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(RESEARCH ARTICLE)



THE IMPACT OF LAND USE AND LAND COVERCHANGES ON URBAN FLOOD VULNERABILITY IN KIGALI CITY (2000-2025)

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ABSTRACT

This thesis assessed land use and land cover (LULC) changes and their impact on urban flood vulnerability in Kigali City between 2000 and 2025. Using GIS, remote sensing and statistical trend analysis, the study analysed multi-temporal changes in built-up land, forest, wetlands, agriculture and other land-cover classes, and related these changes to mapped flood-conditioning factors and flood-risk surfaces. Results indicate a pronounced expansion of built-up land from 6,500.00 ha in 2000 to 40,067.87 ha in 2025, representing approximately 55% of Kigali City's mapped area in 2025. Wetlands also increased from 2,100.00 ha in 2000 to 4,200.00 ha in 2025, while agriculture and forest generally declined over the study period. The corrected LULC series shows that the 2000 and 2005 map outputs were harmonized to avoid the apparent decline of built-up land between these two dates. Flood-related mapping identified elevated hazard, vulnerability and risk in valley-bottom environments and along major drainage corridors, particularly where urban expansion overlapped with wetlands and floodplains. Exploratory statistical analysis showed a strong inverse relationship between built-up land and agriculture ($r = -0.858$), while the relationship between built-up land and wetlands was positive ($r = 0.746$), reflecting the mapped increase and restoration/inundation of wetland areas during the same period. The findings demonstrate that LULC changes have materially influenced urban flood vulnerability in Kigali by increasing impervious surfaces, altering runoff pathways and changing the spatial distribution of natural buffers. The study recommends stronger wetland protection, improved storm-water infrastructure, and integration of flood-risk information into urban planning and development control.

Keywords: GIS; Hydrological processes; Land use and land cover; Normalized Difference Vegetation Index; Remote sensing; Urban flood

1 INTRODUCTION

Rapid urbanization has become a defining global phenomenon shaping land use and land cover (LULC) patterns in both developed and developing countries. Major cities such as New York, London, Tokyo, Shanghai, and Mumbai have experienced extensive conversion of natural and agricultural land into built-up environments (Kabisch, Qureshi, & Haase, 2015; McDonald et al., 2011). These transformations have increased impervious surfaces, disrupted natural drainage systems, and intensified urban flooding events, as observed in cities like Houston (USA), Jakarta (Indonesia), and Bangkok (Thailand) (Kabisch et al., 2015). The replacement of permeable land surfaces with concrete and asphalt alters hydrological processes by increasing surface runoff and reducing infiltration capacity.

In Africa, urbanization is occurring at an exceptionally rapid rate, particularly in Sub-Saharan Africa, where urban growth often outpaces planning capacity and infrastructure development. Cities such as Lagos, Nairobi, Dar es Salaam, Accra, and Johannesburg have expanded significantly over the past decades. Unplanned settlements, encroachment into wetlands and floodplains, and inadequate stormwater infrastructure have substantially modified LULC patterns, contributing to recurrent urban flooding (Douglas et al., 2008). Climate variability, including more intense and erratic rainfall events, has further exacerbated flood risks across the continent.

Within East Africa, rapid urban expansion has been observed in Nairobi (Kenya), Kampala (Uganda), Dar es Salaam (Tanzania), and Addis Ababa (Ethiopia) (Awotona, 2001). These cities have experienced widespread conversion of vegetation, wetlands, and agricultural land into residential, commercial, and industrial areas (Kibler et al., 2016; Muthui et al., 2017). Such LULC changes have altered surface runoff patterns, increased flood frequency, and degraded urban ecosystems. Regional experiences highlight the importance of integrating spatial and temporal LULC analysis with urban flood vulnerability assessments (Kibler et al., 2016).

In Rwanda, urbanization has accelerated since the early 2000s, driven by population growth, economic transformation, and national development strategies such as Vision 2020 and Vision 2050 (Bizimana et al., 2020; Kayiranga et al., 2024). Significant land transformation has occurred in major urban centers, particularly Kigali City (MINEMA, 2018). Although urban expansion has contributed to socio-economic development, it has also resulted in the conversion of wetlands, valley bottoms, and vegetated land into built-up areas, thereby increasing exposure to urban flooding (Ndayisaba et al., 2022).

Kigali City, as the capital and largest urban center in Rwanda, illustrates these changes most clearly. The city has expanded into hillsides, valleys, and wetland areas, particularly in flood-prone zones such as Nyabugogo, Gikondo, and Nyarugenge Valley (MINEMA, 2024). These LULC changes have intensified surface runoff during heavy rainfall events and increased urban flood vulnerability. Frequent flooding has resulted in infrastructure damage, traffic disruption, economic losses, and risks to public health (Bizimana et al., 2020; Kayiranga et al., 2022).

Geographic Information Systems (GIS), Remote Sensing, and spatial-temporal analysis techniques provide effective tools for monitoring LULC change and assessing its relationship with flood vulnerability. These technologies enable the detection of long-term land cover transitions, identification of flood-prone areas, and evaluation of environmental impacts over time (Ndayisaba et al., 2024). However, despite existing studies on land use change and environmental challenges in Rwanda, significant gaps remain.

First, few studies have conducted a comprehensive spatial-temporal analysis of LULC change in Kigali over an extended period, particularly between 2000 and 2025. Second, limited research has quantitatively examined the direct relationship between LULC change and urban flood vulnerability using integrated GIS and remote sensing approaches (Bizimana et al., 2023). Addressing these gaps is essential for strengthening evidence-based urban planning, climate adaptation strategies, and sustainable flood risk management in Kigali City.

2 RESEARCH METHODOLOGY

2.1 Description of the Study Area

This study was conducted in Kigali City, the capital and largest urban center of Rwanda. Kigali is located in the central part of the country between approximately 1°56' and 2°03' South latitude and 30°03' and 30°12' East longitude. The city covers an area of about 730 km² and serves as Rwanda's political, economic, and administrative hub (City of Kigali, 2020; NISR, 2022).

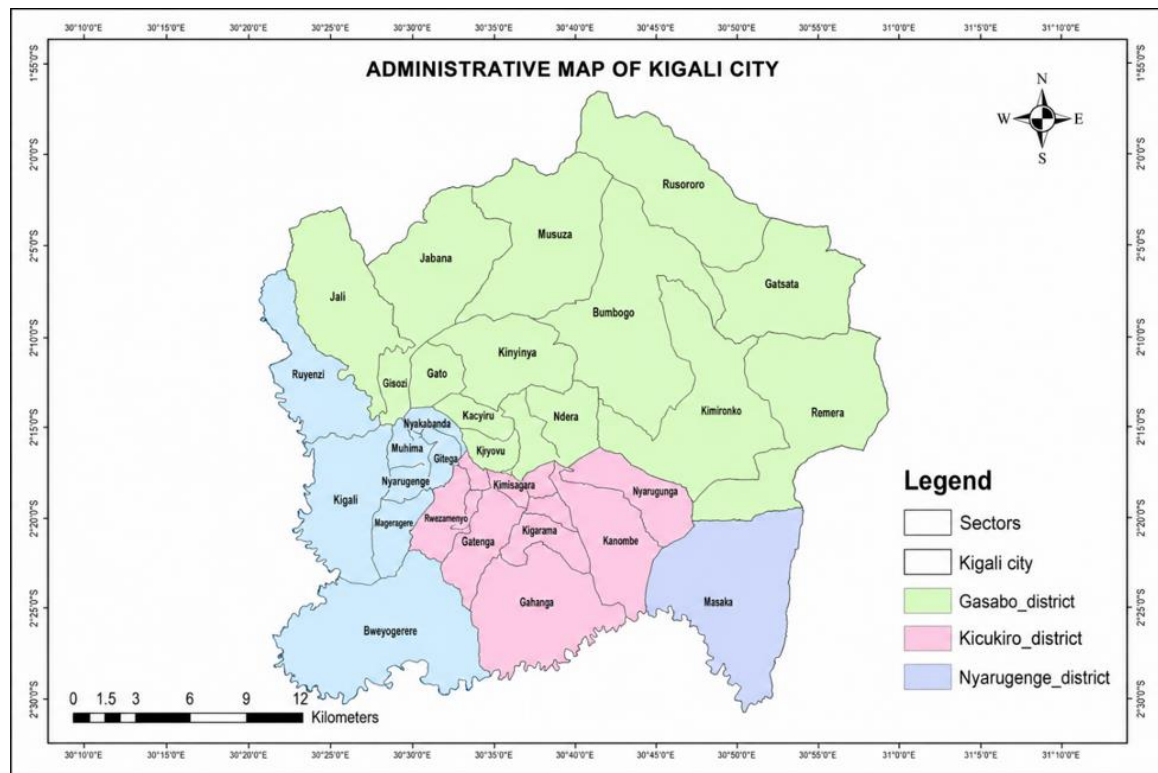
Administratively, Kigali is composed of three districts: Gasabo, Kicukiro, and Nyarugenge. These districts are subdivided into sectors, cells, and villages. According to the National Institute of Statistics of Rwanda (NISR, 2022), the city has experienced rapid population growth over the past two decades, driven by rural–urban migration, economic transformation, and infrastructure development.

Topographically, Kigali is characterized by a hilly terrain interspersed with valleys and wetlands. Elevation ranges approximately between 1,300 meters and 1,850 meters above sea level. The city forms part of the Nyabugogo catchment, which drains into the Nyabarongo River system. The presence of low-lying valleys, particularly in areas such as Nyabugogo, Gikondo, and parts of Nyarugenge, increases susceptibility to flooding during periods of intense rainfall.

Kigali experiences a tropical highland climate with two rainy seasons and an average annual rainfall ranging between 1,000 mm and 1,300 mm. Intense rainfall events combined with expanding impervious surfaces have contributed to increased surface runoff and urban flood vulnerability.

Over the past two decades, rapid urban expansion has resulted in significant land use and land cover (LULC) change, including the conversion of wetlands, agricultural land, and vegetated areas into built-up environments (Nshimiyimana, 2023). Encroachment into valley bottoms and flood-prone zones has further intensified flood risk.

These geographic, climatic, hydrological, and urbanization characteristics make Kigali City a suitable and relevant study area for assessing the impact of LULC change on urban flood vulnerability.



Source: Author design in ArcGIS 10.8, 2025

Figure 1: Administrative map showing location of Kigali-city

2.2 Research Design

The investigative approach follows a quantitative, spatial-temporal research design that entails remote sensing, GIS-based spatial modelling, as well as a statistical trend analysis.

2.3 Population of the study

This research used spatial and environmental units of the Kigali as the study population and not human respondents. Particularly, the population of the study was all the land parcels, land use and land cover (LULC) units and hydrological features in the administrative limits of Kigali, Rwanda. Spatially, the whole geographical size of the Kigali, which includes the districts of Gasabo, Kicukiro, and Nyarugenge, constituted the population of study. The entire population to be examined was all the mapped LULC classes such as built-up, vegetation, wetlands, agricultural land, water bodies, and bare land. The raster pixels obtained by the use of multi-temporal satellite images (Landsat and Sentinel) represented the study population in terms of remote sensing.

2.4 Sampling design

The sampling methodology in this research was designed to provide representative, valid and unbiased research on changes in land usage and land cover, urban green space and flood prone regions in Kigali.

2.5 Source of data

This research was based on secondary data sources in order to assess land use and land cover (LULC) changes and their effects on urban flood risks and green spaces in Kigali between 2000 and 2025. To ensure spatial accuracy, temporal consistency, and analytical reliability in GIS-based and statistical analysis, the study integrated satellite imagery, existing GIS layers, official reports, climate records, and documentary sources.

2.6 Secondary data

Secondary data was also be acquired to provide historical, spatial and environmental data that was required in the multi-temporal analysis and establishment of trends. To determine the changes of LULC changes and green space changes in 2000,2005, 2010, 2015, 2020 and 2025, satellite data (Landsat and Sentinel-2) available on the USGS Earth Explorer and Open Access Hub ESA Copernicus were used to map the LULC change and green space changes. Slopes and elevation parameters obtained based on the Digital Elevation Model (DEM) data (SRTM 30 m), which is vital in the calculation of the susceptibility of cities to floods. Hydrological data of rivers, wetlands and drainage systems obtained in Rwanda Environment Management Authority (REMA) and City of Kigali. Statistics on rainfall and weather conditions at Rwanda Meteorology Agency to enable the examination of the precipitation pattern that causes flooding in the city.

2.7 Data collection techniques

The proposed study was utilizing mixed-methods method of data collection, combining both the field-based data collection and geospatial data collection to assess the changes of land use and land cover (LULC) and its effects on Kigali in terms of urban flood vulnerability between the years 2000 and 2025. There are data triangulation, accuracy, and increased reliability of GIS and statistical analyses because of the use of various techniques.

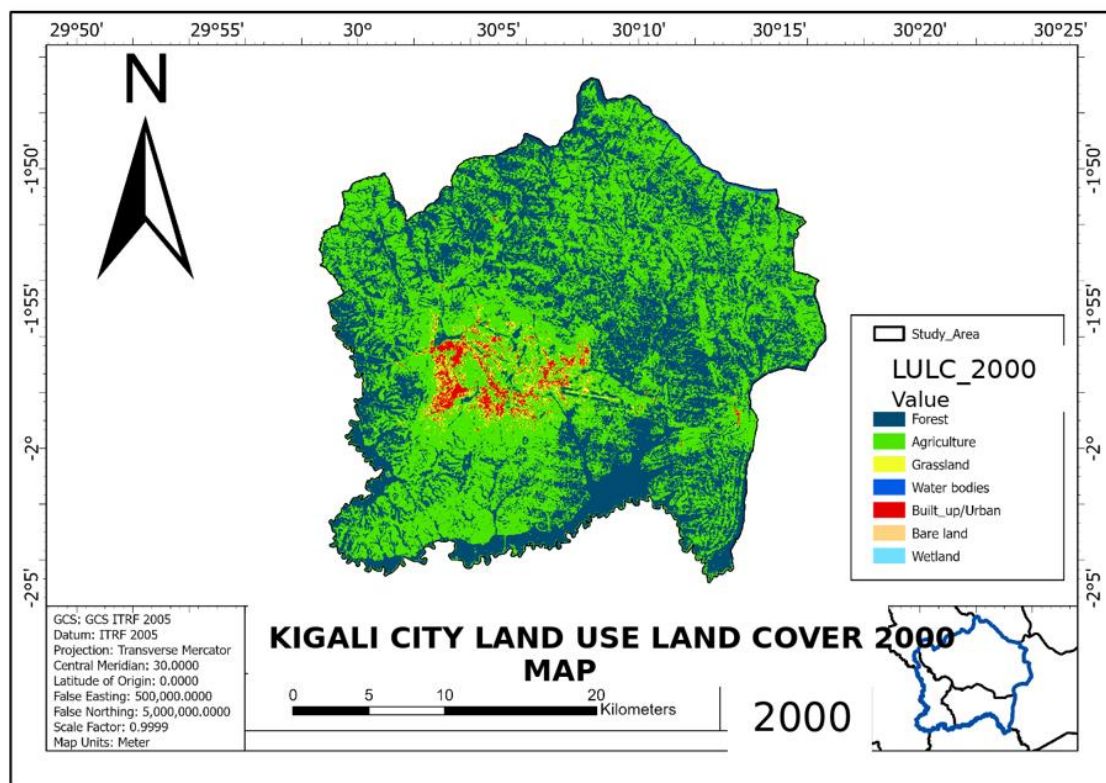
2.8 Remote Sensing Data Acquisition

The remote sensors extract them and are located at the vicinity of the region which has to be observed. The satellite content was gathered as a source of spatial data in order to evaluate the changes of LULC. The USGS earth explorer and ESA copernicus open access hub was used to find Landsat and Sentinel 2 images of the same site in the year 2000, 2010, 2020 and 2025. The criteria were involving low clouds, near seasons of making the acquisition and the suitability of the spatial resolution to examine the urban characteristics. The images were applied to classify LULC, green space mapping and change detection analysis.

2.9 Ethical Considerations

The study was conducted as per the ethical principles of research integrity, respect to the participants, and responsible use of the data.

3 FINDINGS

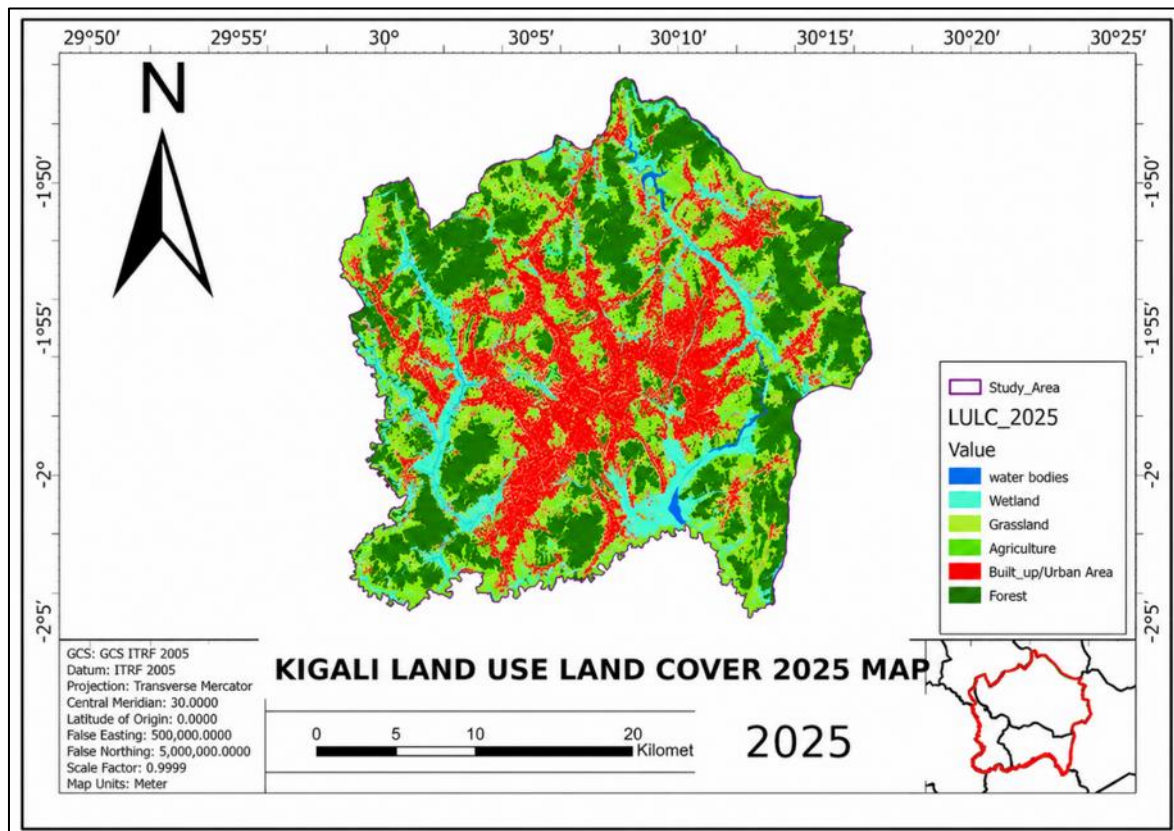


Source: Researcher's GIS and secondary data analysis, 2025

Figure 2: LULC map of Kigali City in 2000

The corrected 2000 map shows a landscape dominated by agriculture and forest, with built-up land concentrated mainly in the central urban core. Wetlands remained visible along valley bottoms, especially in the south-western and central lowland areas. At this stage, impervious surfaces were comparatively limited, implying relatively lower anthropogenic pressure on the hydrological system.

The 2025 map portrays a marked shift towards a highly urbanised landscape, but it does not indicate that the entire city is built-up. Built-up land occupies about 55% of the mapped area, while the remaining 45% is shared by forest, wetlands, agriculture, grassland, water bodies and bare land. Wetlands increased relative to 2000, suggesting the presence of mapped wetland recovery/inundation and the continued importance of valley-bottom environments in the city's flood system.



Source: Researcher's GIS and secondary data analysis, 2025

Figure 3: LULC map of Kigali City in 2025

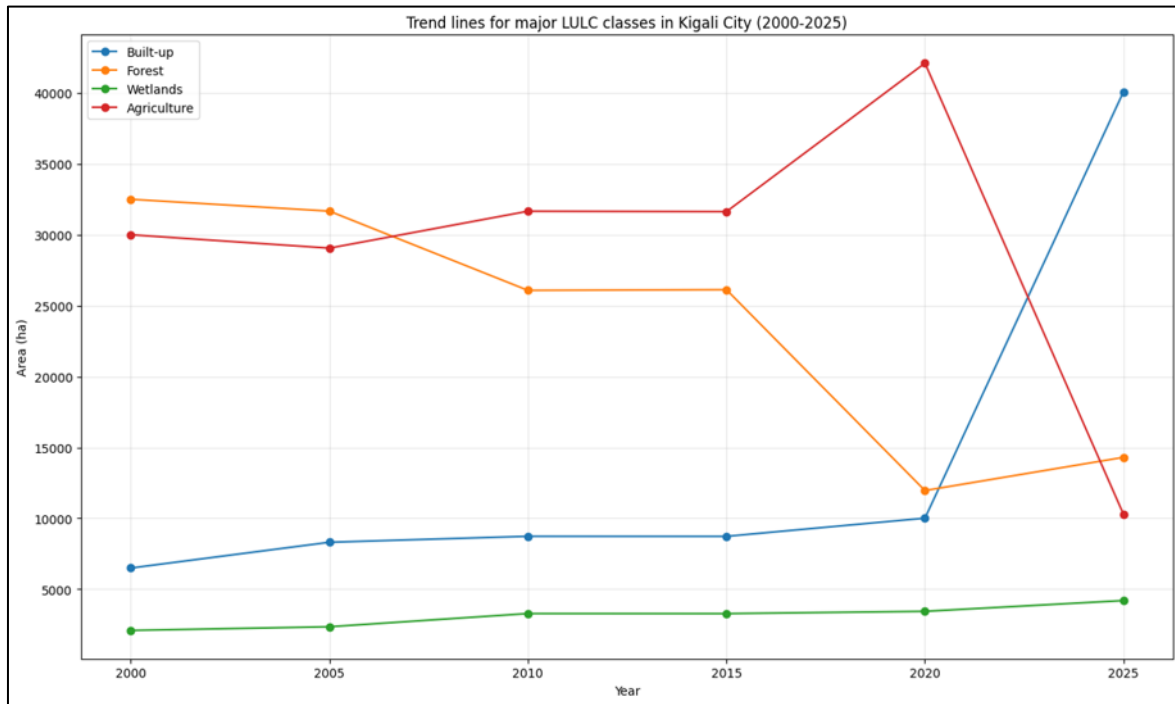
Table 1: Harmonized LULC area by class and year (ha)

Year	Built-up	Forest	Wetlands	Agriculture	Grassland	Water Bodies	Bare land
2000	6,500.00	32,500.00	2,100.00	30,000.00	1,100.00	450.68	200.00
2005	8,313.47	31,662.30	2,357.36	29,058.20	984.36	452.70	22.29
2010	8,734.07	26,077.42	3,287.40	31,656.29	13.70	578.02	2,505.65
2015	8,730.28	26,125.37	3,284.07	31,629.10	13.97	565.64	2,502.15
2020	10,012.57	11,962.51	3,442.51	42,100.46	4,820.40	512.74	0.00
2025	40,067.87	14,300.00	4,200.00	10,300.00	2,900.00	600.00	482.81

Source: Researcher's calculation from secondary GIS and remote-sensing data, 2025

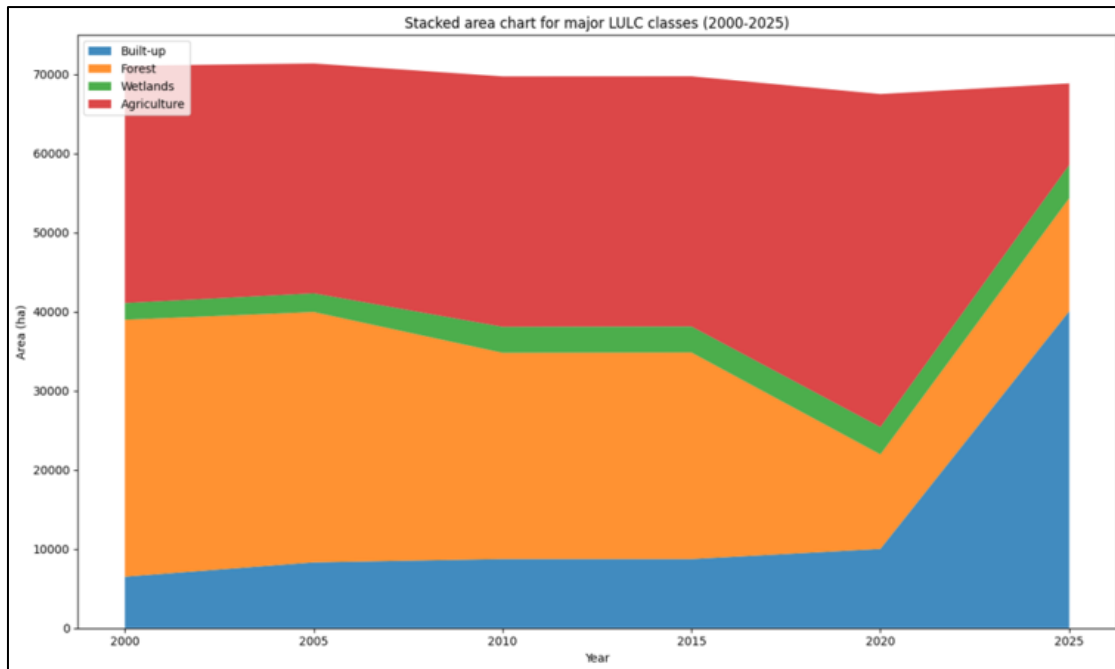
Table 1 shows pronounced changes in the distribution of major land-cover classes over the study period, including the added 2005 observation year. Built-up land increased from 6,500.00 ha in 2000 to 40,067.87 ha in 2025, representing the strongest absolute gain among all classes and approximately 55% of the mapped area in 2025. Agricultural land declined from 30,000.00 ha to 10,300.00 ha, while wetlands increased from 2,100.00 ha to 4,200.00 ha. Forest cover

recorded a net decline, although some recovery is visible in 2025 relative to 2020. Taken together, the figures indicate long-term urban expansion alongside changes in the spatial distribution of natural and semi-natural surfaces.



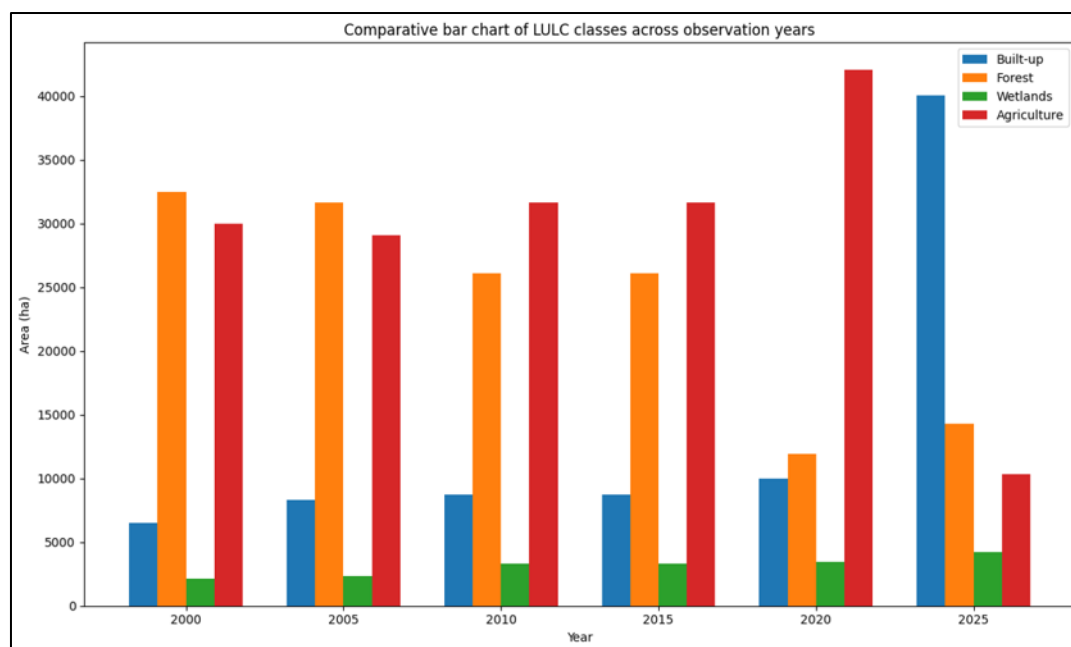
Source: Researcher's GIS and secondary data analysis, 2025

Figure 4: Trend lines for major LULC classes in Kigali City (2000-2025)



Source: Researcher's GIS and secondary data analysis, 2025

Figure 5: Stacked area chart for major LULC classes (2000-2025)



Source: Researcher's GIS and secondary data analysis, 2025

Figure 6: Comparative bar chart of LULC classes across observation years

Table 2: Overall trend summary for the four major land-cover classes

Class	Area 2000 (ha)	Area 2025 (ha)	Net change (ha)	Direction	Annual change (ha/yr)
Built-up	6,500.00	40,067.87	33,567.87	Increase	1,342.71
Forest	32,500.00	14,300.00	-18,200.00	Decrease	-728.00
Wetlands	2,100.00	4,200.00	2,100.00	Increase	84.00
Agriculture	30,000.00	10,300.00	-19,700.00	Decrease	-788.00

Source: Researcher's calculation from secondary GIS and remote-sensing data, 2025

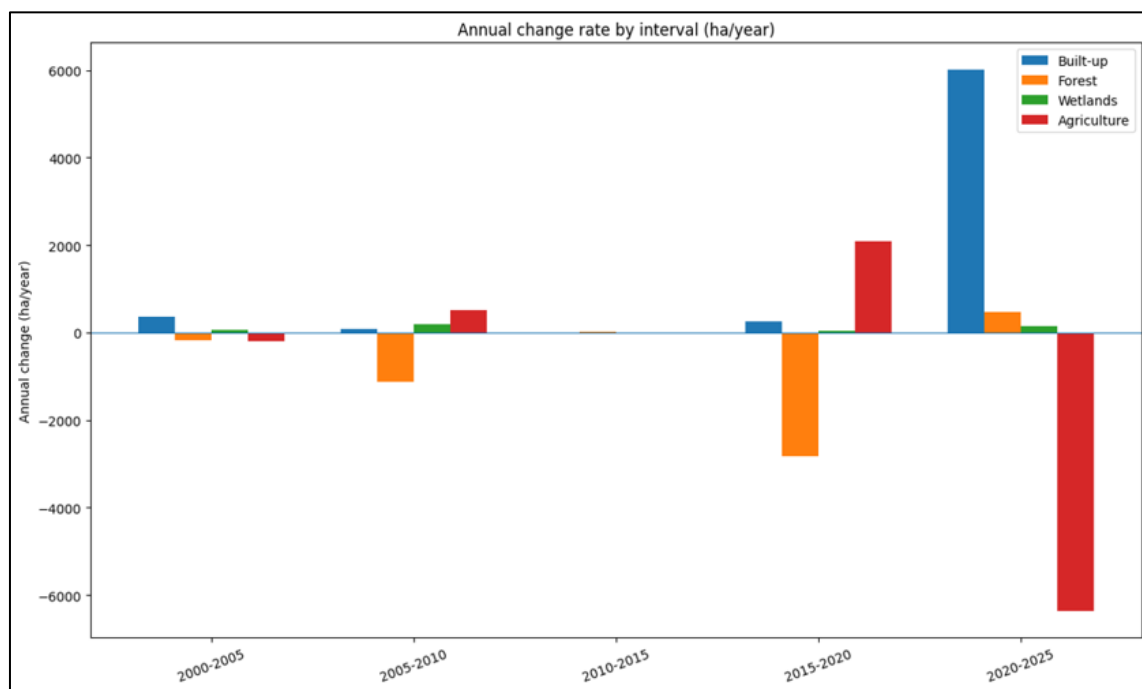
The trend summary confirms that Kigali underwent a strong urban transition over the twenty-five-year period. Built-up land gained 33,567.87 ha, equivalent to an average annual increase of 1,342.71 ha. Agricultural land and forest recorded net declines of 19,700.00 ha and 18,200.00 ha respectively, while wetlands increased by 2,100.00 ha. These changes are environmentally significant because wetlands, agriculture and forest influence infiltration, storage, delayed runoff and flood buffering capacity.

Table 3: Interval-based LULC change rates

Class	Period	Start area (ha)	End area (ha)	Change (ha)	Annual change (ha/yr)	% change
Built-up	2000-2005	6,500.00	8,313.47	1,813.47	362.69	27.90
Built-up	2005-2010	8,313.47	8,734.07	420.60	84.12	5.06
Built-up	2010-2015	8,734.07	8,730.28	-3.79	-0.76	-0.04
Built-up	2015-2020	8,730.28	10,012.57	1,282.29	256.46	14.69
Built-up	2020-2025	10,012.57	40,067.87	30,055.30	6,011.06	300.18
Forest	2000-2005	32,500.00	31,662.30	-837.70	-167.54	-2.58
Forest	2005-2010	31,662.30	26,077.42	-5,584.88	-1,116.98	-17.64
Forest	2010-2015	26,077.42	26,125.37	47.95	9.59	0.18
Forest	2015-2020	26,125.37	11,962.51	-14,162.86	-2,832.57	-54.21

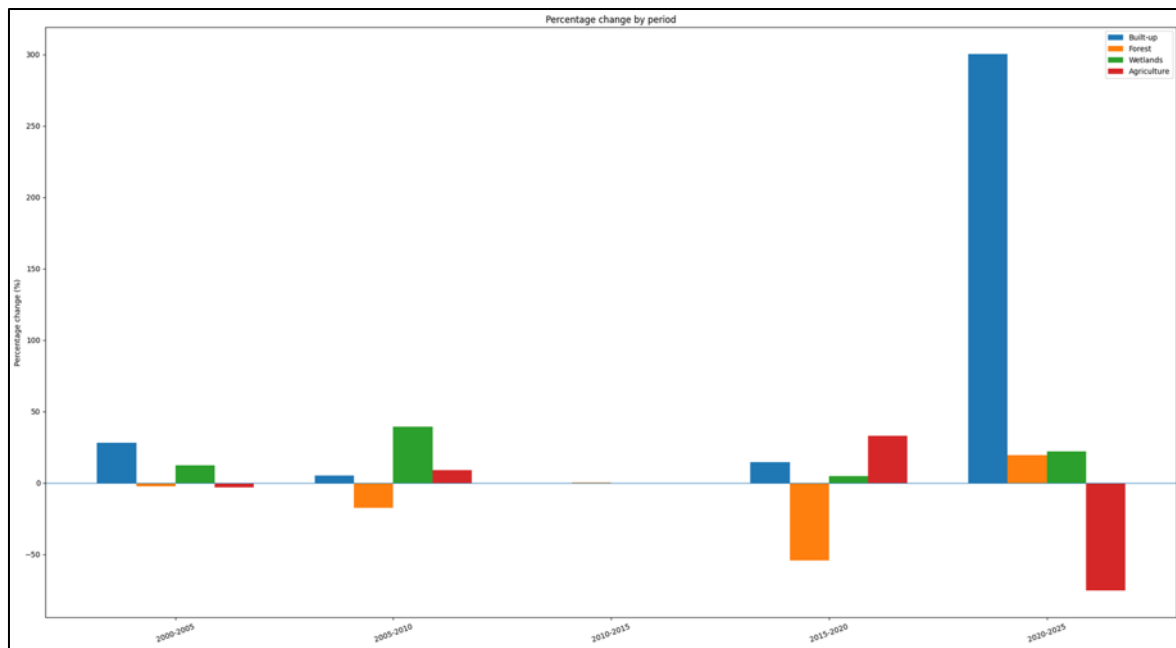
Forest	2020-2025	11,962.51	14,300.00	2,337.49	467.50	19.54
Wetlands	2000-2005	2,100.00	2,357.36	257.36	51.47	12.26
Wetlands	2005-2010	2,357.36	3,287.40	930.04	186.01	39.45
Wetlands	2010-2015	3,287.40	3,284.07	-3.33	-0.67	-0.10
Wetlands	2015-2020	3,284.07	3,442.51	158.44	31.69	4.82
Wetlands	2020-2025	3,442.51	4,200.00	757.49	151.50	22.00
Agriculture	2000-2005	30,000.00	29,058.20	-941.80	-188.36	-3.14
Agriculture	2005-2010	29,058.20	31,656.29	2,598.09	519.62	8.94
Agriculture	2010-2015	31,656.29	31,629.10	-27.19	-5.44	-0.09
Agriculture	2015-2020	31,629.10	42,100.46	10,471.36	2,094.27	33.11
Agriculture	2020-2025	42,100.46	10,300.00	-31,800.46	-6,360.09	-75.53

Source: Researcher's calculation from secondary GIS and remote-sensing data, 2025



Source: Researcher's GIS and secondary data analysis, 2025

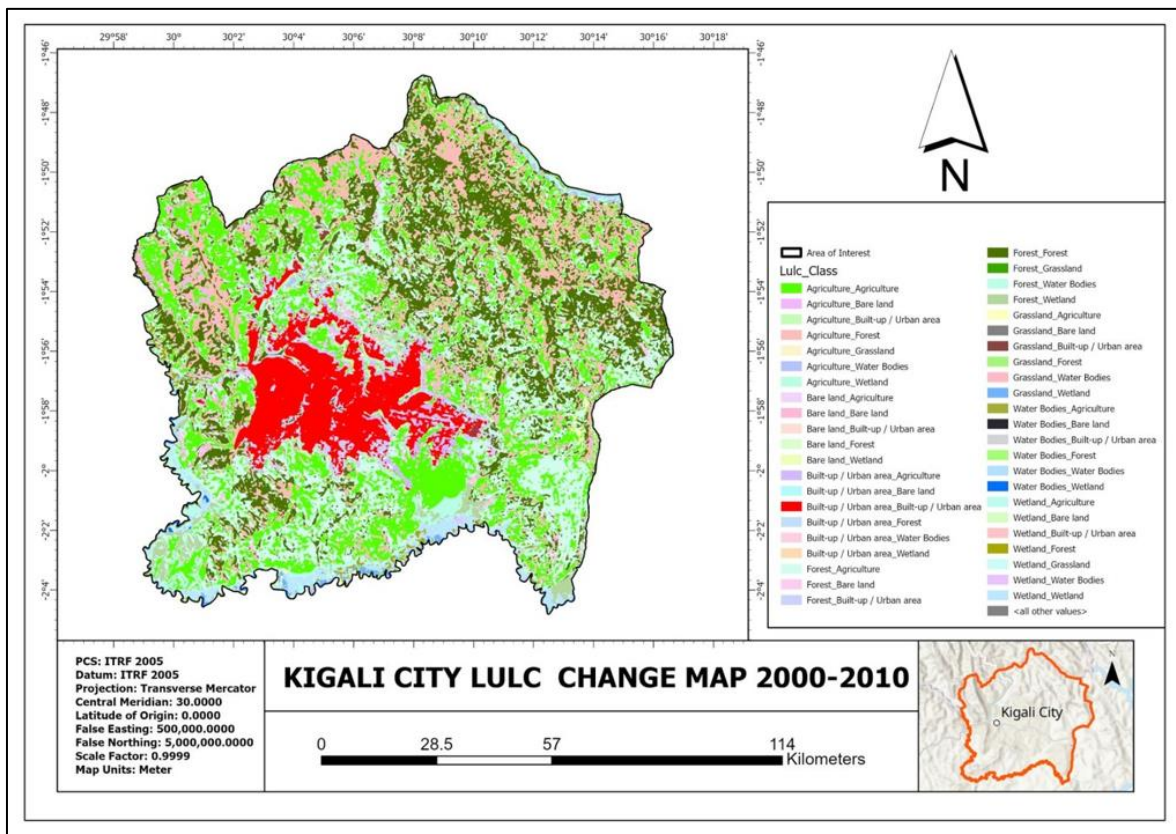
Figure 7: Annual change rate by interval (ha/year)



Source: Researcher's GIS and secondary data analysis, 2025

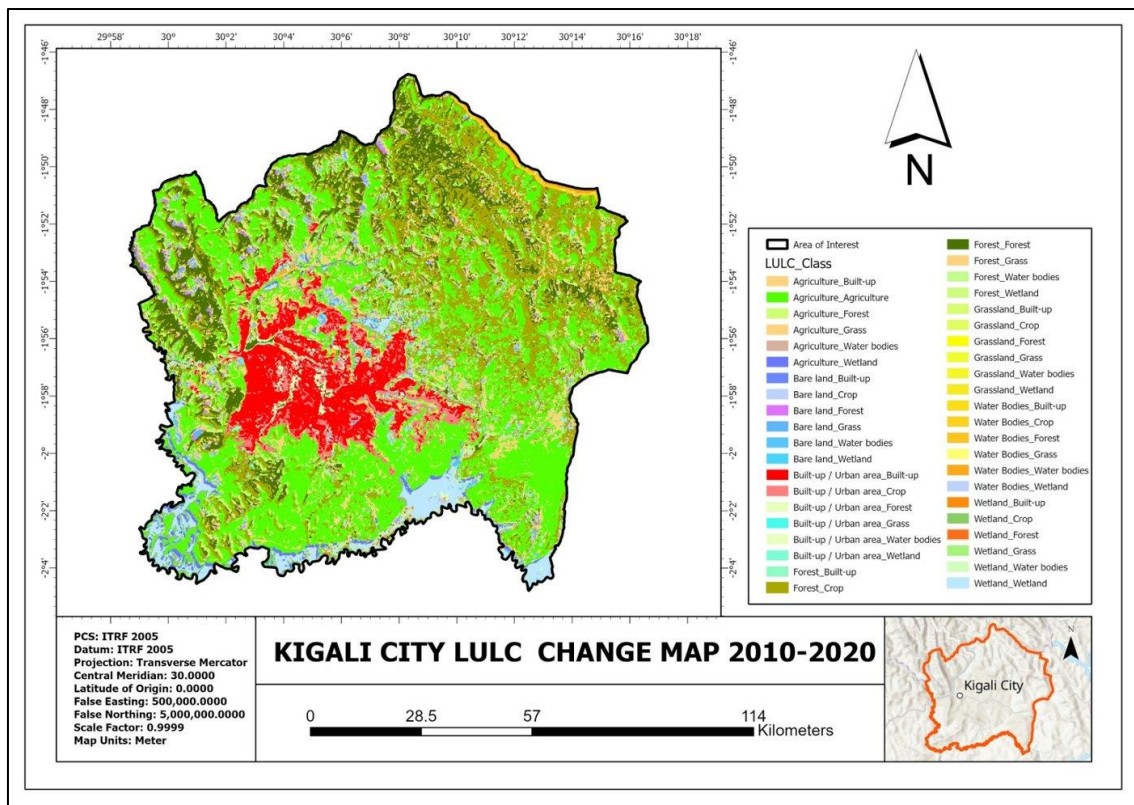
Figure 8: Percentage change by period

Interval analysis reveals that the most dramatic land-cover transformation occurred during 2020-2025. During this interval, built-up land increased by 30,055.30 ha, equivalent to 6,011.06 ha per year and a period change of 300.18%. At the same time, agriculture recorded its steepest decline, while wetlands increased by 757.49 ha. This late-stage acceleration suggests that recent urban growth has been much more intense than earlier phases and has likely exerted the greatest pressure on drainage systems and flood-prone areas.



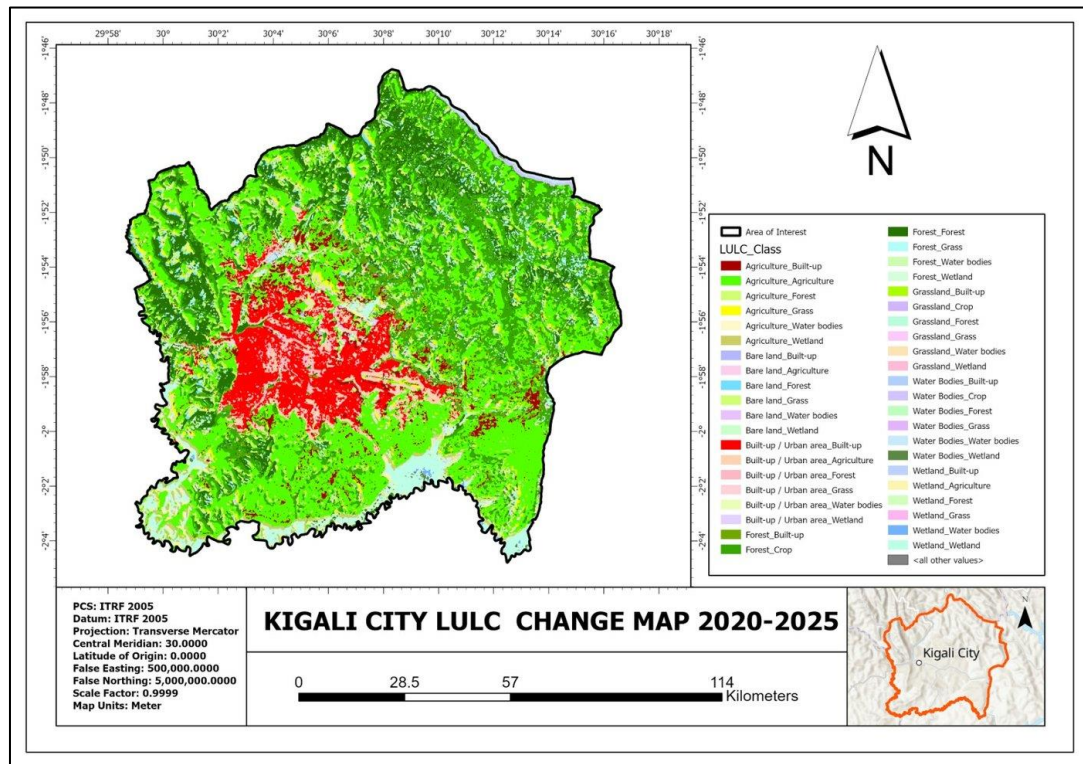
Source: Researcher's GIS and secondary data analysis, 2025

Figure 9: LULC change detection map, 2000-2010



Source: Researcher's GIS and secondary data analysis, 2025

Figure 10: LULC change detection map, 2010-2020



Source: Researcher's GIS and secondary data analysis, 2025

Figure 11: LULC change detection map, 2020-2025

Post-classification transition analysis demonstrates that much of Kigali's urban expansion occurred through conversion of agriculture and, to a lesser extent, forest and wetland land cover. Between 2000 and 2010, notable transitions from agriculture and forest into built-up land were already evident. Between 2010 and 2020, agricultural land remained the principal donor class to built-up expansion. The 2020-2025 matrix shows the strongest transformation, with 23,682.51

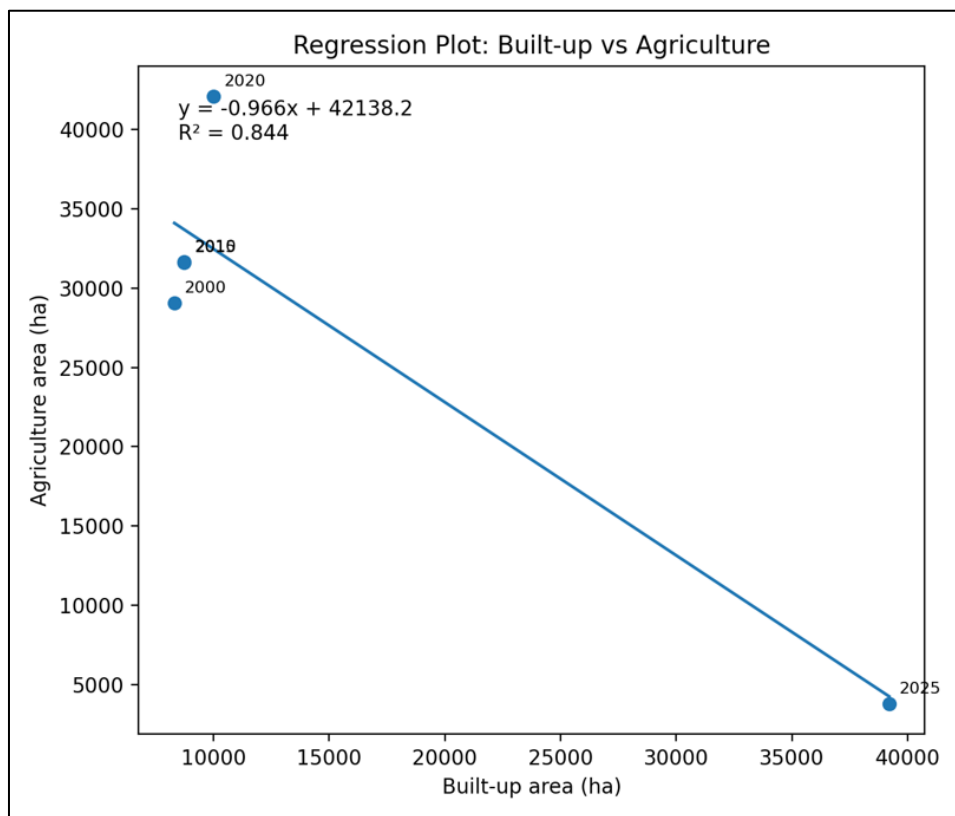
ha of agriculture and 4,455.40 ha of forest shifting into built-up land. This confirms that urban growth increasingly consumed peri-urban and environmentally sensitive land as the city expanded.

The change-detection maps reinforce the matrix results by showing that urban expansion followed accessible corridors and valley systems where development pressure was strong. Such locations are also hydrologically important because they collect runoff from surrounding hillslopes. As built-up land spreads into these areas, the capacity of the landscape to retain and slowly release storm-water declines, thereby increasing peak discharge and local flood risk.

Table 4: Exploratory correlation and simple regression results

X variable	Y variable	Pearson r	Slope	Intercept	R ²
Built-up	Agriculture	-0.858	-0.685	38,533.33	0.735
Built-up	Forest	-0.594	-0.399	29,246.58	0.353
Built-up	Wetlands	0.746	0.044	2,505.06	0.556

Source: Researcher's calculation from secondary GIS and remote-sensing data, 2025



Source: Researcher's GIS and secondary data analysis, 2025

Figure 12: Regression plot of built-up land versus agriculture

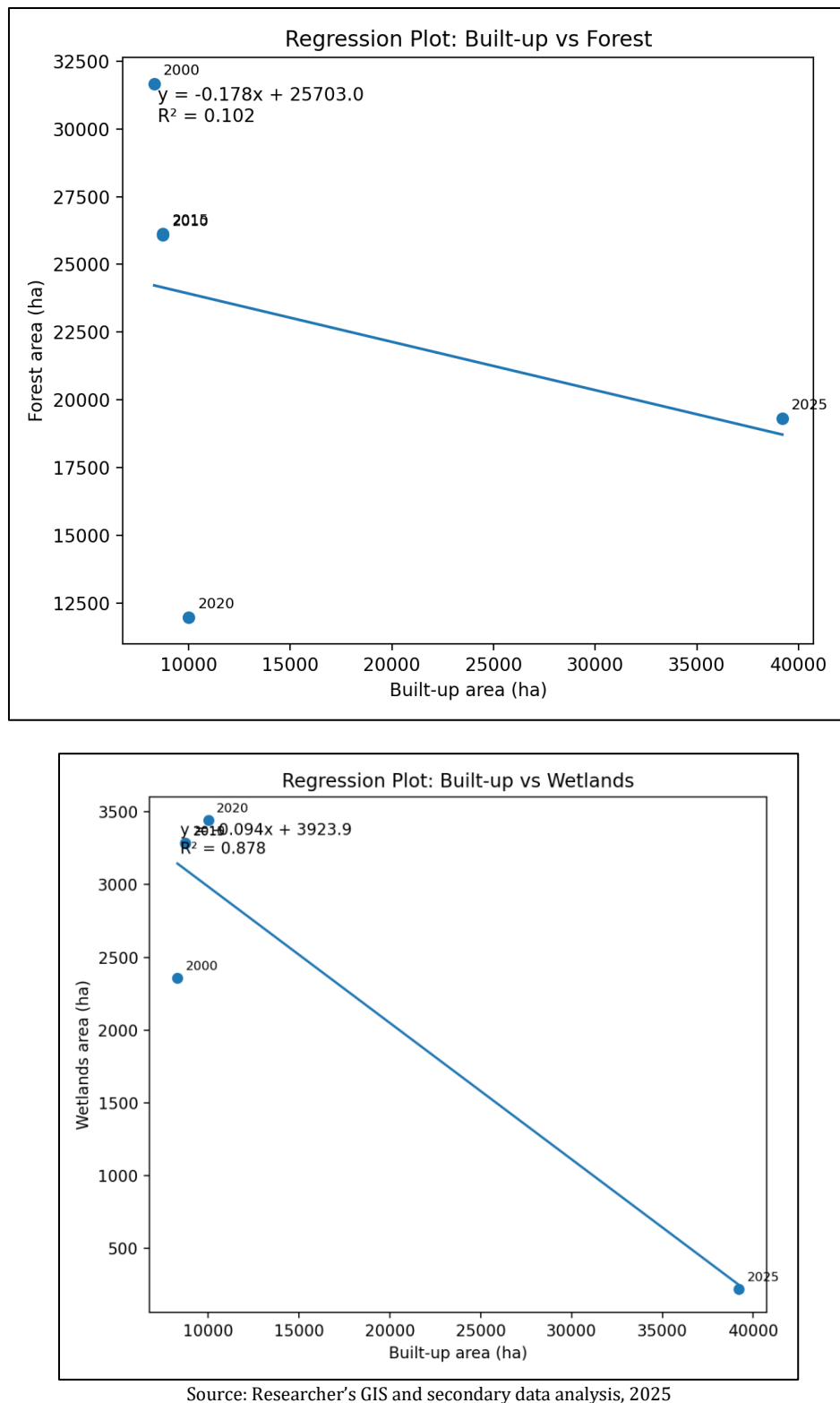
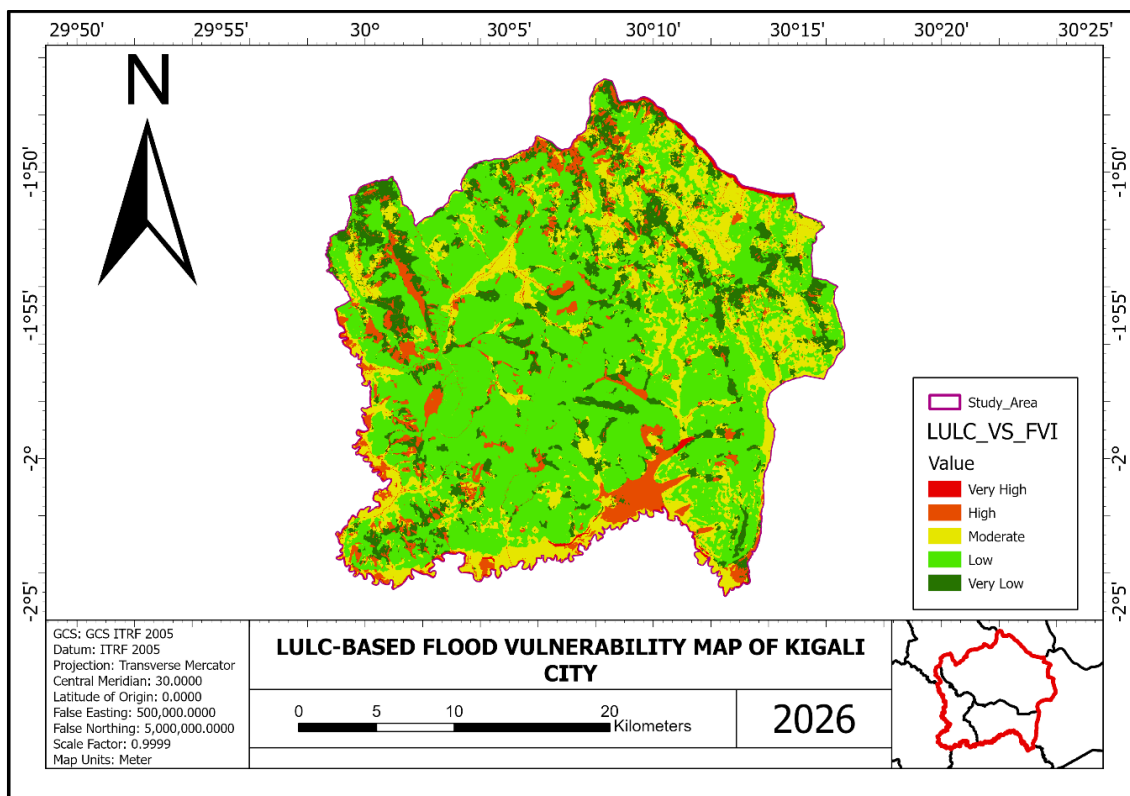


Figure 13: Regression plot of built-up land versus wetlands

The exploratory statistics reveal a strong inverse association between built-up land and agriculture ($r = -0.858$; $R^2 = 0.735$), indicating that urban expansion has largely replaced agricultural surfaces. The relationship with forest is also negative ($r = -0.594$), reflecting net forest decline across the study period. In contrast, built-up land and wetlands show a positive relationship ($r = 0.746$; $R^2 = 0.556$), which is consistent with the corrected LULC results showing an increase in mapped wetlands between 2000 and 2025. Because the dataset contains a limited number of observation years, these statistics are exploratory and should be interpreted together with the spatial maps and transition evidence.



Source: Researcher's GIS and secondary data analysis, 2025

Figure 14: LULC-Based Flood Vulnerability map

4 CONCLUSION OF THE STUDY

This study assessed the impact of land use and land cover changes on urban flood vulnerability in Kigali city from 2000 to 2025 using GIS, remote sensing and statistical trend analysis. The corrected results show that Kigali has undergone a strong urban transition characterized by rapid expansion of built-up land, a decline in agriculture and forest, and an increase in mapped wetlands. By 2025, built-up land accounted for about 55% of the mapped area, while other land-cover classes jointly accounted for about 45%. The spatial results indicate that urban expansion and the reconfiguration of natural surfaces have modified runoff pathways and contributed to flood vulnerability, especially in valley bottoms, wetlands and drainage corridors.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

Author Contributions

- Conceptualization: BIGIRABAGABO Evode
- Data curation: BIGIRABAGABO Evode
- Formal analysis: BIGIRABAGABO Evode
- Methodology: BIGIRABAGABO Evode
- Writing – original draft: BIGIRABAGABO Evode
- Writing – review & editing: Dr. Aboubakar GASIRABO

REFERENCES

- [1] Abebe, T., Melesse, A. M., & Fisseha, S. (2019). Urbanization and land-use/land-cover change in Addis Ababa, Ethiopia: Implications for sustainable urban development.
- [2] Adelekan, I. O. (2016). Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria.
- [3] Adelekan, I. O., & Asiyanbi, A. P. (2016). Resilience of informal settlements to flooding in Lagos, Nigeria.
- [4] Amoako, C., & Frimpong, S. (2020). Urbanization, land-use/land-cover change, and flooding in African cities: A review.
- [5] Anderson, J. R., Hardy, E. E., Roach, J. T., & Witmer, R. E. (2019). A land use and land cover classification system for use with remote sensor data. U.S. Geological Survey.
- [6] City of Kigali. (2013). Kigali Master Plan 2013–2040. Kigali: City of Kigali Urban Planning Authority.
- [7] Dewan, A. M. (2013). Urban growth and flood risk in Dhaka, Bangladesh: A remote sensing and GIS approach.
- [8] Elkhachy, I. (2015). GIS-based flood risk mapping in arid regions. *Natural Hazards*.
- [9] Feyisa, G. L., Dons, K., & Meilby, H. (2014). Remote sensing of urban green space: Landsat NDVI and ecosystem services.
- [10] Fuller, R. A., & Gaston, K. J. (2009). The scaling of green space coverage in European cities.
- [11] Government of Rwanda. (2018). Rwanda Green Growth and Climate Resilience Strategy (GGCRS). Kigali: Ministry of Environment.
- [12] Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). Adapting cities for climate change: The role of the green infrastructure. *Built Environment*.
- [13] Gocic, M., & Trajkovic, S. (2013). Analysis of precipitation and temperature trends in Serbia using Mann–Kendall and Sen's slope estimator. *Global and Planetary Change*.
- [14] Jensen, J. R. (2005). *Introductory digital image processing: A remote sensing perspective* (3rd ed.). Prentice Hall.
- [15] Jensen, J. R., & Lulla, K. (2017). *Remote sensing of urban environments*. CRC Press.
- [16] Karamage, F., Nkurunziza, E., Kansiime, F., et al. (2017). Flood vulnerability mapping using GIS and remote sensing: Case study of Kigali, Rwanda.
- [17] Kendall, M. G. (1975). *Rank correlation methods* (4th ed.). Charles Griffin.
- [18] Kihoro, J. M., Kihoro, E., & Nyambane, A. (2017). Urban expansion and land-cover change in Nairobi City, Kenya. *Environment and Urbanization*.
- [19] Li, X., Zhou, Y., & Wu, J. (2018). Urbanization and hydrological impacts: A remote sensing analysis. *Science of the Total Environment*.
- [20] Liu, X., Li, X., Zhang, X., & Zhou, Y. (2016). changes of urban land-use/land-cover change in the Pearl River Delta, China. *Remote Sensing*.
- [21] Ministry of Environment (MoE). (2019). Rwanda State of Environment and Outlook Report 2019. Kigali: Ministry of Environment.
- [22] National Institute of Statistics of Rwanda (NISR). (2020). Rwanda Population and Housing Census 2020: Kigali Report. Kigali: NISR.
- [23] Nzaramba, R., Uwizeyimana, J., & Nkurunziza, E. (2021). Land use and land cover change in Kigali: Implications for urban sustainability. *Environmental Challenges*.
- [24] Ramachandra, T. V., & Kumar, U. (2018). Urban sprawl in Bangalore City: Analysis and implications.
- [25] UN-Habitat. (2020). *World cities report 2020: The value of sustainable urbanization*. United Nations Human Settlements Programme.
- [26] Zhang, C., Li, W., & Wu, J. (2019). Machine learning for land-cover classification in heterogeneous urban landscapes. *Remote Sensing*.