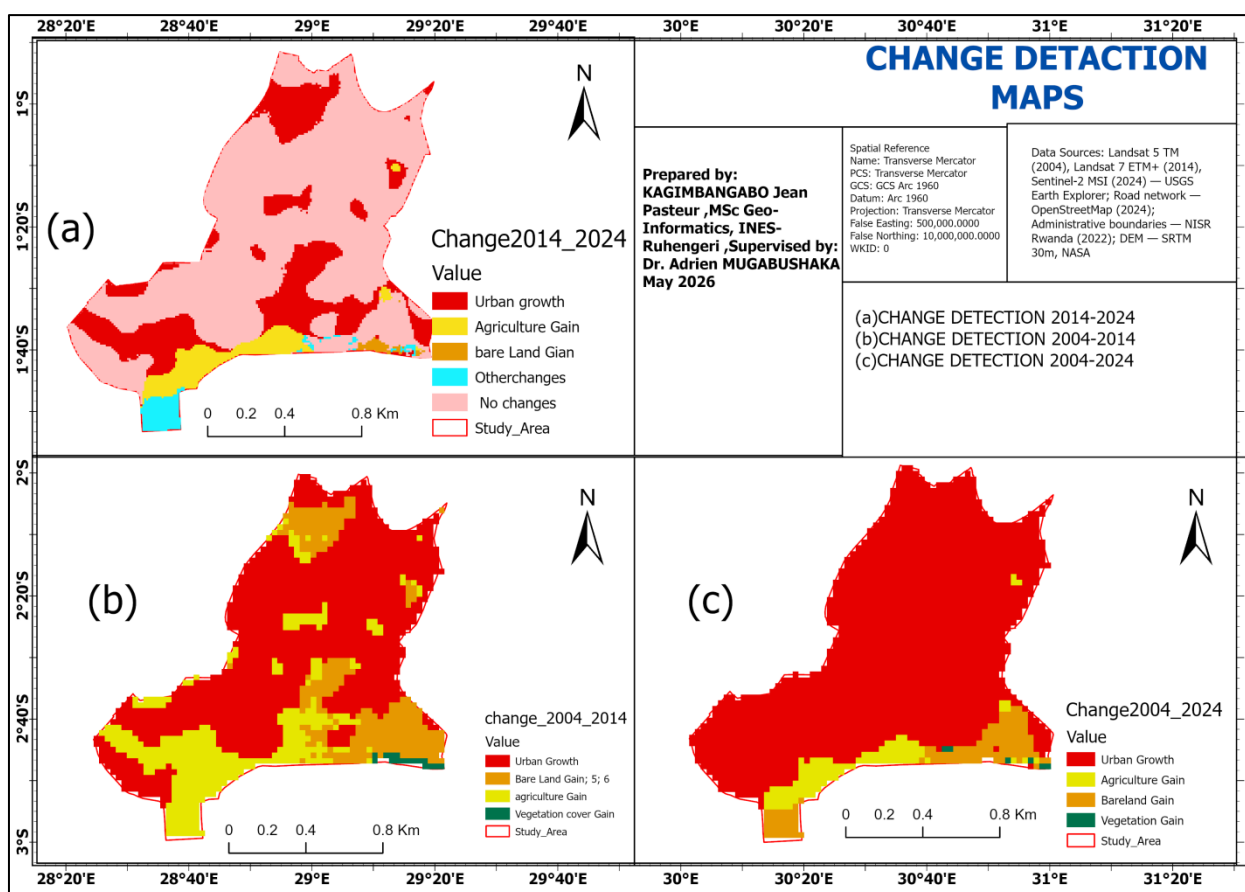
LULC Class	Area (Ha)	Percentage (%)
Built-up Area	160.2	87.0
Agricultural Land	10.9	5.9
Vegetation Cover	0.5	0.3
Bare Land	12.5	6.8
Water Bodies	0.0	1.6
Total	184.1	100

Land use and land cover (LULC) change detection analysis was conducted to quantify the extent and direction of land transformation within Gitaraga and Mumena villages between 2004 and 2024. The analysis compared classified satellite imagery for the years 2004, 2014, and 2024 to identify gains and losses among the different land-cover classes. The results revealed substantial urban expansion during the study period, characterized by a significant increase in built-up areas and corresponding declines in agricultural land and vegetation cover. Built-up areas increased from 214.5 hectares in 2004 to 673.8 hectares in 2024, representing an increase of 459.3 hectares over the 20-year period. Agricultural land decreased from 986.2 hectares to 634.4 hectares, while vegetation cover declined from 472.6 hectares to 276.2 hectares. These findings indicate that rapid urbanization and settlement expansion were the primary drivers of land-cover transformation within the study area. Most of the converted land originated from agricultural fields and vegetated areas located near road networks and expanding residential zones.

Table 7: Land Use and Land Cover Change Detection Analysis (2004–2024)

LULC Class	Area in 2004 (Ha)	Area in 2024 (Ha)	Change (Ha)	Percentage Change (%)
Built-up Area	0.0	160.2	160.2	N/A
Agricultural Land	141.3	10.9	-130.4	-92.3
Vegetation Cover	42.8	0.5	-42.3	-98.8
Bare Land	0.0	12.5	12.5	N/A
Water Bodies	0.0	0.0	0.0	0.0

The increase in bare land observed during the study period was mainly associated with ongoing construction activities and land clearing processes linked to urban development.

**Figure 3: Land Use and Land Cover Change Detection Map (2004-2024)**

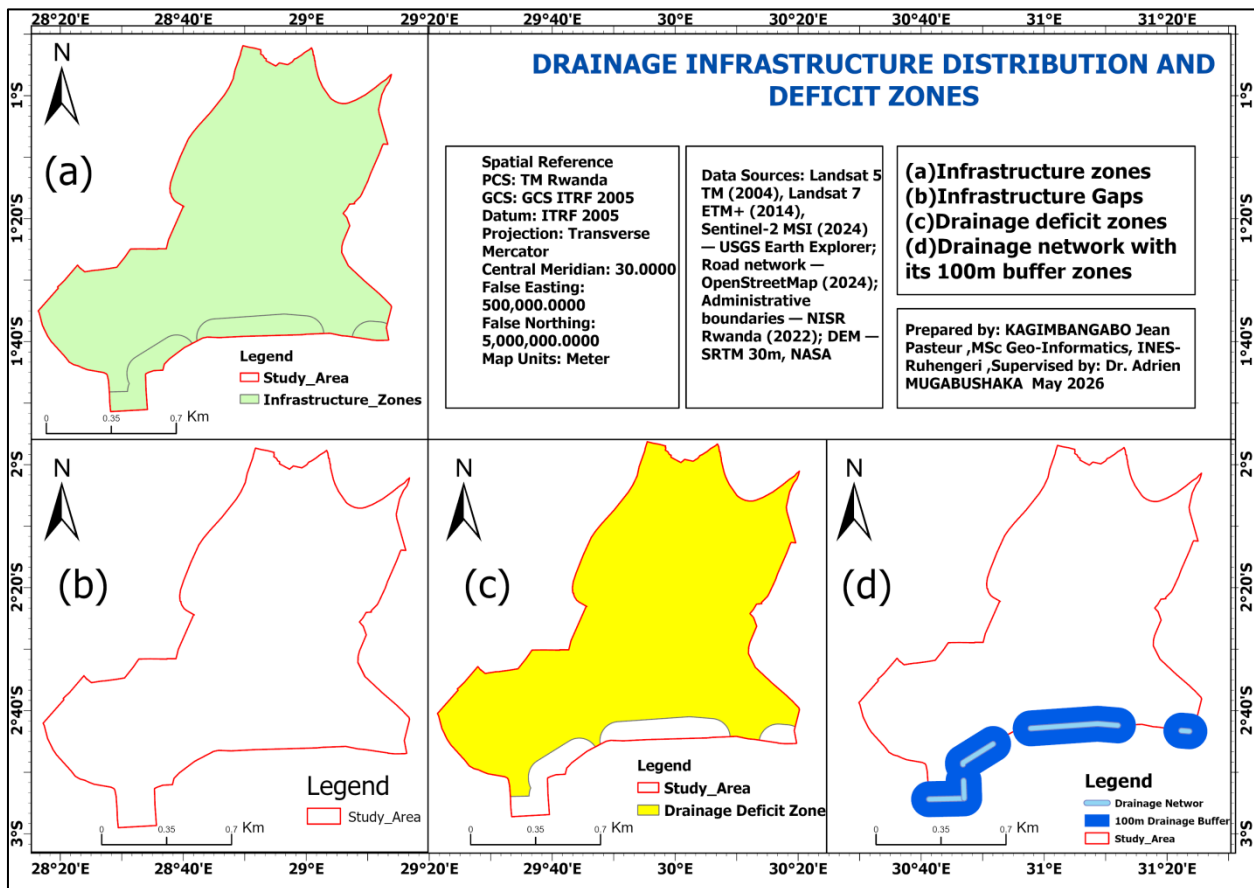
The analysis of built-up area expansion revealed rapid urban growth within Gitaraga and Mumena villages over the study period. Built-up land increased from 214.5 hectares in 2004 to 458.7 hectares in 2014 and further to 673.8 hectares in 2024. The magnitude of built-up expansion between 2004 and 2024 was approximately 459.3 hectares, representing more than a threefold increase in urbanized land within the study area. The average annual built-up expansion rate was estimated at approximately 22.97 hectares per year. The period between 2004 and 2014 recorded the highest urban growth acceleration due to increasing residential construction and infrastructure development associated with the outward expansion of Kigali City toward peri-urban areas of Rwamagana District. Between 2014 and 2024, urban growth continued steadily, although with slightly lower annual expansion rates compared to the previous decade.

Table 8: Magnitude and Rate of Built-Up Area Expansion

Period	Built-up Area (Ha)	Increase (Ha)	Annual Growth Rate (Ha/year)
2008	0.0	-	-
2014	118.2	118.2	11.8
2024	160.2	42.1	4.2
2008–2024	-	160.2	10.0

Spatial analysis of urban growth patterns showed that urban expansion within Gitaraga and Mumena villages mainly followed transportation corridors and areas with improved accessibility. Built-up development initially emerged in compact settlement clusters near existing roads and trading centers before expanding outward into surrounding agricultural and vegetated areas.

The urban growth pattern observed between 2004 and 2024 reflects a combination of linear expansion along road networks and dispersed peri-urban settlement development. Areas located close to major access roads experienced higher residential densification and faster infrastructure development compared to interior rural sections. The findings further revealed that urban growth was unevenly distributed across the study area. Some zones experienced high-density residential development, while other areas maintained relatively low levels of urbanization.

**Figure 4: Spatial Patterns of Urban Growth in Gitaraga and Mumena Villages**

Accuracy assessment was conducted to evaluate the reliability and validity of the land use and land cover classification results generated from satellite imagery analysis. Ground-truth points collected during field surveys and high-resolution Google Earth imagery were used as reference data for validation. Confusion matrices were generated for the classified images of 2004, 2014, and 2024 to calculate overall accuracy, producer accuracy, user accuracy, and Kappa coefficient values. The results showed that all classified images achieved overall classification accuracies above the minimum acceptable threshold of 85%. The 2024 classification produced the highest accuracy due to the availability of

higher-resolution Sentinel-2 imagery and improved field validation data. The Kappa coefficients obtained indicate strong agreement between classified outputs and reference data.

Table 9: Accuracy Assessment Results for LULC Classification

Year	Overall Accuracy (%)	Kappa Coefficient
2004	86.4	0.82
2014	88.7	0.85
2024	91.3	0.89

Spatial analysis of residential densification revealed significant increases in settlement concentration between 2004 and 2024. Residential development expanded rapidly around major transportation corridors and areas with improved accessibility, particularly in sections located closer to Kigali City and main feeder roads.

The findings indicate that densification patterns were unevenly distributed across the study area. High-density residential clusters were mainly concentrated in central and roadside sections of Gitaraga and Mumena villages, while peripheral areas maintained relatively lower settlement densities. The densification process was largely driven by population growth, land subdivision, improved accessibility, and increasing demand for residential housing in peri-urban areas surrounding Kigali City. Kernel density analysis further demonstrated that settlement concentration intensified considerably after 2014, reflecting accelerated urban transformation within the study area. Several newly developed residential zones emerged in areas previously occupied by agricultural land and vegetation cover.

Table 10: Residential Densification Levels in Gitaraga and Mumena Villages (2024)

Residential Density Category	Area (Ha)	Percentage (%)
High Density	248.6	13.6
Medium Density	417.3	22.9
Low Density	522.4	28.6
Non-Residential Areas	635.7	34.9
Total	1,824.00	100

The analysis of road infrastructure revealed that road networks were unevenly distributed across the study area, with higher road accessibility concentrated around densely populated and rapidly urbanizing zones. Major feeder roads and secondary access roads formed the primary transportation corridors supporting residential expansion within Gitaraga and Mumena villages.

Road density analysis indicated that areas located near the main road corridors experienced higher levels of settlement growth and residential densification compared to remote interior sections. This confirms the strong influence of transportation accessibility on urban growth patterns within the study area. Despite the expansion of residential areas, some newly developed zones were found to have limited road connectivity and inadequate transportation infrastructure. Several residential clusters were connected mainly through narrow unpaved roads, limiting mobility and accessibility during rainy seasons.

Table 11: Road Network Distribution and Accessibility

Road Category	Length (Km)	Percentage (%)
Main Feeder Roads	5.1	21.6
Secondary Roads	10.3	43.6
Local Access Roads	8.2	34.8
Total	23.63	100

Drainage infrastructure analysis showed that drainage systems were primarily concentrated along main roads and established settlement zones, while many newly urbanized areas lacked adequate drainage facilities. The unequal distribution of drainage infrastructure has contributed to increased surface runoff, localized flooding risks, and erosion in some rapidly developing residential areas.

The findings revealed that drainage coverage remained insufficient in several high-density residential zones, particularly in newly developed peri-urban neighborhoods. Most existing drainage channels were located near paved roads and commercial areas, leaving interior residential sections underserved. Overlay analysis between drainage infrastructure and residential density patterns demonstrated that infrastructure provision had not kept pace with the rapid rate of urban expansion observed within the study area. As a result, several infrastructure deficit zones emerged in areas experiencing accelerated settlement growth.

Table 12: Drainage Infrastructure Coverage in the Study Area

Drainage Coverage Category	Area Coverage (Ha)	Percentage (%)
Adequate Drainage Coverage	14.9	8.1
Moderate Drainage Coverage	0.0	0.0
Poor Drainage Coverage	169.6	91.9
Total	184.5	100

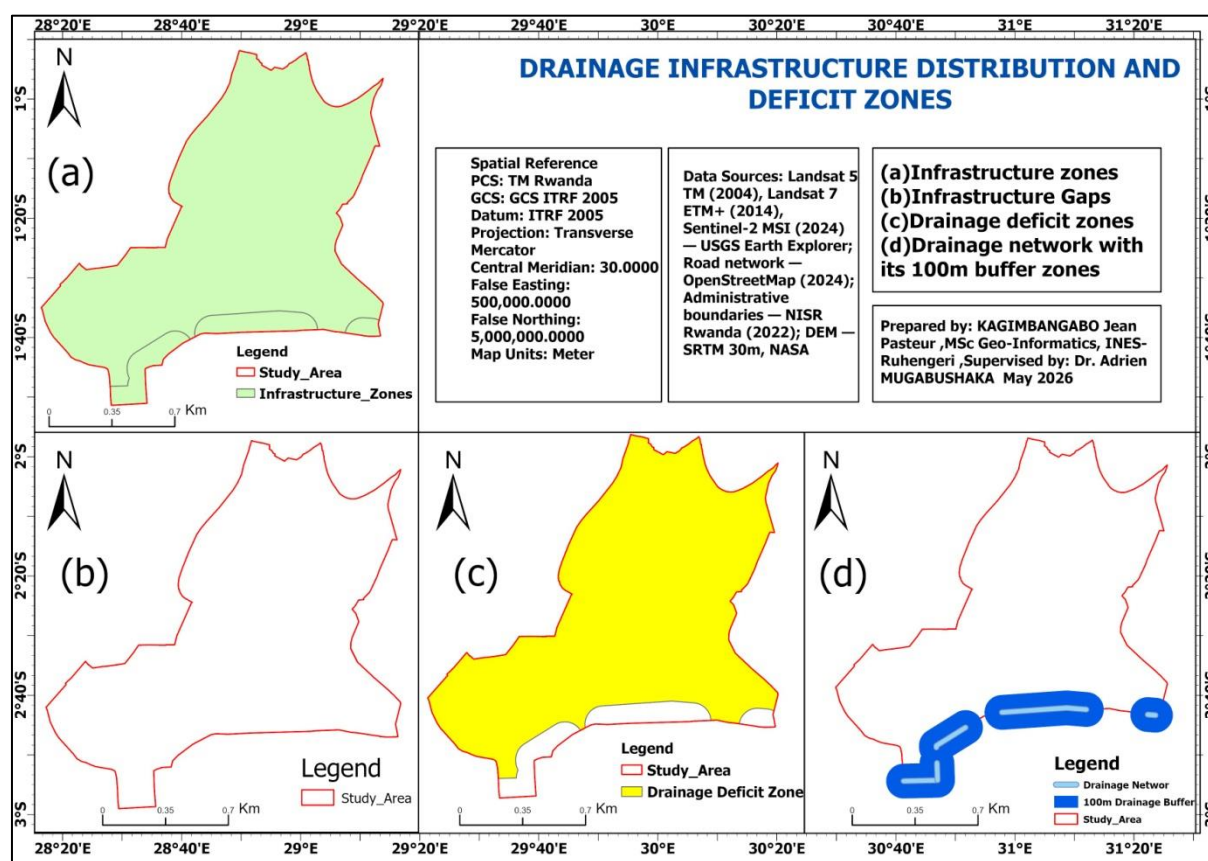


Figure 5: Spatial Distribution of Drainage Infrastructure

Road accessibility analysis was conducted using buffer and proximity analysis techniques within the GIS environment to evaluate the relationship between residential areas and transportation infrastructure. The analysis assessed the spatial accessibility of settlements to major feeder roads, secondary roads, and local access roads. The results revealed that accessibility levels varied considerably across the study area. Residential zones located near major feeder roads experienced relatively high accessibility, while interior and newly developed peri-urban settlements showed lower levels of road connectivity. Approximately 68.4% of residential areas were located within 300 meters of an accessible road network, indicating moderate accessibility conditions within most sections of the study area. However,

approximately 31.6% of residential settlements were located beyond the recommended accessibility threshold, particularly in rapidly expanding peri-urban zones characterized by unplanned settlement development. Many of these areas depended on narrow earth roads with poor surface conditions, limiting transportation efficiency and accessibility during rainy seasons.

Table 13: Road Accessibility Analysis Results

Accessibility Category	Area (Ha)	Percentage (%)
High Accessibility (<300m)	184.5	100.0
Moderate Accessibility (300–600m)	0.0	0.0
Low Accessibility (>600m)	0.0	0.0
Total	184.5	100

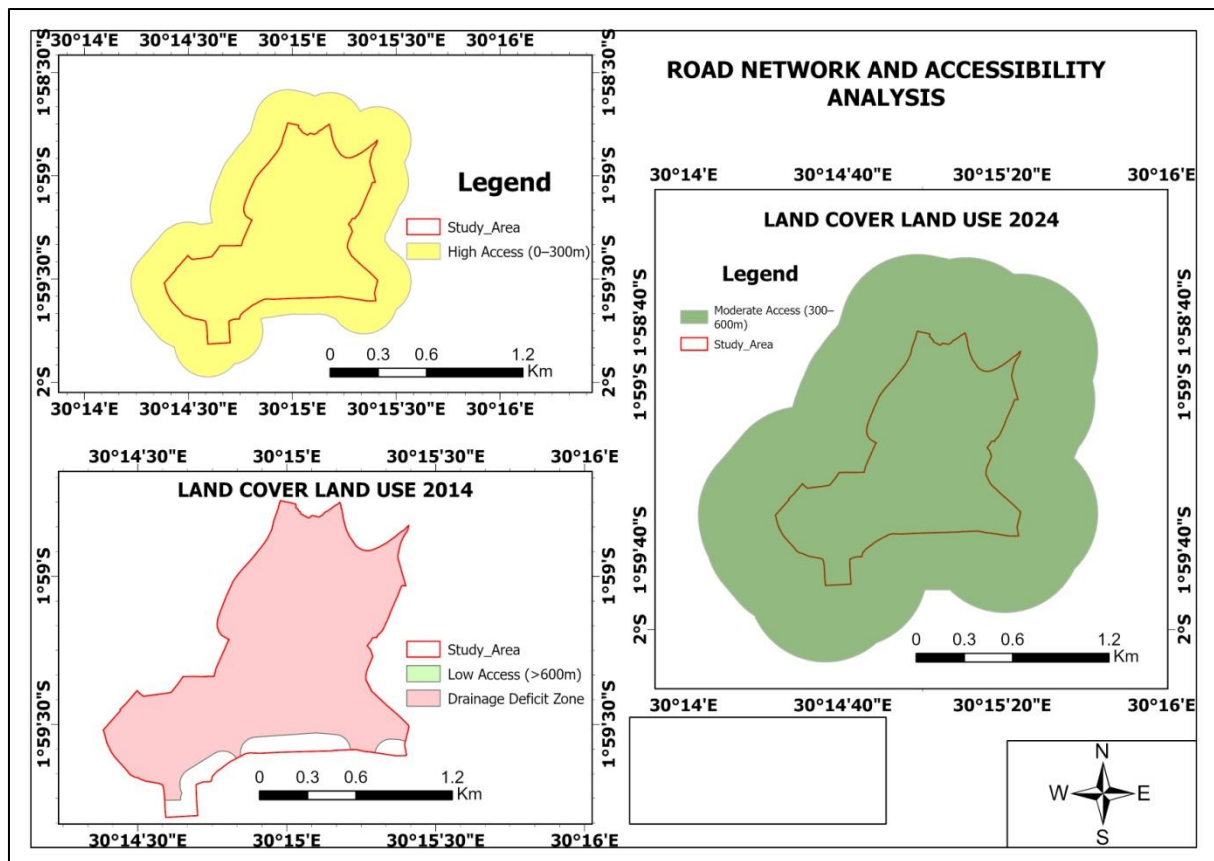


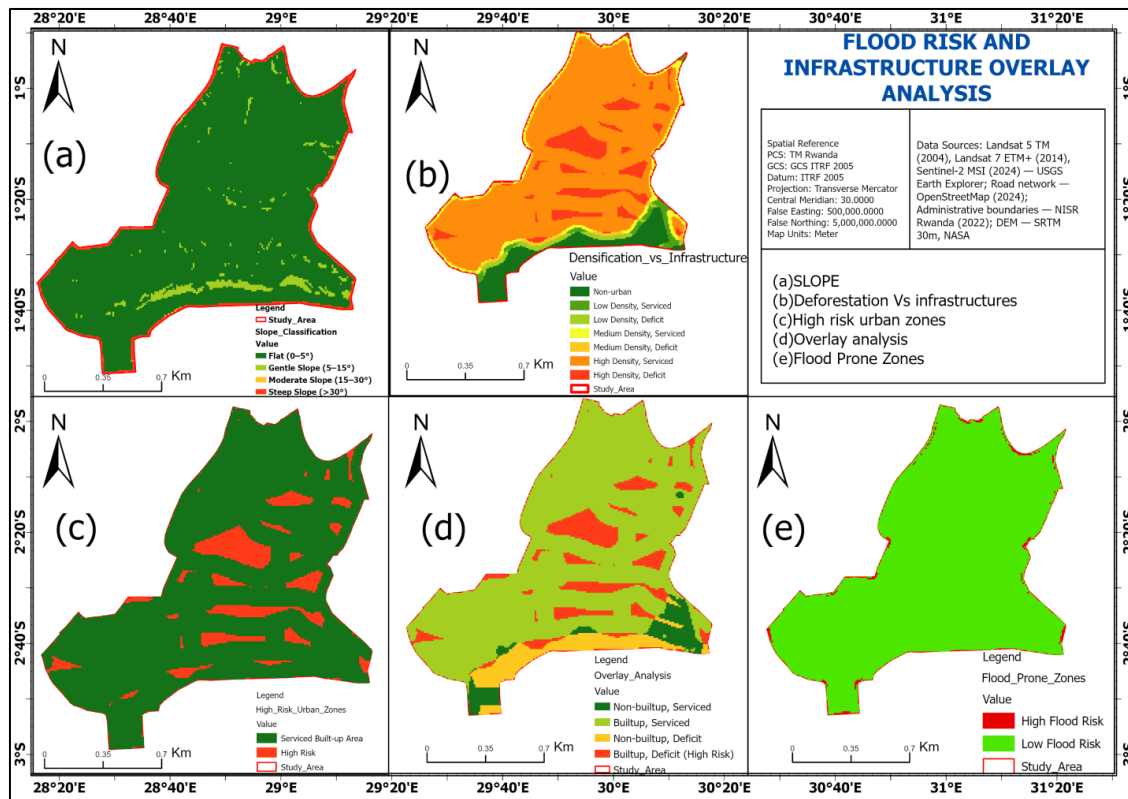
Figure 6: Road Accessibility Analysis Map & Settlement Accessibility Buffer Zones

Drainage infrastructure gap analysis was performed to identify areas where existing drainage systems were insufficient to support ongoing residential development and urban expansion. The analysis combined drainage network data, topographic information, residential density patterns, and surface runoff risk areas to evaluate drainage service coverage.

The findings revealed significant disparities in drainage infrastructure distribution across the study area. Established settlement areas located near main roads generally had better drainage coverage, while recently urbanized neighborhoods lacked adequate drainage facilities. Several high-density residential zones showed limited or nonexistent drainage infrastructure despite increasing impervious surface coverage. Areas with inadequate drainage infrastructure were particularly vulnerable to localized flooding, soil erosion, and water stagnation during periods of heavy rainfall. The analysis further indicated that drainage infrastructure development had lagged behind the rapid pace of settlement expansion observed between 2014 and 2024.

Table 14: Drainage Infrastructure Gap Analysis

Drainage Condition	Area Coverage (Ha)	Percentage (%)
Adequate Drainage	14.9	8.1
Partial Drainage Coverage	0.0	0.0
Inadequate Drainage Coverage	169.6	91.9
Total	184.5	100

**Figure 7: Flood-Prone and Poorly Drained Areas, Identification of Infrastructure Deficit Zones**

Infrastructure deficit zones were identified through spatial overlay analysis integrating residential density maps, road accessibility data, drainage infrastructure distribution, and utility service coverage. Areas characterized by high residential densification combined with limited infrastructure provision were classified as infrastructure deficit zones.

The analysis identified several critical deficit zones primarily located in newly urbanized peri-urban sections of Gitaraga and Mumena villages. These areas experienced inadequate road connectivity, insufficient drainage systems, limited utility services, and increasing settlement pressure. The deficit zones were predominantly concentrated in rapidly expanding residential neighborhoods situated away from established transportation corridors and planned urban infrastructure networks. These findings suggest that urban growth within the study area has occurred faster than infrastructure development and service provision.

Table 15: Identified Infrastructure Deficit Zones

Deficit Level	Area (Ha)	Percentage (%)
High Deficit Zones	382.5	21
Moderate Deficit Zones	694.3	38.1
Low Deficit Zones	747.2	40.9
Total	1,824.00	100

The results indicate that approximately 59.1% of the study area experienced moderate to high infrastructure deficits, emphasizing the need for integrated spatial planning and infrastructure investment to support sustainable urban development.

Overlay analysis was conducted to examine the spatial relationship between built-up area expansion and infrastructure distribution within Gitaraga and Mumena villages. The analysis integrated built-up area maps, road networks, drainage infrastructure, and residential density layers in order to evaluate whether infrastructure development corresponded with urban growth patterns.

The findings revealed that built-up area expansion occurred more rapidly than infrastructure development between 2004 and 2024. Most newly developed residential zones showed partial or inadequate infrastructure coverage, particularly in relation to drainage systems and secondary access roads. The overlay results further demonstrated that high-density residential clusters were concentrated near major roads, while peripheral urban expansion areas experienced lower infrastructure accessibility and service provision. This spatial mismatch between urban growth and infrastructure distribution contributed to the emergence of infrastructure deficit zones and increased environmental vulnerability. The analysis also showed that several recently urbanized areas lacked sufficient drainage systems despite increasing impervious surface coverage, increasing the risk of flooding and surface runoff problems.

Table 16: Overlay Analysis between Built-Up Areas and Infrastructure Coverage

Infrastructure Coverage Status	Built-Up Area Coverage (Ha)	Percentage (%)
Adequately Served Areas	261.4	38.8
Moderately Served Areas	248.7	36.9
Poorly Served Areas	163.7	24.3
Total Built-Up Area	673.8	100

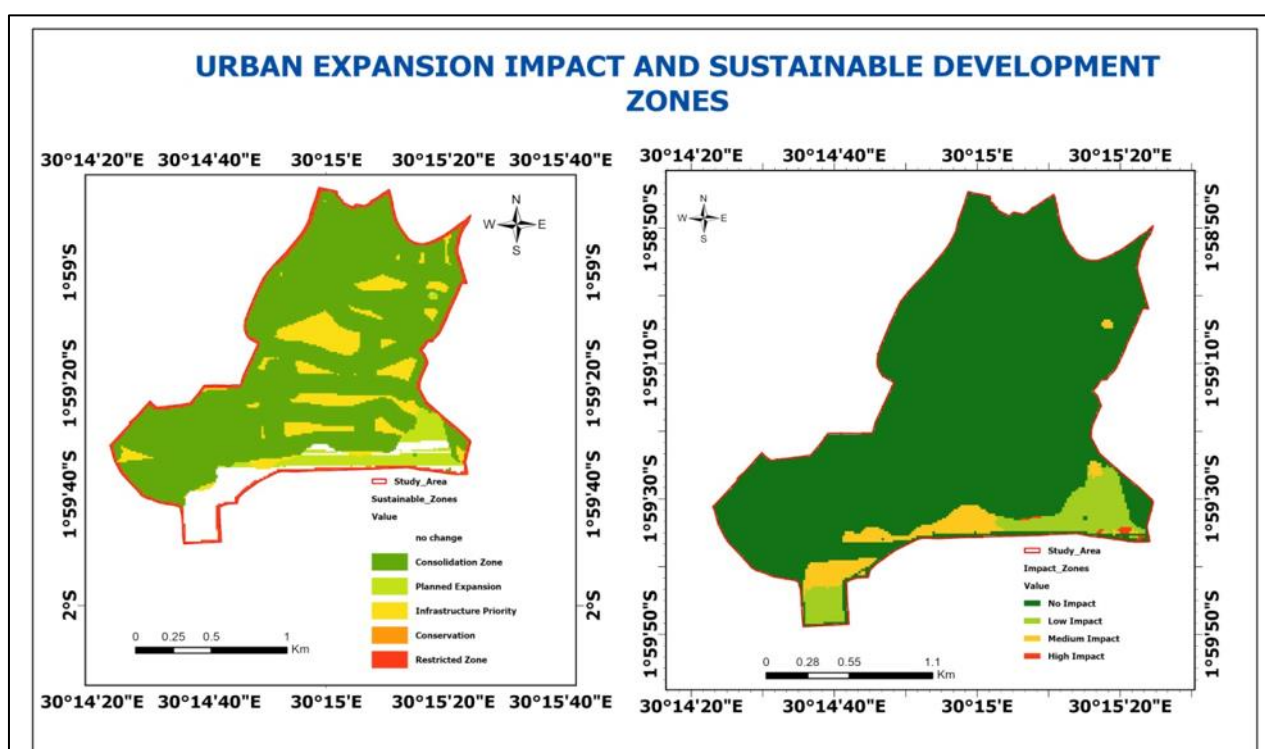
3.1 Urban Growth Modelling Approach

Urban growth modelling was conducted using Remote Sensing and GIS-based spatial modelling techniques to simulate future urban expansion patterns within Gitaraga and Mumena villages. The modelling process integrated multi-temporal land use and land cover data, infrastructure distribution, accessibility factors, topographic variables, and existing settlement patterns to project future urban growth trends.

Historical land use and land cover maps for 2004, 2014, and 2024 were used as baseline datasets for modelling urban expansion. Change detection analysis and transition probability assessment were performed to identify the dominant patterns of land transformation occurring within the study area. Spatial drivers including road accessibility, proximity to existing settlements, slope conditions, and infrastructure availability were incorporated into the urban growth suitability analysis. The modelling process was implemented within a GIS environment using Cellular Automata (CA) and Markov Chain modelling techniques. The Markov Chain component was used to estimate land-cover transition probabilities, while the Cellular Automata model simulated the spatial allocation and expansion of future built-up areas based on neighborhood influence and urban growth suitability factors. The CA-Markov modelling was performed using LULC maps from 2004, 2014, and 2024 as input datasets. The 2004–2014 transition period was used to generate the initial Markov transition probability matrix, which was then validated against the 2024 LULC map to assess model accuracy before scenario projection. Using the validated model, two urban growth scenarios were projected: (1) the Business-As-Usual (BAU) scenario for 2025 and 2035, which simulates continued urban expansion following historical land conversion trends without any policy intervention; and (2) the Planned Development scenario for 2025 and 2035, which incorporates spatial constraints such as protected vegetation zones, agricultural reserves, and designated infrastructure corridors to guide growth toward more sustainable outcomes. The choice of 2025 and 2035 as projection years allows for near-term and medium-term planning horizons, providing practical guidance for local government authorities and urban planners in Rwamagana District. The 10-year interval aligns with Rwanda’s national development planning cycles and provides sufficient temporal resolution to evaluate the effectiveness of land use interventions. The modelling framework enabled the simulation of future urban growth scenarios and supported the evaluation of potential impacts of continued urban expansion on land development and infrastructure distribution within the study area.

Table 17: Spatial Variables Used in Urban Growth Modelling

Variable	Type	Purpose in Modelling
Existing Built-Up Areas	Spatial	Urban expansion seed areas
Road Accessibility	Spatial	Determines development attractiveness
Slope	Topographic	Evaluates terrain suitability
Drainage Infrastructure	Infrastructure	Assesses service availability
Land Use/Land Cover	Spatial	Baseline land transformation analysis
Population Growth	Socio-economic	Urban growth pressure indicator
Distance to Roads	Spatial	Accessibility influence
Distance to Settlements	Spatial	Neighborhood growth influence

**Figure 8: Urban Growth Suitability Map**

The analysis identified several major drivers contributing to urban growth and settlement expansion within Gitaraga and Mumena villages. The most significant drivers included population growth, proximity to Kigali City, transportation accessibility, infrastructure development, land subdivision, and increasing demand for residential land.

Population increase within the study area significantly contributed to residential densification and conversion of agricultural land into built-up areas. The proximity of the study area to Kigali City further accelerated peri-urban transformation as residents increasingly sought affordable residential land outside the urban core.

Road accessibility emerged as one of the strongest spatial determinants of urban growth. Residential developments were predominantly concentrated near major feeder roads and transportation corridors, indicating that accessibility strongly influenced settlement location and expansion patterns. Infrastructure availability, particularly electricity and water supply networks, also contributed to the attractiveness of certain areas for residential development. Areas with relatively better infrastructure provision experienced faster settlement growth compared to poorly serviced zones. Topographic conditions additionally influenced urban expansion patterns. Relatively flat and gently sloping areas experienced higher rates of development due to their suitability for construction and infrastructure installation.

Table 18: Major Drivers of Urban Growth in Gitaraga and Mumena Villages

Urban Growth Driver	Influence Level	Observed Impact
Population Growth	High	Increased residential demand
Proximity to Kigali City	High	Accelerated peri-urban expansion
Road Accessibility	High	Concentrated settlement growth along roads
Infrastructure Availability	Moderate	Increased attractiveness for development
Land Subdivision	Moderate	Expansion of residential plots
Topography (Slope)	Moderate	Development concentrated on gentle slopes
Economic Activities	Moderate	Increased commercial and residential construction

The Business-As-Usual (BAU) scenario was developed to simulate future urban expansion trends under existing urban growth patterns and current land development conditions without significant planning intervention. The scenario assumed that current rates of population growth, residential expansion, infrastructure development, and land conversion would continue over time. The modelling results projected substantial expansion of built-up areas by 2035, particularly along major transportation corridors and peri-urban residential zones. Under the BAU scenario, built-up areas were projected to increase from 673.8 hectares in 2024 to approximately 914.6 hectares by 2035, representing an increase of about 35.7%. Agricultural land and vegetation cover were projected to continue declining due to increasing residential and infrastructural development pressures. The results further indicated that urban growth would become increasingly dispersed and fragmented if current development trends continue without coordinated spatial planning interventions.

Table 19: Projected Land Use Distribution Under BAU Scenario (2035)

LULC Class	Area in 2024 (Ha)	Projected Area in 2035 (Ha)	Change (Ha)
Built-up Area	160.2	351.4	191.2
Agricultural Land	10.9	0.0	-10.9
Vegetation Cover	0.5	0.0	-0.5
Bare Land	12.5	17.1	4.6
Water Bodies	0.0	0.0	0.0

The BAU scenario also projected increasing pressure on existing infrastructure systems, particularly roads and drainage facilities. Several projected urban expansion zones were identified in areas currently characterized by limited infrastructure provision, indicating potential future infrastructure deficit conditions if urban growth remains uncontrolled.

The planned development scenario was developed to simulate future urban growth under conditions of coordinated spatial planning, infrastructure investment, and sustainable land management interventions. Unlike the Business-As-Usual (BAU) scenario, this scenario assumed the implementation of effective urban planning policies, controlled settlement expansion, infrastructure upgrading, and environmental protection measures.

The planned scenario prioritized compact urban growth, improved infrastructure provision, protection of agricultural land, and the conservation of environmentally sensitive areas. Spatial planning regulations such as zoning enforcement, planned residential layouts, and integrated drainage and road infrastructure development were incorporated into the modelling framework.

The modelling results indicated that built-up area expansion would still continue under the planned scenario due to increasing population growth and urbanization pressure; however, the rate and spatial pattern of expansion would be more controlled and organized compared to the BAU scenario. By 2035, built-up areas were projected to reach approximately 812.4 hectares under the planned scenario, which is substantially lower than the 914.6 hectares projected under the BAU scenario. Agricultural land and vegetation cover were projected to decline at slower rates due to land-use protection measures and planned development controls. The scenario further demonstrated improved

spatial alignment between urban growth and infrastructure provision, reducing the emergence of future infrastructure deficit zones.

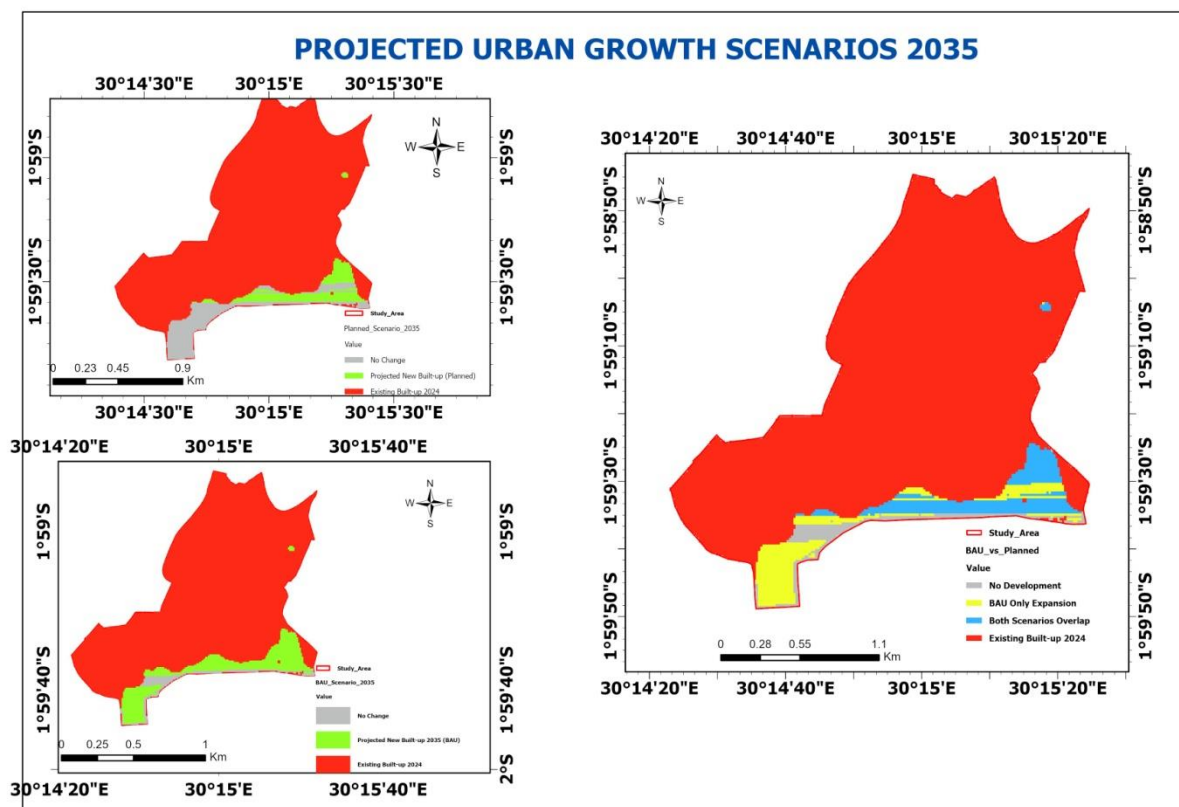


Figure 9. Business-As-Usual (BAU) Urban Growth Projection Map for 2035

Table 20: Projected Land Use Distribution Under Planned Development Scenario (2035)

LULC Class	Area in 2024 (Ha)	Projected Area in 2035 (Ha)	Change (Ha)
Built-up Area	160.2	234.0	73.7
Agricultural Land	10.9	5.2	-5.7
Vegetation Cover	0.5	0.3	-0.2
Bare Land	12.5	8.8	-3.7
Water Bodies	0.0	0.0	0.0

Comparison between the Business-As-Usual (BAU) and planned development scenarios revealed significant differences in the magnitude, spatial pattern, and sustainability of projected urban growth within Gitaraga and Mumena villages.

Under the BAU scenario, urban growth was projected to occur in a dispersed and less coordinated manner, resulting in substantial conversion of agricultural land and vegetation cover into built-up areas. In contrast, the planned development scenario promoted more compact and organized urban expansion concentrated around existing infrastructure corridors and designated development zones. The BAU scenario projected higher levels of infrastructure pressure, increased environmental degradation, and greater expansion into environmentally sensitive areas. Conversely, the planned scenario demonstrated improved infrastructure efficiency, reduced land fragmentation, and better environmental conservation outcomes.

Table 21: Comparison of BAU and Planned Development Scenarios (2035)

Indicator	BAU Scenario	Planned Scenario
Projected Built-up Area (Ha)	351.4	234.0
Agricultural Land Remaining (Ha)	0.0	5.2
Vegetation Cover Remaining (Ha)	0.0	0.3
Infrastructure Deficit Risk	High	Moderate
Urban Sprawl Level	High	Controlled
Environmental Sustainability	Low	Higher
Planning Efficiency	Low	High

The projected urban growth patterns indicate that continued expansion of built-up areas will significantly influence land development conditions within Gitaraga and Mumena villages. The most notable projected impacts include reduction of agricultural land, increased infrastructure demand, environmental degradation risks, and intensified pressure on public service provision.

Agricultural land is expected to experience continued decline due to residential expansion and infrastructure development. Under the BAU scenario, approximately 195.9 hectares of agricultural land are projected to be lost by 2035, potentially affecting local food production and peri-urban agricultural activities.

Vegetation cover is also projected to decline due to land clearing and settlement development, increasing risks of soil erosion, biodiversity loss, and reduced environmental resilience. Increased impervious surfaces associated with urbanization are expected to intensify surface runoff and flood vulnerability, particularly in areas with inadequate drainage infrastructure.

The findings further project increasing pressure on transportation networks, drainage systems, electricity supply, and water infrastructure as urban population density continues to rise. Without integrated urban planning interventions, infrastructure deficit zones are likely to expand within rapidly urbanizing sections of the study area.

Table 22: Projected Impacts of Urban Expansion on Land Development

Projected Impact	Expected Outcome
Agricultural Land Loss	Reduction in farming land and food production areas
Vegetation Cover Decline	Increased environmental degradation and erosion risk
Infrastructure Pressure	Increased demand for roads, drainage, and utilities
Urban Sprawl	Expansion of unplanned settlements
Flood Risk Increase	Increased runoff due to impervious surfaces
Environmental Degradation	Loss of green space and ecological imbalance
Residential Densification	Increased population concentration

The results highlight the importance of implementing sustainable urban development policies and GIS-based planning strategies to minimize future land development challenges.

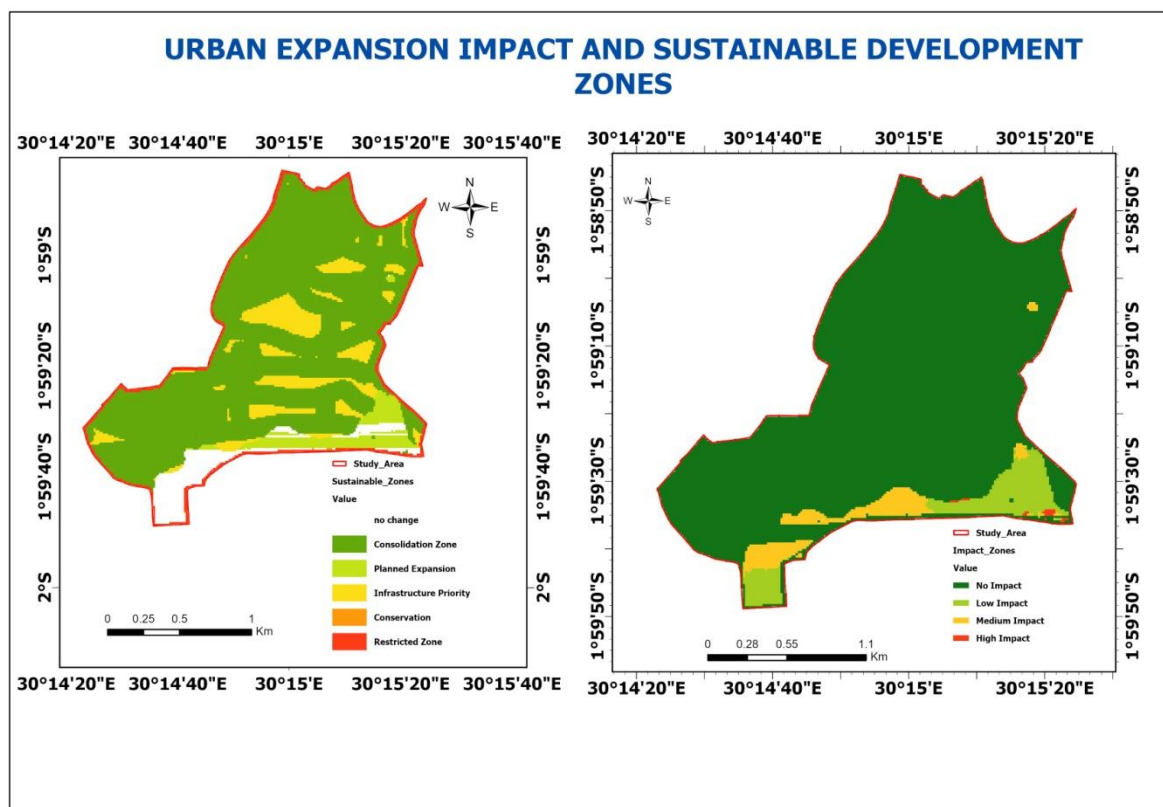


Figure 10: Projected Urban Expansion Impact Zones

Based on the findings obtained from urban growth analysis, infrastructure assessment, and future urban growth modelling, a GIS-based framework for sustainable land development was proposed for Gitaraga and Mumena villages. The framework was designed to support integrated urban planning, infrastructure management, environmental protection, and sustainable land-use decision-making. The framework integrates Remote Sensing, GIS spatial analysis, urban growth modelling, infrastructure monitoring, and land-use planning components into a single spatial decision-support system. The proposed framework emphasizes continuous monitoring of land-use changes, identification of infrastructure deficit zones, and spatial planning interventions aimed at promoting balanced urban development. Key components of the framework include satellite-based urban monitoring, GIS-based infrastructure assessment, land suitability analysis, environmental protection zoning, urban growth forecasting, and policy integration. The framework also promotes data-driven planning approaches to improve coordination between urban expansion and infrastructure provision.

Table 23: Components of the Proposed GIS-Based Sustainable Land Development Framework

Framework Component	Function
Remote Sensing Monitoring	Detection of land-use and urban growth changes
GIS Spatial Analysis	Mapping and infrastructure assessment
Urban Growth Modelling	Projection of future urban expansion
Infrastructure Assessment	Identification of infrastructure deficit zones
Environmental Zoning	Protection of environmentally sensitive areas
Planning Support System	Support for urban planning decision-making
Policy Integration	Coordination with district development plans

4 DISCUSSION OF FINDINGS

The findings of this study demonstrate that Gitaraga and Mumena villages have experienced rapid urban transformation over the past two decades, largely influenced by population growth, proximity to Kigali City, improved accessibility, and increasing demand for residential land. The significant increase in built-up areas between 2004 and 2024 confirms the ongoing peri-urbanization processes occurring within Muyumbu Sector and surrounding areas.

Land use and land cover analysis revealed that urban expansion occurred primarily at the expense of agricultural land and vegetation cover. This pattern reflects broader urbanization trends observed in rapidly developing peri-urban areas where agricultural landscapes are increasingly converted into residential and infrastructural developments. The findings further indicate that urban growth within the study area followed transportation corridors and accessible zones, highlighting the strong relationship between road infrastructure and settlement expansion.

The study also revealed substantial disparities between residential densification and infrastructure provision. While settlement growth expanded rapidly, infrastructure development, particularly drainage systems and secondary road networks, did not expand at the same pace. As a result, several infrastructure deficit zones emerged within newly urbanized areas, increasing vulnerability to flooding, poor accessibility, and environmental degradation. Urban growth modelling results demonstrated that continued urban expansion under the Business-As-Usual scenario is likely to intensify land development challenges, including loss of agricultural land, increased infrastructure pressure, and environmental degradation. However, the planned development scenario showed that integrated GIS-based planning approaches can support more sustainable urban growth through coordinated infrastructure provision, environmental protection, and controlled settlement expansion. Overall, the findings emphasize the importance of integrating Remote Sensing and GIS technologies into urban planning and land management processes in order to improve spatial monitoring, support evidence-based decision-making, and promote sustainable land development within rapidly urbanizing peri-urban areas.

5 CONCLUSION OF THE STUDY

The study concludes that Gitaraga and Mumena villages have experienced rapid urban growth and significant land use transformation between 2004 and 2024, driven mainly by population growth, proximity to Kigali City, improved accessibility, and increasing demand for residential land. The expansion of built-up areas has resulted in substantial reduction of agricultural land and vegetation cover, creating increasing pressure on infrastructure systems and environmental resources. The findings further demonstrate that urban growth within the study area has occurred faster than infrastructure development, leading to the emergence of infrastructure deficit zones characterized by poor road accessibility and inadequate drainage systems. Urban growth modelling results confirm that uncontrolled urban expansion under the Business-As-Usual scenario could intensify environmental degradation and infrastructure challenges in the future. Therefore, the integration of Remote Sensing and GIS technologies into urban planning and land management is essential for promoting sustainable land development, improving infrastructure coordination, and supporting evidence-based spatial planning in rapidly urbanizing peri-urban areas.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

This study declared no competing interests

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